Rigging an Early 17th – Century Portuguese Indiaman

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Abstract

The Pepper Wreck is an early 17th Century nau da India, the first Portuguese Indiaman ever to be excavated by archaeologists, and it is believed to be the remains of the Nossa Senhora dos Mártires, lost on the Tagus River sandbar, Portugal, in 1606. The archaeological remains yielded enough information to allow a tentative reconstruction of the hull and rigging. A series of tests was performed on the reconstructed ship, which allowed a better understanding of these ship type and are the basis of an ongoing in-depth study of its sailing characteristics, intern space and life aboard.

Introduction

The Pepper Wreck was found in 1992 and archaeologically excavated between 1996 and 2000 (Figures 07-01 and 02). It has been identified as the Portuguese nau *Nossa Senhora dos Mártires*, lost at São Julião da Barra on the 14th of September 1606, on its returning voyage from Cochin, India, where it had been laden with a rich cargo of peppercorns, cotton bails, spices, drugs and a number of exotic products from the rich markets of the Indian and Pacific oceans (Alves et al. 1998).

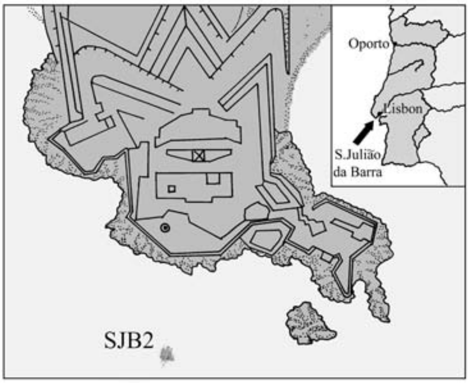

Figure 07-01 – The shipwreck site.

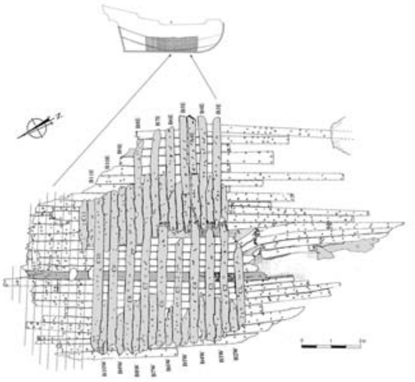

Figure 07-02 – Pepper Wreck hull remains.

The hull remains were preserved in a layer of peppercorns and the excavation of a small area around the shipwreck yielded more than 2000 artifacts, all consistent with the time frame of the voyage of the nau *Nossa Senhora dos Mártires* (Afonso 1998). For instance, astrolabe SJB III is dated to 1605, the date of departure of the nau *Nossa Senhora dos Mártires*, and bears the "G" of the Portuguese Góis workshop where it is thought to have been made (Figure 07-03).

Figure 07-03 – The three astrolabes found near the Pepper Wreck site.

Shattered against the rocky bottom off the fortress of São Julião da Barra in a matter of a few hours, the hull of the *Nossa Senhora dos Mártires* was salvaged soon after the shipwreck and during the following years. Only a small portion of the forward bottom of the hull survived, protected between two rocky outcrops, at a dept of around 9 m. After analysis, the artifacts distribution was consistent with the reconstructed site formation process. The positions of the astrolabes SJB II and SJB III, together with a pair of dividers found nearby and a small iron gun, are close to where the starboard stern castle is though to have been broken, and an anchor and bronze culverin were found on the starboard bow, to leeward of the strong southern winds that are described in the contemporary accounts of the shipwreck (Figure 07-04).

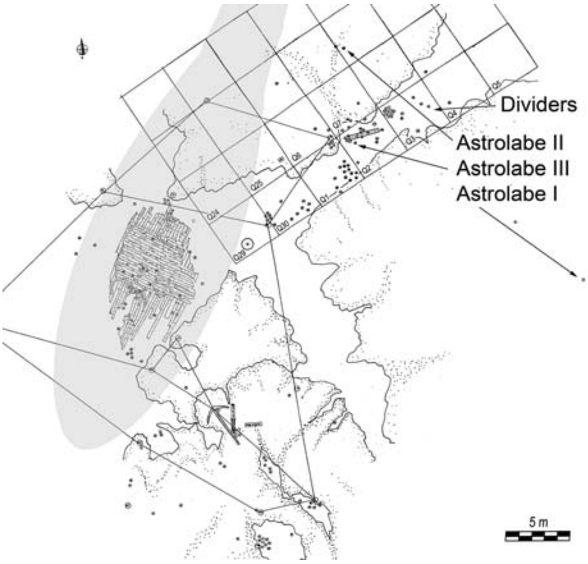

Figure 07-04 – The Pepper Wreck site plan.

