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Rigging the Pepper Wreck. Part I—Masts and Yards

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Discovered in 1993 at the mouth of the Tagus River, the SJB2 shipwreck—or 'Pepper Wreck'—was tentatively identified as the Portuguese Indiaman *Nossa Senhora dos Mártires*, lost in this place on its return voyage from Cochin, in India, on 14 September 1606. Its archaeological excavation led to a tentative reconstruction of the hull, based in contemporary texts on shipbuilding. Further analysis of these texts allowed us to propose a reconstruction of the rigging.

Key words: Pepper Wreck, *Nossa Senhora dos Mártires*, Portugal, 17th-century shipbuilding, India route, Portuguese *nau*.

The hull remains of the 'Pepper Wreck' (officially designated SJB 2) were found during a survey at the mouth of the Tagus River, near Lisbon, Portugal, in 1994, and excavated between 1996 and 2000 by a joint team from the Portuguese Centro Nacional de Arqueologia Náutica e Subaquática and the Institute of Nautical Archaeology at Texas A&M University. A search in the database of the National Museum of Archaeology showed the *nau Nossa Senhora dos Mártires* as the most probable identification of this shipwreck. It was lost in front of the fortress of São Julião da Barra on 14 September 1606, returning from India with a main cargo of peppercorns (Castro, 2005).

A small portion of the bottom of the ship's hull was preserved, including a section of the keel, an apron, eleven frames, and some of the planking, extending over an area measuring 7 by 12 m (Alves *et al*., 1998). After analysis it was found that this was the portion of the ship's bottom immediately forward of the midship frames. Based on the scantlings' dimensions and on the analysis of the carpenters' marks found on the timbers, the Pepper Wreck hull remains were reconstructed following the rules and proportions indicated in contemporary texts on shipbuilding (Castro, 2003). Three Portuguese treatises on shipbuilding and a handful of sets of rules on how to build ships—*regimentos* in Portuguese—contain valuable information about a number of types of ships from this period. However, not being written for 21st-century nautical archaeologists, these texts are unclear in many places and often lack basic information, which is implied rather than expressly stated.

For these reasons, our understanding of Portuguese shipbuilding for the India Route in the late 16th and early 17th centuries cannot be based on contemporary written sources alone. A shipwreck like the Pepper Wreck, with real scantlings and carpenter's marks that set some of the hull's basic dimensions, was therefore a good opportunity to propose a tentative reconstruction of the hull. Although this reconstruction is only tentative and stands as an educated guess, it is nevertheless a good educated guess, based on archaeological data. The next logical step for the understanding of these ships was to try to reconstruct the ship's sail plan. It was Fernando Oliveira's *Liuro da fabrica das naus*, written around 1580, that best described the hull of the Pepper Wreck (Oliveira, 1991). However, this treatise does not include a section on rigging. We have searched all the possible sources—which were recently compiled in an outstanding work by Francisco Contente Domingues (2004)—and found three *regimentos* with descriptions of the rigging of both India Route *naus* and galleons from this period:

a) 'Medidas para fazer hũa Nao de Seicentas Tonelladas', an anonymous *regimento* from the *Livro náutico*, a manuscript dated to the

late 16th century, probably around 1590, in the Códice 2257 of Biblioteca Nacional de Lisboa, Reservados.

b) 'Medidas para fazer hũ galião de quinhentos toneis', also from the *Livro náutico*.

c) 'Conta e Medida de hũa Nao de quarto cubertas como adiante se vera …' from the *Livro de traças de carpintaria*, Manoel Fernandez, 1616 (Fernandez, 1989).

d) A text titled 'Conta das medidas de uma nau da India' was included in the manuscript *Coriosidades de Gonçallo de Sousa*, dated to the 1620s, in Biblioteca da Universidade de Coimbra—Reservados, ms. 3074. It is thought to be a copy of the same original from which text (c) was taken, and therefore presents very similar values for the hull dimensions and deserves mention here only because it indicates a different rake for the main mast (Xavier, 1992).

All these texts are thought to have been written between 1580 and 1620 and although they refer to the same type of ship—an India *nau*—they describe slightly different vessels. It was not until the late 1610s that Philip III of Spain—who was also Philip II of Portugal—issued legislation in order to regulate the size and shape of these ships (Rubio Serrano, 1991). We do not know exactly to what extent he succeeded in this attempt to standardize the types and sizes of seagoing vessels because there is a large gap in the written sources that describe the large ships of Portugal and Spain. Around the turn of the 16th century, roughly between 1570 and 1620, there is a group of documents, both in Portuguese and Spanish, describing several types of ships and boats. Then follows a period of almost complete silence as far as written sources are concerned, and it is not until the very end of the 17th century that we encounter again a group of technical texts with descriptions of ocean-going ships, such as Gastañeta's *Arte de Fabricar Reales* (Fernandez Gonzalez *et al*., 1992).

These texts define slightly different ships, and it is important to describe them here, beforehand, because the sizes of masts and spars are often related to the sizes of some of the most important components of a ship, such as the keel length. The main difference between these ships and the *nau* of Fernando Oliveira—and therefore the reconstruction of the Pepper Wreck—is that the latter has three decks, as was the norm throughout the 16th century, whereas the *naus* of documents (a) and (c) have four, as was the trend in the first decades of the 17th century. It is interesting to note that 17th century 4-deckers have slightly shorter keels and slightly higher rakes of the sternposts, which compensate the values of their lengths overall. Furthermore, the values of the maximum beam of these India *naus* grow continuously during the period under analysis, and so does the area of the main deck, both forward, through a slight lengthening of the spring of the stem posts, and abaft, through a widening of the transom (Table 1). All measurements in these documents are given in *rumos* (1.54 m), *braças* (1.76 m), *goas* (77 cm), *palmos de goa* (25.67 cm), *palmos de vara* (22 cm), and *dedos* (1.83 cm). The capacity is indicated in *tonéis*, a unit corresponding to the space necessary to house a barrel 1.54 m in height and 1.03 m in diameter.