Astrolabe SJB I was 20 m away from the center of the shipwreck site and, although it may have belonged to another shipwreck that occurred at São Julião da Barra – there are historical references pertaining to many shipwrecks in this area – may also attest the violence of the storm and the rapid drift of the ship, once it lost headway and started heeling in the swell, and hitting the bottom.

The study of the hull, the most important artifact, yielded precious and unexpected information, of which the carpenter's marks found at the turn of the bilge are undoubtedly the most relevant (Castro 2003a and 2005a).

Identification

The amount of peppercorns found over and around the hull remains pointed clearly to a returning India nau, a hypothesis that was reinforced by the nature of the artifact collection. The date of this shipwreck was objectively determined after 1605, the date inscribed on the astrolabe SJB III (Figure 07-03), but very soon after, because Wan-Li porcelain (Figure 07-05) was dated to the last decade of the 16th century (Shingraw and Porten 1996).

Figure 07-05 – The seven porcelain plates (lot 183) found stacked in square Q1, with a layer of straw in between each one of them.

Curiously, the bronze culverin was dated to the mid-16th century, based on the signature of its maker, Remigy de Halut, who had been a founder at Malines, Belgium, between 1536 and 1568 (Figure 07-06). It was not uncommon for ships to carry old guns – certainly in service – as attested, for instance, by the elusive "CFRO" guns, found in shipwrecks such as the one of the great galleon *São Bento*, lost in 1554, at the mouth of the Msikaba River, South Africa, and the shipwreck of Ponta do Altar B, Portugal, dated to the early 17th Century (Auret and Maggs 1984, 4-7; Alves 1992).

Figure 07-06 – Inscription on the bronze culverin bearing the signature of Remigy de Halut gun (Photo: Pedro Gonçalves, CNANS).

A quick search in the archival database immediately yielded a shipwreck exactly on that spot: the India nau *Nossa Senhora dos Mártires*, lost right in front of the São Julião da Barra fortress in September of 1606, on its return trip from Cochin, the Portuguese port in the Indian subcontinent.

The ship's hull

The ship's hull remains were recorded in plan and sections were taken at every preserved frame station. The planking was mapped at a 1/1 scale and all spike holes' positions were double-checked. Samples were taken from the keel, frames, apron and planking, for timber species identification. The first clue to the study of the ship remains was the nature of the scantlings: a certain number of very important features measured either exactly or very close (within a 3 or 4% error) to the units in the Portuguese shipyards. The second clue was the timber utilized to build this ship. The two species identified, cork oak (*Quercus suber*) for the keel, frames and apron, and umbrella pine (*Pinus pinea*) for the hull planking, were indicated in Portuguese shipbuilding treatises of this time, the first preferred for the structure and the later for the hull planking, as found on the site. The third clue was the shape of the bottom, expressed by the values of the rising of the floor timbers over the keel, and the values of the narrowing of the turn of the bilge marks found. It was possible to measure the narrowing values only in four frames, where the turn of the bilge marks, inscribed by the shipwright, were still visible. These later values were obtained after "closing" a fracture with highly eroded edges and are not all equaly reliable. The values obtained after subtracting the width of the fracture nevertheless fit very well the shape obtained with theoretical values. The forth clue pertained to the construction details, which looked very familiar when compared with the drawings and descriptions of contemporary shipbuilding treatises.

Carpenter's marks were paramount for the interpretation of this ship's construction, and consisted of three types of marks with obvious archaeological significance: turn of the bilge marks, centre and sides of the keel marks, and frame numbers (Castro 2005a).

The caulking arrangement was another detail adding to the already strong conviction that this was a Portuguese ship (Castro 2005a). It consists of one or two layers of oakum pressed from the outside against a twisted string of lead and has been reported in only another two shipwrecks: the Portuguese wreck of the Seychelles, probably the nau *Sto. António*, lost in 1589; and the Molasses Reef shipwreck, lost in the Turks and Caicos Islands during the first decade of the 16th century and though to have been at least related to a Portuguese venture, because the ballast is known to have been loaded in the Tagus estuary.