Rigging an India *nau* in the late 16th century was not an exact science. Neither ships nor rigs were standardized and there was some leeway in the design and definition of the ship's masts, spars and tops. This is probably the reason why document (a), a *regimento* for a *nau* in the *Livro náutico*, has two consecutive lists of masts and

Table 1. *Basic dimensions of the vessels under study*

	Oliveira *c*.1580	a) LN—*Nau* *c*.1590	b) LN—Galleon *c*.1590	c) Fernandez 1616	d) Sousa *c*.1620
Tonnage	500 *tonéis*	600 *tonéis*	500 *tonéis*	no mention	no mention
No. of Decks	3	4	3	4	4
Keel Length	27.72 m	26.18 m	27.72 m	26.95 m	26.95 m
Spring of Stem	9.24 m	8.98 m	7.70 m	9.50 m	9.50 m
Length Overall	39.27 m	37.86 m	37.73 m	39.78 m	40.04 m
Max. Beam	12.32 m	12.38 m	13.35 m	14.37 m	14.50 m
Transom	6.16 m	6.42 m	6.67 m	7.57 m	10.01 m*

* Almost certainly a mistake: in the original 39 *palmos de goa*, instead of the more plausible 29 *palmos de goa*.

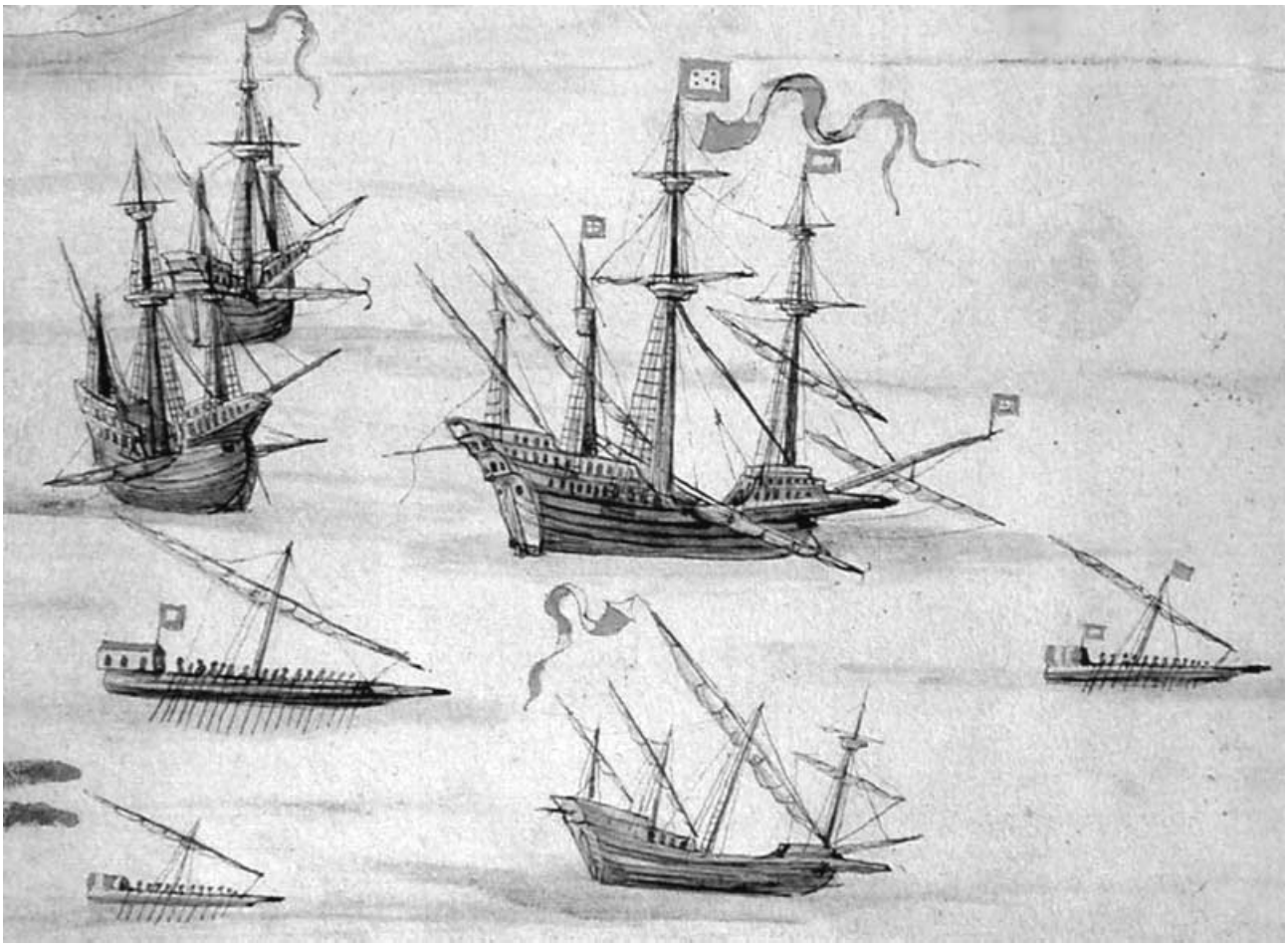

Figure 1. *Naus*, galleons and *caravelas de armada*, *c*.1538. (Detail from *Roteiro da Índia de D. João de Castro*, Ms 33, Biblioteca da Universidade de Coimbra, reproduced with permission)

yards after the description of the hull timbers. These lists in most cases are redundant, in others complete or clarify each other, but in the case of the ship's main mast are very different. I cannot find an explanation for this, since the manuscript bears no comments on this subject. The galleon described in (b) is quite different from the *naus* of the remaining documents. It has three decks and four masts: fore, main, mizzen and bonaventure. Galleons are mentioned as part of the Portuguese armadas to India in the early 16th century (Domingues, 2004), and seem to have a particular function as war vessels, although it is not known how this differed from the function of the famous *caravelas de armada*, also with four masts, but carrying lateen sails on the main, mizzen and bonaventure masts (Fig. 1).

Text (c) is probably the most interesting, in view of the marvellous illustrations that the author included in the manuscript that forms this well-known codex, the *Livro de traças de carpintaria*. It is a pity that there are almost no clues pertaining to the ship's rigging in the drawings. Looking at the values in Table 1 it almost seems that the *nau* of Fernando Oliveira evolved into two different types of ships: the slimmer late 16th century galleon of *Livro náutico* and the larger, beamier and more capacious *nau* of the early 17th century (Figs 1 to 3). One wonders how these *naus* performed under sail with a fourth deck, a wider midship section, and a shorter keel. The extra draught resulting from adding a new deck must have increased the ship's stability as did the wider beam. The case for wider beams is actually made in the early 1630s Spanish text *Diálogos entre un vizcayno y un montañés* (Vicente, 1998). However, the overall result in performance is easy to imagine, and on 17 May 1597, in the middle of the Indian Ocean, Gaspar Ferreira, a skilled and seasoned pilot of