The archaeological data retrieved from this ship's hull remains was therefore analyzed in light of the contemporary Portuguese treatises. These were primarily:

a) Fernando Oliveira's *Livro da Fabrica das Naus*, dating to the 1580s (Oliveira 1991);

b) João Baptista Lavanha's *Livro Primeiro de Arquitectura Naval*, from around 1610 (Lavanha 1996);

c) Manoel Fernandez' *Livro de Traças de Car*pintaria, dated to 1616 (Fernandez 1989);

d) Two contracts from the late 1590s, by Valentim Themudo and Gonçalo Roiz (Lavanha 1996);

e) Figueiredo Falcão's *O Livro de toda a Fazenda* (Falcão 1859);

However, a list of prices pertaining to the construction of two India naus in the 1620s from the Harvard University library was also consulted, as well as the recipes contained in the *regimentos* of the manuscript *Livro náutico*, dated to c. 1590 and therefore closely related to period in which this ship was built and sailed (Domingues 2004)

Based on the values of the narrowing and the rising of the bottom at each station preserved in the ship remains it was concluded that this portion of the hull was located more or less before the three master frames, which were not preserved, but clearly visible from the fastening marks on the surviving hull planking (Figure 07-02).

The ship treatises and *regimentos* give a solid number of simple fractional relations between the ship's main dimensions that make a strong case for the definition of a standard India nau within relatively small ranges of values. India naus remain nevertheless largely unknown to us and we must keep in mind that whatever standard may have existed or not, it was one that evolved continually, as time went by.

A set of lines was developed based on the portion of the hull remains preserved at São Julião da Barra and on the proportions indicated in the contemporary ship treatises and texts (Figure 07-07) and indicated below, on Table 01.

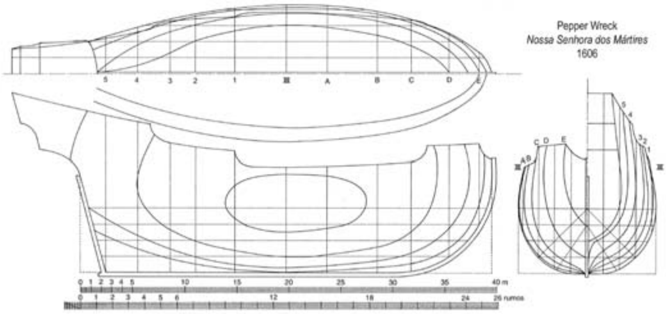

Figure 07-07 – Set of lines drawings from 2001.

All measurements in the contemporary 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). Cargo capacities are indicated in *tonéis*, a unit that corresponds to the space necessary to house a barrel 1.54 m in height and 1.03 m in diameter, or 6 by 4 *palmos de goa*.

Table 1- Basic measures for the construction of Oliveira's India nau

Element	Rule of Proportion	Value (m)
A. Keel	18 *rumos* for 600 *tonéis*	27.72
B. Spring of the stem post	1/3 of A	9.24
C. Height of the stem post	1/3 of A	9.24
D. Rake of the stern post	1/4 of A/3	2.31
E. Height of the transom	1/3 of A	9.24
F. Maximum breadth	1/3 to 1/2 of A	12.32
G. Flat amidships	1/3 to 1/2 of F	4.10
H. Room and space	1 *palmo de goa* + 1 *palmo de vara*	0.48
I. Rising of the bottom	Forward: H; Aft: 1.5 H	0.48/0.72
J. Narrowing of the bottom	1/6 of G	0.68
K. Height of the fashion pieces	Start at 1/3 of E	3.08
L. Breadth of the transom	1/2 of F	6.16
M. Maximum breath on main deck	F - (≈ 1+1 *palmos de goa*)	11.81
N. Depth of the hold	14 *palmos de goa*	3.59
O. Depth of the second deck	9 *palmos de goa*	2.31
P. Depth of the gun deck	9 *palmos de goa*	2.31
Q. Length of the quarter deck	1/2 of length of deck (D+A+B)	20.46
R. Height of the quarter deck	8 *palmos de goa*	2.05
S. Length of the poop deck	1/2 of Q	13.86
T. Height of the poop deck	7 *palmos de goa*	1.80
U. Length of the forecastle	1/2 of M	5.90
W. Height of the forecastle	1/3 of M	3.94
V. Height of bulwarks on the deck	1 *rumo*	1.54
X. Height of bulwarks on the castles	3 *palmos de goa*	0.77
Y. Length overall	A+B+D	39.27
Z. Depth in hold	N+O+P	8.21

After this analysis the *Nossa Senhora dos Mártires* was reconstructed as a ship with a keel of around 27.72 m (18 *rumos*) and an overall length of close to 40 m.