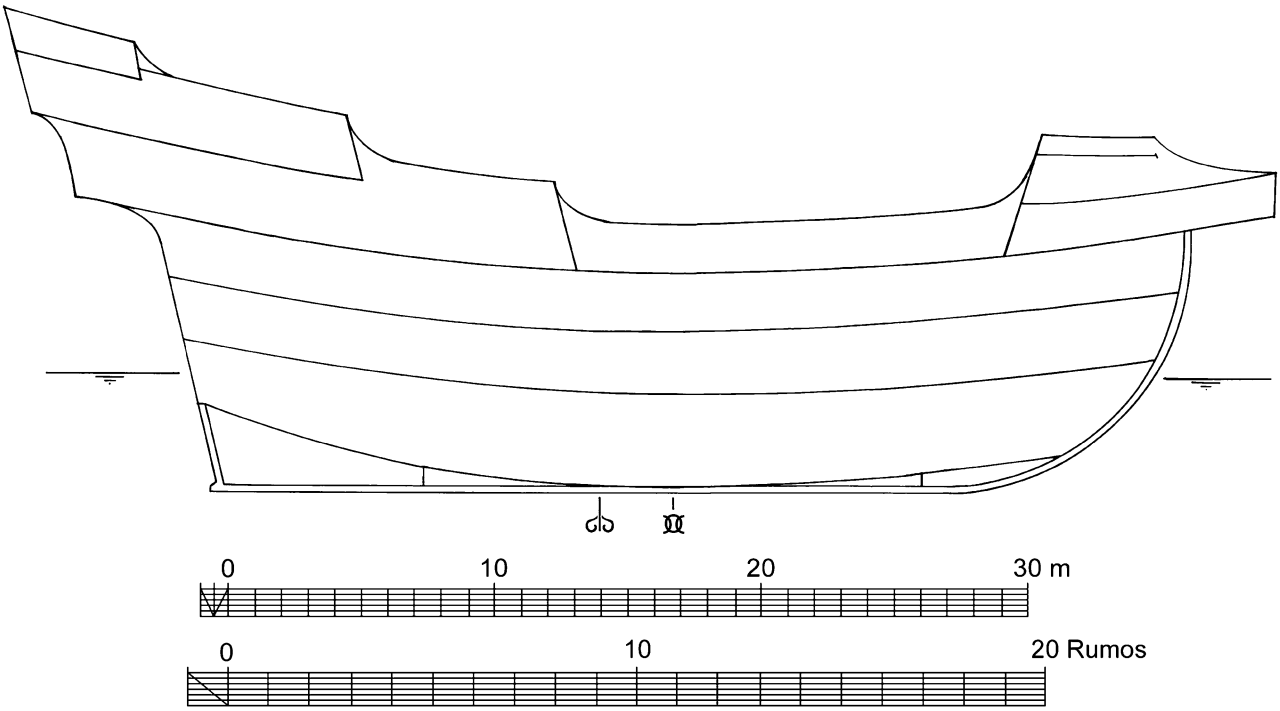

Figure 2. The Pepper Wreck as reconstructed after Fernando Oliveira's *Livro da fabrica das naus.* (Filipe Castro)

the Portuguese India Route, wrote this entry in his diary: 'The ship does not hold the sail. May God forgive the one who built it and armed such high castles over so short a keel. As the wind is calm, all we can do is to fall before it and watch the stem post turning to leeward in a way that makes my guts burn, just from standing on such a ship!' (Fonseca, 1938).

It is worth noting that between 1590 and 1630 the percentage of ships lost on the return voyage from Cochin to Lisbon rose considerably (Guinote *et al*., 1998). It is known that some of the reasons for this increase in the losses of ships were Dutch and English piracy, stormy weather around the Cape of Good Hope due to a deliberate delay in the departures, possibly to avoid pirate attacks, and excess of loading. Maybe this trend in the design also had its role among the main causes of shipwreck during this period. Be that as it may, the aim of this study is not to find out the causes of the increase in the numbers of shipwrecks in the late 16th century, but to try to find out the main characteristics of the rigging of the Pepper Wreck.

Mainmast

All authors agree that the mainmast was stepped on the centre of the keel, abaft the midships frame, and raked a few degrees to the stern. No authors indicate explicitly this rake but they mention the position of the deck beams to be placed above the mast-step mortise, as well as the height of the hold. The values for the different rakes can easily be obtained from this information and are indicated in Table 2. Another text, *Coriosidades of Goncalo de Sousa*, the manuscript presumed to be a copy of the same original that was copied into the *Livro de traças de carpintaria*, recommends a more pronounced rake for the mainmast. Although it is not possible to understand the mast-step arrangement and the overlaying deck beams in the text, the author states that on the second deck the mast hole should move abaft 1 *palmo de vara* (22 cm). Given the fact that the height between decks is 8.5 *palmos de goa* (2.18 m), the rake is 9.91%, a value far above those indicated by the other authors.

Table 2. *Rake of the mainmast*

a) LN—*Nau* *c*.1590	b) LN—Galleon *c*.1590	c) Fernandez 1616	d) Sousa *c*.1620
3.5%	—	6.1%	10%

The length of the main mast is consistently indicated as 18 *braças*, or 31.68 m. The *regimento* of the galleon from *Livro náutico* says that the