The lines drawing developed in 2001 from the analysis of the ship's hull remains and published in 2003 and 2005 (Castro 2003a and 2005a) was later used in a tentative reconstruction of the ship's structure, and completed with information contained in the treatises mentioned above, as well as a number of ship representations dating to the 16th and 17th centuries (Castro 2003b).

As a result, the position of the ship's decks and the basic defining dimensions of the hull were reviewed and corrected in order to get a better, a perhaps more accurate, representation of this ship type (Figure 08). However, because ship treatises, *regimentos*, and other texts on shipbuilding, were not intended for the average twenty-first century nautical archaeologist, they are always incomplete, often times unclear, and sometimes contradictory. This makes it almost impossible to state whether a reconstruction based on such small hull remains as the Pepper Wreck is accurate or not.

Only careful analysis, based on scientific premises, may make it possible to evaluate a given reconstruction, and to state whether it is a plausible solution or not.

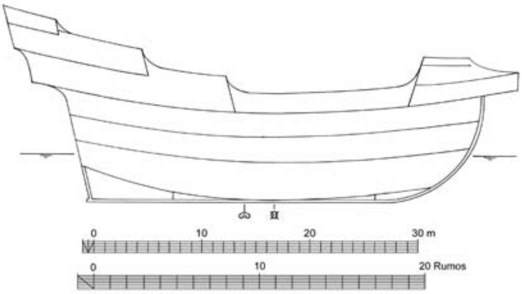

Figure 07-08 – Reviewed model, 2005.

The ship's rigging

The next logical step for the understanding of our India nau was the reconstruction of the ship's masts and spars, sail plan, and then standing and running rigging.

Reconstructing the ship's rigging is again a purely conjectural endeavor, but again the contemporary written sources have provided enough data to produce an educated guess. A comprehensive list of the documents of potential interest was published in the meantime, providing an easy access to most of the documents consulted (Domingues 2004; Castro 2005b). Four of these documents were especially important:

a) "Medidas para fazer hũa Nao de Seicentas Tonelladas" *regimento* from the *Livro náutico*, a manuscript dating to the late 15th century (c. 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) "Conta das medidas de uma nau da India" from the manuscript Coriosidades de Gonçallo de Sousa, dated to c. 1620, in the Biblioteca da Universidade de Coimbra – Reservados, ms. 3074.

The first three sources contain both values and rules for the calculation of the lengths and diameters of masts and spars of several types of vessels (Table 2). The fourth is believed to be a copy of a source common to the *Livro de traças de carpintaria* (Xavier 1992) and was only used because it contained information that helped determine the rake of the main mast.

All texts pertain to similar vessels and were written over the period of time spanning from 1580 to 1620. It is a pity that Fernando Oliveira's *Liuro da fabrica das naus*, the written source that best described the hull of the Pepper Wreck, does not include a section on rigging. Moreover, given the date of its construction, it is possible that the *Nossa Senhora dos Mártires* was a four-decker.

In fact, the main difference between the ships described in the documents mentioned above and the nau of Fernando Oliveira – and therefore the reconstruction under analysis – is that the later has three decks, as was the norm throughout the sixteenth century, and the naus described in the documents indicated in a) and c) had four decks, as it was the trend in the first decades of the seventeenth century (Barcelos 1899).

As it has been noted elsewhere (Castro 2005b), it is interesting to mention the fact that 17th century four-deckers had slightly shorter keels and slightly higher rakes of the sternposts, which seem to compensate the values of their lengths overall. Furthermore, the values of the maximum beam of these India naus grew continuously during the period under analysis, and so did 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 2. 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.

The sizes of masts and spars were determined based on the lists of dimensions given in the documents in Table 2. When they were redundant, the documents did not yield very different values, and it was therefore fairly easy to build a table with the values proposed for the Pepper Wreck reconstruction (Tables 3, 4 and 5, from Castro 2005b). The symbol 'Ø' indicates a diameter.

Table 3. Masts: proposed basic dimensions

Mast	**Length**	**Ø$_{\text{max.}}$**	**Ø$_{\text{min.}}$**	**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 4. Mast tops: proposed basic dimensions

Top	**Ø$_{\text{rail}}$**	**Ø$_{\text{basis}}$**	**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 5. Yards: proposed basic dimensions

Yard	Length	$\O_{\text{max.}}$	$\O_{\text{min.}}$	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.