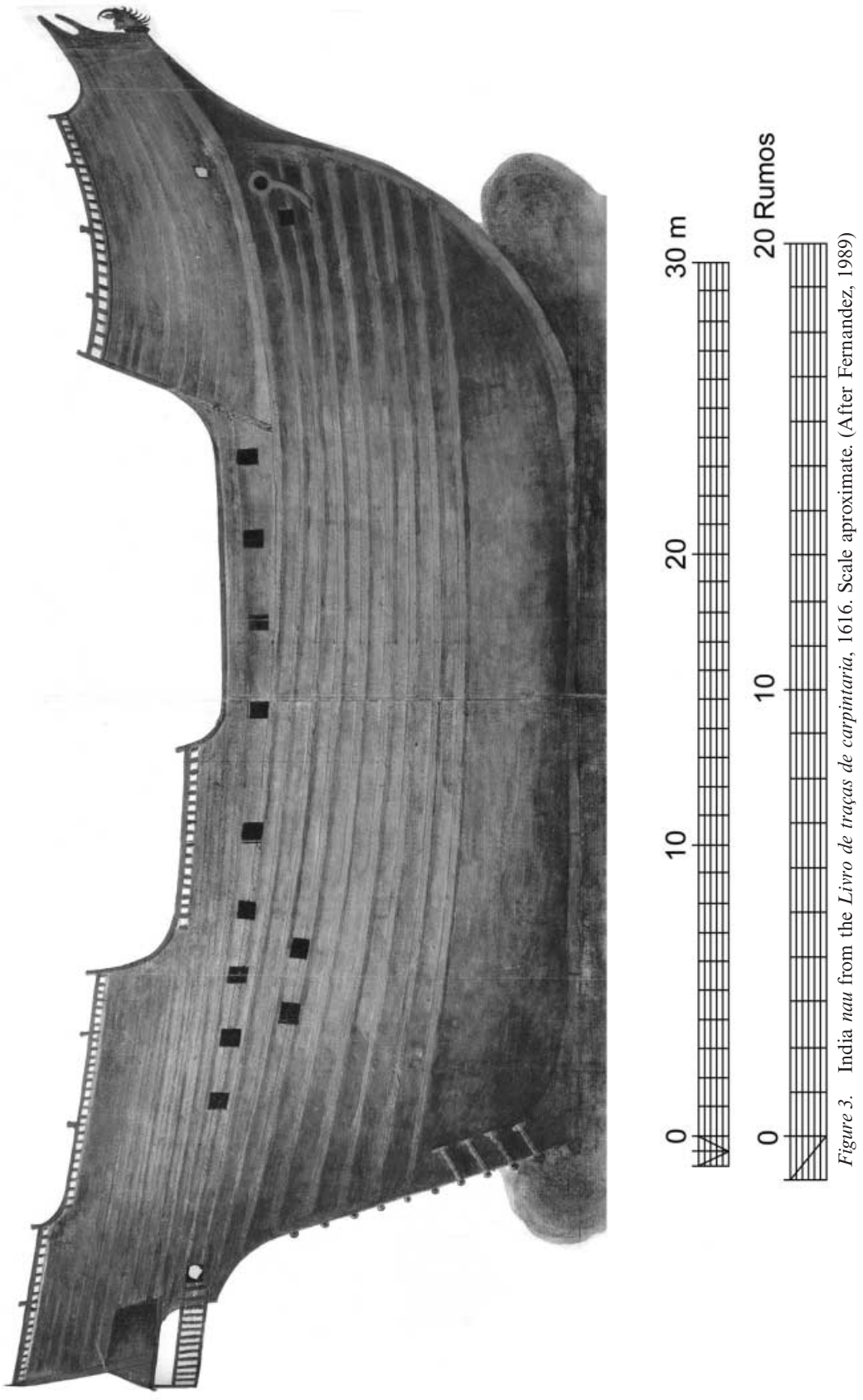

Figure 3. India *nau* from the *Livro de traças de carpintaria*, 1616. Scale aproximate. (After Fernandez, 1989)

Table 3. *Mainmast dimensions (L = Length; Ø = Diameter, W = Weight)*

a) LN—*Nau* *c.*1590	b) LN—Galleon *c.*1590	c) Fernandez 1616
L = 31.68 m (doubling not incl.) $Ø_{deck\ level}$ = 99/124 cm $Ø_{top}$ = 53/62 cm W = 7.47/11.19 t	L = 31.68 m (doub. not mentioned) $Ø_{deck\ level}$ = 134 cm $Ø_{top}$ = 67 cm W = 13.07 t	L = 31.68 m (incl. doubling = 2.64 m) $Ø_{deck\ level}$ = 116 cm $Ø_{top}$ = 83 cm W = 12.81 t

main mast should be as long in *braças* as the keel is in *rumos* (18 *rumos* or 27.72 m). The *regimento* for the *nau* in the same book states that the mast should have as many *braças* of length as the number of *rumos* of the keel (in this case 17 *rumos*), plus one. Fernandez just indicates a value: 18 *braças*. There are doubts whether this length should include the doubling (*calcês*) as a general rule. The author of the *regimento* of a *nau* from the *Livro náutico* states that the 18 *braças* do not include the doubling, but Fernandez mentions the doubling included in the 18 *braças* of total height (Table 3).

The rules to calculate the mast diameters vary. The *nau* from *Livro náutico* has two different maximum diameters. The first list mentions 4.5 *palmos de vara* (99 cm) at the main deck level, which tapered to 53 cm at the level of the cheeks (*romãs*), immediately below the trestle-trees. The second list, however, states that the maximum diameter of the mainmast should be $^{1}/_{10}$ of the maximum beam or, in this case, 1.24 m. This is the rule for the mainmast of the galleon in the *Livro náutico*: $^{1}/_{10}$ of the ship's maximum beam at deck level, or 1.34 m, tapering to half of that value below the cheeks (at the section called *garganta*). Fernandez indicates 4.5 *palmos de goa* (1.16 m) for the mainmast diameter, tapering to $^{5}/_{7}$ of that value, or 83 cm, at the top, below the cheeks. François Pyrard de Laval, a French traveller from the early 17th century, wrote a few lines about these massive masts, describing them as 'so enormous that there are no trees so big and so thick' to make them. According to him they were assembled from different timbers firmly kept together with iron hoops and rope woolding (Laval, 1944).

These large diameters raise the question of the weight of the masts. Considering a density ρ = 0.52 t/m3, an average value for Riga pine (*Pinus sylvestris*), which was the most likely timber used for the building of masts and spars in Portugal at the time (Costa, 1997), it is easy to estimate the weight of these massive yards from the expression:

$$\text{Weight} = [(Ø\text{max.} + Ø\text{min.})/4]^2 \times \pi \times L \times \rho$$

Where the symbol Ø indicates the diameter of the yard, π is a constant equal to 3.14159, L is the length of the spar and ρ the density of the timber. This formula is a simplification because masts were not actually conical. All spars' diameters tapered to the extremities along a curve determined with a geometric algorithm such as the well-understood *mezzaluna* (Anderson, 1925). In this particular case it should also be noted that masts taper upwards and downwards from their maximum diameter sections, at main deck level. We have deliberately ignored the tapering downwards to compensate for the weight of the iron hoops and rope woolding.

Both the *Livro náutico* and Fernandez give dimensions for the tops, which look very heavy, both on the main and fore masts, circular, protected with bulwarks, and with a conical shape (Fig. 4). In the *Livro náutico* the top dimensions are defined as simple proportions of the ship's beam: $^{1}/_{3}$ for the diameter of the upper rail, reducing $^{1}/_{5}$ of that value for the lower platform. The same value— $^{1}/_{5}$ of the diameter of the upper rail is the height of the bulwark. Fernandez's tops are lighter, almost cylindrical and have slightly lower bulwarks (Table 4). Pyrard de Laval says that these tops were fitted with artillery and could accommodate 'ten or twelve men'.