Given the sizes of the masts and spars, defining the sizes of the sails became quite easy (Figure 09).

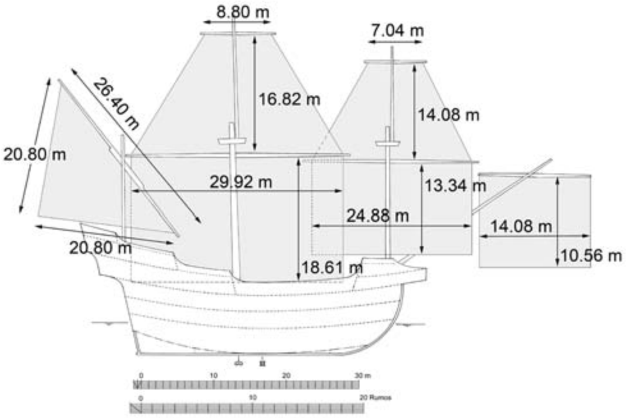

Figure 07-09 – Tentative sail plan.

Whether this configuration is plausible is another matter, and that can only be accessed through further study, which is being developed at the Secção Autónoma de Engenharia Naval (Instituto Superior Técnico), Lisbon, Portugal.

Testing the plausibility of the reconstruction

Once completed, this tentative reconstruction was ready to be analyzed with hard scientific methods, in order to test its plausibility and build a model that could be easily modified when new data about these ships becomes available.

The answers to the many research questions facing the investigator today are not simple: we are aiming at a moving target. Ships evolved constantly, and what we are trying to understand are the principles that presided over their conception, rather than a set of fixed values for their dimensions and proportions.

The best strategy is to try to understand which ranges of values are actually plausible, when we compound the archaeological data with documentary evidence – both descriptions and representations – and then test our theoretical model again and again, humbly and patiently, against all the information we will be able to gather.

A methodology was devised for testing and evaluating the sailing characteristics of the ship reconstructed from archaeological and documentary evidence (Castro and Fonseca, 2006). The research plan is extensive since it covers a large number of topics related to the assessment of nautical qualities of the ship and it is expected that within the step by step research process, a number of hypothesis related to the tentative reconstruction will be either validated or adjusted/modified. The planned work includes the use of computer programs based on mathematical models, and also experimental testing with scaled models of the ship and sailing rig.

The main objectives of the research plan are: (a) to understand the complexities of the construction sequence and structural details, (b) to determine the fundamental characteristics of these ships in terms of total weight, weight distribution, displacement and trim, (c) to assess the sailing abilities under different weather conditions, in terms of stability, propulsion force, resistance to the advance, performance regarding the waves, and maneuverability, and (d) to assess the ship's structural strength to extreme loads and fatigue loads.

The first steps of the work plan have been taken and the following paragraphs present the main results and conclusions drawn until now. Very briefly, the main results include an assessment of the ship tonnage and comparison with contemporary documented values, and an analysis of the ship stability and comparison with modern stability criteria.

Cargo Capacities According with XVI Century Empirical Methods

One of the ways of checking the plausibility of the lines plan given in Figure 07-08 is to calculate the capacity of the interior spaces of the ship and estimate if the ballast, cargo and provisions that these ships were known to transport (from written sources), could be carried inside the reconstructed hull. This can be made using a combination of the old Portuguese tonnage measurement techniques and modern cargo capacity calculations. This section also presents an analysis of the distribution of ballast and cargo inside the hull form and cargo spaces. Besides being an interesting exercise on its own, this analysis is necessary to estimate the position of the centre of gravity of the ballast and cargo, both needed for the ship stability calculations.

Costa (1997) cites several XVI century documents, which describe in variable depth the empirical tonnage measurement techniques used at the time. These consisted in measuring each of the fixed decks of the ship using arcs of *tonel*, *pipa* and *quarto*. The *tonel* was a barrel with a height of one *rumo* (1.5 m) and a maximum diameter of 1m, but the dimensions of the other two types of barrel are not known with certainty, although it is known that 2 *pipas* are equivalent in capacity to one *tonel*.