Table 4. *Mainmast top dimensions*

a) LN—*Nau* *c.*1590	b) LN—Galleon *c.*1590	c) Fernandez 1616
$Ø_{basis}$ = 3.30 m $Ø_{rail}$ =4.12 m Height = ?	$Ø_{basis}$ = 3.56 m $Ø_{rail}$ = 4.45 m Height = 0.89 m	$Ø_{basis}$ = 3.59 m $Ø_{rail}$ = 4.10 m Height = 0.77 m

Figure 4. Tops in the mid-16th century. (From Anon, *c*.1538, *Breviário da condessa de Bertianos*, Ms, Biblioteca da Academia das Ciências, Lisbon, with permission)

Table 5. *Main yard dimensions (L = Length; Ø = Diameter; W = Weight)*

a) LN—*Nau* *c*.1590	b) LN—Galleon *c*.1590	c) Fernandez 1616
L = 37.14/29.92 m	L = 40.05 m	L = 31.68 m
$Ø_{max.}$ = 51 cm	$Ø_{max.}$ = 67 cm	$Ø_{max.}$ = 51 cm
$Ø_{min.}$ = 26 cm	$Ø_{min.}$ = 34 cm	$Ø_{min.}$ = 26 cm
W = 2.31/1.86 t	W = 4.17 t	W = 1.97 t

Main yard

According to Fernandez, the main yard should be as long as the mainmast, or 18 *braças* (31.68 m), and have a maximum diameter of 51 cm (2 *palmos de goa*), tapering to half of that value at both ends. For the author of the *regimentos* of the *Livro náutico* the main yard should be as long as three times the value of the maximum beam, or 37.14 m for the *nau* and 40.05 m for the galleon (Table 5). There is some confusion here since the two lists of dimensions of masts and yards in the *nau regimento* indicate different rules. The first list has no mention of any relation with the maximum beam and indicates instead that the main yard should be 17 *braças* long (29.92 m). The diameters of *Livro náutico*'s main yards are different: 2 *palmos de goa* for the *nau*, as in Fernandez, and half of the diameter of the mainmast for the galleon. In both these cases the diameter tapers to half of its value at the ends. This is a general rule: in all the documents under analysis, when stated, the diameters of the yards at their extremities are always half of the maximum diameter, which is measured 'on the halyard'.

Again, these diameters raise the question of the weight of the yards. It is slightly more complex to estimate their weight. Although the 1616 text and drawings from Fernandez's book clearly refer to modern yards, the 1590 texts suggest the possibility that the main yard was composed of two overlapping halves (*penões*), or pennons, scarfed in the centre. This is a somehow strange reference since, to my knowledge, there is no iconographic evidence of this solution from the 1550s onwards. Anyway, since neither the extension of the overlap nor the shape of the scarf are clear in any of the texts considered, it is difficult to apply the expression used to obtain the weight of the masts in this particular case. The values expressed for the main yards of both the *nau* and galleon of the *Livro náutico* are therefore perhaps

higher that the real weights, although by less than 5%. Again we are not adding the weight of any iron hoops, rope woolding, cable or blocks.

When we consider that to this weight one must add the weight of the mainsail, we understand why there was a windlass (*estrinca*) on the gun-deck dedicated to the manouvre of hoisting the mainsail. These high values for the weight of the main yards are corroborated by Pyrard de Laval, who says, perhaps exaggerating but nevertheless in a quite informative way, that main yards were '24 *braças* [42.24 m] long' and that 'it takes more than two hundred persons to hoist such a yard, and always with two solid capstans' (Laval, 1944). Pyrard de Laval was certainly referring to the capstan and the windlass.

Main topmast

Topmasts are smaller and lighter in this period than they would be during the next centuries. There is no clear pattern in the values indicated in the texts considered, and the only rule of thumb stated, for the galleon, is that the topmast should be $^1/_3$ of the mainmast in length (Table 6). Diameters are only clearly indicated for the *naus*. The *Livro náutico* mentions 1.5 *palmos de goa* and Fernandez indicates 2 *palmos de vara*. The galleon *regimento* says that the maximum diameter of the main topmast should be $^3/_4$ of the diameter of a *penão*, an expression that is difficult to understand. As mentioned before, *penão* is each one of the halves of a yard when square sail yards are composed of two halves scarfed together in the center. About 150 years earlier, Zorzi Timbota defined the total thickness of the two *pennoni* in the zone of the overlap scarf as $^7/_5$ of the maximum diameter of the yards (Bellabarba, 1988). Assuming that the author of this *regimento* is talking about the main yard, for a maximum diameter of 67 cm each *penão* should be 48 cm thick and the topmast should have a diameter of 36 cm. The weights in Table 6 were calculated considering that the diameters at the top of the mast were half of the maximum diameters defined in the manuscripts.

Table 6. *Main topmast dimensions (L = Length; Ø = Diameter; W = Weight)*

a) LN—*Nau* *c.*1590	b) LN—Galleon *c.*1590	c) Fernandez 1616
L = 13.20/12.32 m $Ø_{max.}$ = 39/31 cm W = 0.46 t	L = 10.56 m $Ø_{max.}$ = 36 cm W = 0.31 t	L = 18.48 m $Ø_{max.}$ = 44 cm W = 0.82 t

Main top yard

The main top yard must be $^1/_3$ of the length of the main yard for both ships in the *Livro náutico*, and its maximum diameter is given in both cases as half of a *penão*. The *nau*'s *regimento* has again two different solutions, the second being 6 *braças* long and 1 *palmo de goa* thick. We are left with two values for this length: $^1/_3$ of 37.14 m and 6 *braças*. According to Fernandez, the main top yard may vary between 6 and 6.5 *braças* and should be 1 *palmo de goa* and 2 *dedos* thick in the centre. Following also in this case the reasoning adopted to estimate the diameter of the topmast, the *penão* of the *nau*'s main yard obtained is 37 cm, and the maximum diameter of the top yard results 19 cm. Similarly, the diameter of the galleon's topsail yard obtained is 24 cm (Table 7).

Foremast

It is difficult to determine where to step the foremast in these models. From the drawings in Manoel Fernandez's book it seems likely that it was stepped far forward, near the stem post, at the level of the lower deck. This is also what the *regimento* of the galleon in the *Livro náutico* indicates. The best clue is given by Gonçalo de Sousa, who says that it should be stepped on the

Table 7. *Main top yard dimensions (L = Length; Ø = Diameter; W = Weight)*

a) LN—*Nau* *c.*1590	b) LN—Galleon *c.*1590	c) Fernandez 1616
L = 12.38/10.56 m $Ø_{max.}$ = 26/19 cm $Ø_{min.}$ = 10 cm W = 0.11/0.09/0.09 t	L = 13.35 m $Ø_{max.}$ = 24 cm $Ø_{min.}$ = 12 cm W = 0.18 t	L = 11.44/10.56 m $Ø_{max.}$ = 29 cm $Ø_{min.}$ = 15 cm W = 0.23/0.21 t

Table 8. *Foremast dimensions (L = Length; Ø = Diameter; W = Weight)*

a) LN—*Nau* *c*.1590	b) LN—Galleon *c*.1590	c) Fernandez 1616
L = 26.40 m $Ø_{max.}$ = 88 cm $Ø_{min.}$ = ? W = 6.13 t	L = 26.40 m $Ø_{max.}$ = 77 cm $Ø_{min.}$ = ? W = 4.70 t	L = 27.28 m $Ø_{max.}$ = 77 cm $Ø_{min.}$ = ? W = 4.85 t

Table 9. *Foremast top*

a) LN—*Nau* *c*.1590	b) LN—Galleon *c*.1590	c) Fernandez 1616
$Ø_{basis}$ = 2.14 m $Ø_{rail}$ =3.20 m Height = ?	$Ø_{basis}$ = 2.22 m $Ø_{rail}$ = 3.34 m Height = ?	$Ø_{basis}$ = 3.08 m $Ø_{rail}$ = 3.59 m Height = 0.64 m

lower deck, '4 *palmos* from the stem' over two beams. In other words, it should be stepped between 88 cm (if we consider *palmos de vara*) and 103 cm (if we consider *palmos de goa*) from the inner surface of the inner stem post. The total height of the foremast varies. In both the *nau* and galleon of the *Livro náutico* the foremast length is 15 *braças*, its upper tip standing 1 *braça* below the tip of the mainmast. Fernandez states 15.5 *braças*. Again, the *Livro náutico* indicates that these heights do not include the doublings (Table 8). The diameters are 4 *palmos de vara* for the *nau* in the *Livro náutico*, 3.5 *palmos* [*de goa*] for the galleon, and 3 *palmos de goa* for Fernandez's *nau*. The galleon *regimento* states that the 3 *palmos* are the equivalent of $^3/_4$ of the mainmast diameter. This is certainly a mistake, because the galleon's mainmast is supposed to have a diameter equal to $^1/_{10}$ of the maximum beam, or 134 cm, and $^3/_4$ of this value is 101 cm, far more than 3 *palmos de goa*.

The weights were calculated assuming that these masts taper to half of their diameters at the base. Once again, the dimensions of the tops are defined in the *Livro náutico* as simple proportions of the maximum beam of the ships: $^1/_4$ of the beam for the upper rail and $^1/_6$ of the beam for the basis. No value is given for the height of the bulwarks (Table 9). Fernandez defines these tops in the same way as those of the mainmast, the diameter of the upper rim—measured on the inner surface of the rail—being equal to the diameter of the basis of the main top. The rails are 1 *palmo de goa* thick, an understandable thickness considering that there were light artillery pieces, such as swivel guns, mounted on it.

Table 10. *Fore yard dimensions (L = Length; Ø = Diameter; W = Weight)*

a) LN—*Nau* *c*.1590	b) LN—Galleon *c*.1590	c) Fernandez 1616
L = 22.88/22.44 m $Ø_{max.}$ = 51/37 cm $Ø_{min.}$ = 19 cm W = 0.89 / 0.72 t	L = 26.70 m $Ø_{max.}$ = 48 cm $Ø_{min.}$ = 24 cm W = 1.41 t	L = 24.64 m $Ø_{max.}$ = 51 cm $Ø_{min.}$ = 22 cm W = 1.10 t

Fore yard

Livro náutico says that the fore yard should be as long as $^3/_4$ of the main yard for *naus* and $^2/_3$ of the main yard for the galleons. The maximum diameter should be equal to one *penão*. The *regimento* for the *nau* of Fernandez indicates 14 *braças* of length and 2 *palmos* [*de vara*] of thickness (Table 10).

Fore topmast

The fore topmast is a small spar. The galleon *regimento* indicates its length as $^1/_3$ of the length of the foremast and the remaining texts indicate only values in *braças* (Table 11). As to the diameter of the fore topmast, Fernandez states 1.5 *palmos de goa* on the basis, tapering to $^1/_3$ of that diameter on the top, and the *Livro náutico* 33 cm for both the *nau* and the galleon, where this value is calculated as $^2/_3$ of maximum diameter of the main topmast. Again, when it was not specified otherwise, weights were calculated considering that these masts taper to half of their diameters at the top.

Table 11. *Fore topmast dimensions (L = Length; Ø = Diameter; W = Weight)*

a) LN—*Nau* *c*.1590	b) LN—Galleon *c*.1590	c) Fernandez 1616
L = 10.44/8.90 m $Ø_{max.}$ = 33 cm $Ø_{min.}$ = ? W = 0.26 t	L = 8.90 m $Ø_{max.}$ = 33 cm $Ø_{min.}$ = ? W = 0.22 t	L = 14.08 m $Ø_{max.}$ = 39 cm $Ø_{min.}$ = 13 cm W = 0.39 t

Table 12. *Fore top yard dimensions (L = Length; Ø = Diameter; W = Weight)*

a) LN—*Nau* *c.* 1590	b) LN—Galleon *c.* 1590	c) Fernandez 1616
L = 10.62/8.80 m $Ø_{max.}$ = 22/15 cm $Ø_{min.}$ = 11/8 cm W = 0.06/0.05/0.04 t	L = 8.90 m $Ø_{max.}$ = 20 cm $Ø_{min.}$ = 10 cm W = 0.08 t	L = 8.80 m $Ø_{max.}$ = 26 cm $Ø_{min.}$ = 13 cm W = 0.14 t

Table 14. *Bowsprit yard dimensions (L = Length; Ø = Diameter; W = Weight)*

a) LN—*Nau* *c.*1590	b) LN—Galleon *c.*1590	c) Fernandez 1616
L = 15.84 m $Ø_{max.}$ = 33 cm $Ø_{min.}$ = 17 cm W = 0.40 t	L = 17.79 m $Ø_{max.}$ = 39 cm $Ø_{min.}$ = 20 cm W = 0.63 t	L = 15.84 m $Ø_{max.}$ = ? $Ø_{min.}$ = ? W = ?

Fore top yard

The fore top yard of *Livro náutico*'s *nau* should be 1 *braça* shorter than the main top yard, and have 2 *dedos* less in diameter. The galleon's fore top yard should be $^{1}/_{3}$ of the fore yard in length and have 2 *dedos* less in diameter. Fernandez's *nau* should have a fore top yard 5 *braças* long and 1 *palmo de goa* thick at the centre (Table 12).

Bowsprit

No indication about the way in which the bowsprit was stepped is given in any of these documents, nor there is any mention of the angle at which it springs forward. From the drawings on folios 113 and 114 of Fernandez's book we get 34º and 38º for the only bowsprit represented, pertaining to a 'foreign *patacho*'. Regarding its length, Fernandez indicates 16 *braças* and both *regimentos* of the *Livro náutico* indicate 15 *braças* for the bowsprits of both the *nau* and the galleon. On this last *regimento* it is expressly mentioned that the bowsprit should be as long as the foremast (Table 13). Only Fernandez mentions the diameter of the bowsprit, and then only at the base, 'inside the ship'. It should have the same diameter as the main yard: 2 *palmos de goa*. On the estimation of the bowsprit's weight it was assumed that it tapered to half of its maximum diameter at its outermost extremity.

Bowsprit yard

The bowsprit yard of the *nau* from *Livro náutico* should have 9 *braças* in length and 1.5 *palmos de vara* in diameter. The galleon's one should have $^{2}/_{3}$ of the fore yard length and be half as thick as the foremast. Fernandez indicates 9 *braças* in length for the bowsprit yard, but makes no mention of the diameter (Table 14).

Mizen-mast

The mizen-mast should be stepped at the level of the main deck or slightly above, on the transom structure (*almeida*), as Fernandez says. Its length is the same in both Fernandez's and the *Livro náutico*'s *naus*, 10 *braças*, and the *regimento* of the *Livro náutico* states that its cap should stand 2 *braças* below the level of the cap of the lower mainmast. The mizen-mast of the galleon should be longer, 12 *braças*, but stepped 1 *braça* below the main deck level, and therefore standing the same 2 *braças* below the level of the cap of the lower mainmast. This mizen-mast was presumably stepped forward of the transom, since this is a 4-masted ship (Table 15). In Fernandez's *nau* the diameter of the mizen-mast is defined as 2 *palmos de vara*. Again here, the diameters indicated in the two lists of the *nau*'s *regimento* do not match. The first list says 2 *palmos de goa* (51 cm), and the second says half

Table 13. *Bowsprit dimensions (L = Length; Ø = Diameter; W = Weight)*

a) LN—*Nau* *c.*1590	b) LN—Galleon *c.*1590	c) Fernandez 1616
L = 26.40 m $Ø_{max.}$ = ? $Ø_{min.}$ = ? W = ?	L = 26.40 m $Ø_{max.}$ = ? $Ø_{min.}$ = ? W = ?	L = 28.16 m $Ø_{max.}$ = 51 cm $Ø_{min.}$ = ? W = 1.68 t

Table 15. *Mizzenmast dimensions (L = Length; Ø = Diameter; W = Weight)*

a) LN—*Nau* *c.*1590	b) LN—Galleon *c.*1590	c) Fernandez 1616
17.60 m $Ø_{max.}$ = 51/44 cm $Ø_{min.}$ = ? W = 1.05/0.78 t	21.12 m $Ø_{max.}$ = 67 cm $Ø_{min.}$ = 44 cm W = 2.66 t	17.60 m $Ø_{max.}$ = 44 cm $Ø_{min.}$ = ? W = 0.78 t

Table 16. *Mizzen yard dimensions and weights*

a) LN—*Nau* *c*.1590	b) LN—Galleon *c*.1590	c) Fernandez 1616
Length = 22.88 m	Length = 28.16 m	Length = 28.16 m
$Ø_{max.}$ = 22/19 cm	$Ø_{max.}$ = 34 cm	$Ø_{max.}$ = 29 cm
$Ø_{min.}$ = 11/10 cm	$Ø_{min.}$ = 17 cm	$Ø_{min.}$ = 15 cm
Weight = 0.25 t	Weight = 0.75 t	Weight = 0.56 t

of the foremast's diameter, or 44 cm. The galleon's mizen-mast should be 67 cm thick—half of the mainmast diameter—and taper to $^2/_3$ of this value at the top. The weights of these masts were estimated considering that their diameters at the top are $^2/_3$ of their maximum diameters.

Mizen yard

The mizen yard dimensions vary quite a bit, depending on the author. For the *nau* in the *Livro náutico* it should be 13 *braças* long and be 1 *palmo de vara* thick. For the galleon it should be twice the length of the portion of the mizen-mast that stands above the poop deck—which is 8 *braças*—and half as thick as the mizen-mast. In Fernandez's *nau* it should be 16 *braças* long, 9 abaft the mast and 7 before. Its diameter should be 1 *palmo de goa* and 2 *dedos*. Again, as in all the other yards, these central diameters taper to half toward the extremities (Table 16).

Bonaventure mast arrangement

Only the galleon has such a mast and its respective outrigger (*botaló*). They are defined with 8 (14.08 m) and 7 *braças* (12.32 m) respectively, although no mention of the way in which they are stepped is made anywhere. The bonaventure mast should have a diameter $^3/_4$ of the mizen-mast (50 cm), and the outrigger as much as the fore topmast, or 33 cm. The bonaventure yard should be twice as long as the portion of the mast standing above the poop deck level and have half of its diameter.

The Pepper Wreck masts and spars

Following the rules stated above it was relatively easy to define a plausible set of masts and yards for the Pepper Wreck proposed reconstruction. In most situations the values or rules of thumb indicated for the *naus* of Fernandez's *regimento* were clear enough, and the rigging of the *nau* and galleon from *Livro náutico* were only used as models for comparison. The main dimensions of the masts, tops and yards of the Pepper Wreck proposed reconstruction are indicated in Tables 17, 18, and 19, and schematically represented in Fig. 5.

Table 17. *Masts: proposed basic dimensions*

Mast	Length	$Ø_{max.}$	$Ø_{min.}$	Weight
Main	31.68 m	116 cm	83 cm	12.81 t
Main top	18.48 m	44 cm	22 cm	0.82 t
Fore	27.28 m	77 cm	51 cm	4.56 t
Fore top	14.08 m	39 cm	13 cm	0.39 t
Mizzen	17.60 m	44 cm	29 cm	0.96 t
Bowsprit	28.16 m	51 cm	26 cm	1.70 t

Table 18. *Mast tops: proposed basic dimensions*

Top	$Ø_{rail}$	$Ø_{basis}$	Height	Weight*
Main	4.10 m	3.59 m	0.77 m	1.28 t
Fore	3.59 m	3.08 m	0.64 m	1.07 t

* estimated based on a simple structure with two trestletrees and four crosstrees; the upper rail should be 1 *palmo de goa* square to support the artillery.

Table 19. *Yards: proposed basic dimensions*

Yard	Length	$Ø_{max.}$	$Ø_{min.}$	Weight
Main	31.68 m	52 cm	26 cm	1.97 t
Main top	10.56 m	29 cm	15 cm	0.21 t
Fore	24.64 m	44 cm	22 cm	1.10 t
Fore top	8.80 m	26 cm	13 cm	0.14 t
Mizzen	28.16 m*	29 cm	15 cm	0.56 t
Bowsprit	15.84 m	33 cm	17 cm	0.40 t

* With two pennons of 15.84 and 12.32 m respectively.

Conclusion

Although this is only a theoretical reconstruction, these values seem plausible enough to deserve further analysis, and this is the next step planned in the study of the Pepper Wreck. To our knowledge there are no Portuguese documents from this period from which we can determine the shape of the sails. However, the task of estimating the size and shape of this reconstruction's

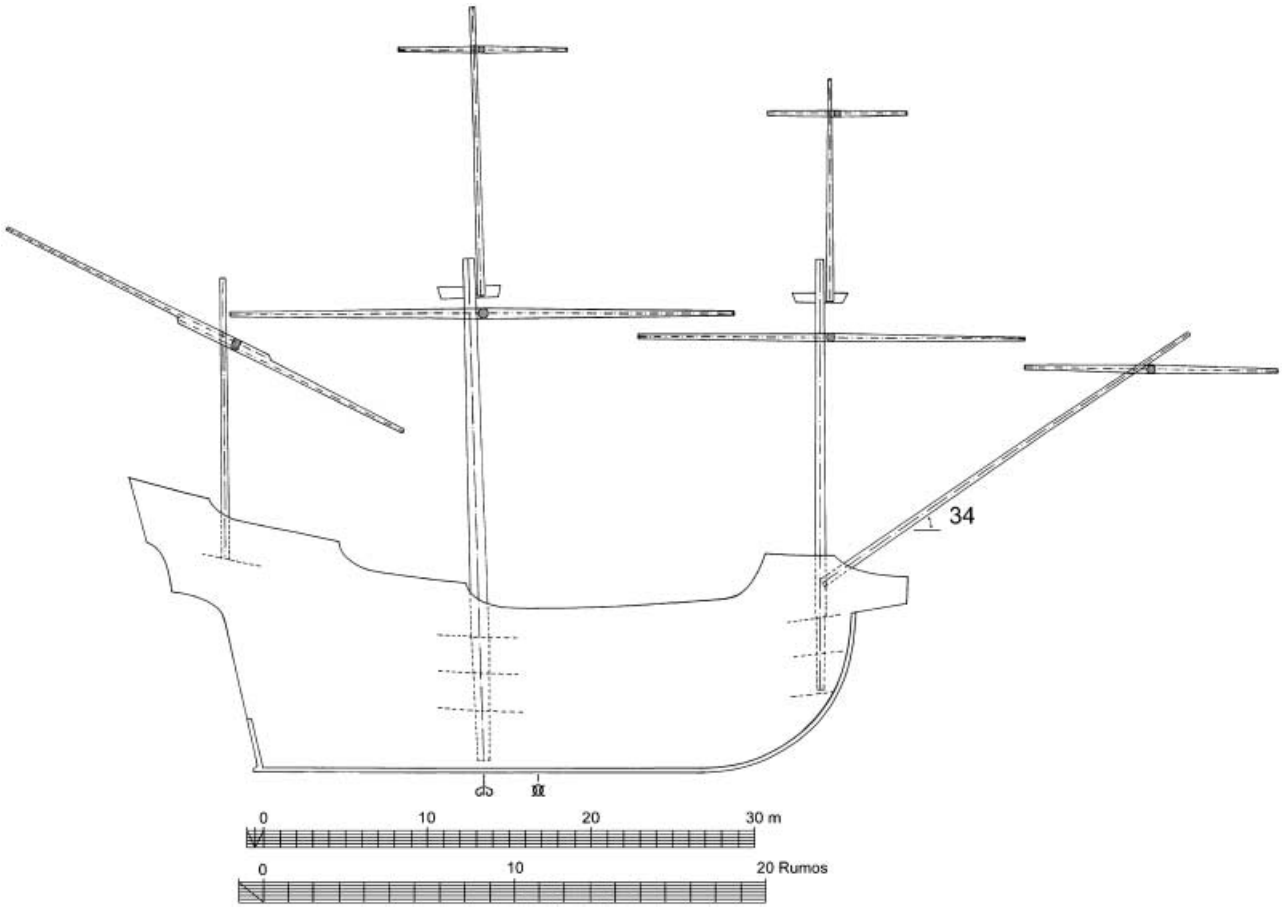

Figure 5. Plan of the Pepper Wreck masts and yards. (Filipe Castro)

sails does not seem very difficult, considering the lengths of the yards and the heights of the masts obtained from the manuscripts mentioned above, together with the iconography of this period and the excellent description in the Spanish treatise *Instrucción náutica para el buen uso y regimento de las naos*, from Diego Garcia de Palacio (1587).

The objective of this study is to provide a set of drawings that allows us to test the theoretical performance of this ship under sail before the wind for diverse ballast conditions, and sail combinations and sizes. We believe that these tests will enable us better to understand the rigging of this ship and refine the sizes and positions of its masts and spars. Perhaps an improved reconstruction will prove to be reliable enough to deserve the construction of a model and the simulation of more complex sailing conditions in wind-tunnel and tow-tank experiments.

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Cover inset: a scientist recording sediment levels on a shipwreck site near Kinlochbervie, Scotland, UK (*IJNA* 33.1: 19) (*Photo: Philip Robertson*).

Design: *patia* cross-section (*Drawing: Eric Kentley*)

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