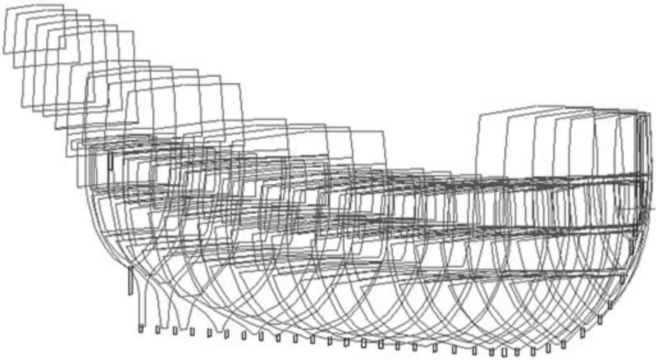

Figure 07-10 - Model of the ship's hull and cargo spaces.

For the purpose of applying these measurement techniques, a numerical model of the ship's hull and decks was created (Figure 10), allowing a "virtual" measurement of the capacity of the ship's inner spaces. Within each deck, the space was divided in transverse sections of 1.5 m in length, and the net breadth of each section was measured using the arcs. The values obtained for each transverse section were then added to attain the total tonnage capacity of each deck. This procedure was then repeated for all decks and the values summed to yield a total tonnage for the ship. The capacities of the three decks were found to be those shown in Table 6 and the total tonnage is slightly higher than 600 *toneis.* If the allowance for unusable spaces is made, then the result is a value slightly below 600.

Table 6. Tonnage capacity of the decks of the Pepper Wreck Nau.

Space	Capacity (*toneis*)	Area (m^2)
Third deck	250	378
Second deck	212	319
First deck (hold)	142	216
Total	604	913

The numerical model used for this estimation takes into account the floors, frames and beams, which reduce the useful space aboard the ship. These structural elements are described in some detail in Oliveira (1580) and in the *Livro Náutico* (1590). However, the book ignores pieces of the structure, masts, hatches and other un-useful areas, which are known to have been deducted from the useful cargo spaces by XVII century calculations of the tonnage capacity, at least when this tonnage measurement was carried out according with the rules used at the Lisbon shipyards, where the *Nossa Senhora dos Mártires* most probably was built. Unfortunately, these rules are only known in an indirect manner by means of texts, reproduced in Costa (1997), containing short accounts of the procedures used in Lisbon when evaluating the tonnage of specific ships. For this reason it is expected that the results presented in table 2 slightly overestimate the tonnage numbers that can found in some old documents.

Regarding the actual tonnage capacity of the XVI and XVII centuries Portuguese ships, authors such as Barata (1989) give tables which relate the length of the keel of different vessels with its capacity expressed in *toneis*. For this type of ship, with a keel length of 18 *rumos*, the indicated tonnage capacity is 600 *toneis*, a value corroborated both by Oliveira (1580) and by the shipbuilding instructions contained in the *Livro Nautico* (1590). One concludes that there is a close agreement between the tonnage estimation based on the hull reconstruction presented here and the tonnage referred in several historical documents for an 18 *rumos* of keel *Nau*. This result enhances the confidence in the bodylines reconstruction (Figure 10) and general arrangement derived earlier.

Cargo Capacities Obtained by Modern Naval Architecture Methods

Table 7 shows the cargo capacities of the three decks, modeled as above, and calculated using modern mathematical techniques, current in naval architecture. Information of this type, relative to the lower deck (hold), can be used to verify if the ballast could be easily accommodated inside the hold and to estimate the location of its centre of gravity. The same applies to the pepper cargo and to the substantial amount of water, wine and provisions carried onboard.

Table 7. Capacity of cargo spaces and centers of gravity

Space	Volume(m^3)	LCG(m)	TCG(m)	VCG(m)
Lower deck	719.2	19.88f	0.00	2.55
Middle deck	735.9	19.54f	0.00	5.23
Gun deck	881.7	19.47f	0.00	7.71

The exact amounts of ballast carried in these ships are not known, but Blot (1994) indicates that a 18th century ship with 64 guns carried 270 t of ballast. Taking into account the dimensions of that ship and the dimensions of the *Nossa Senhora dos Martires*, the ballast could be estimated, with a considerable uncertainty, to amount to 154t. Castro (2001) indicates that taking into account the ballast found in the Molasses Reef and Highborn Cay wrecks (Oertling 1989a, 1989b), the ballast for this ship could be in the region of 200 t. In this study, a value of 175 t has been considered.

The ballast consisted generally of broken limestone (1.55 t/m^3) and was carried directly above the keel, inside the lower hold. The 175 t of ballast then occupy 113m^3 and would fill the lower hold up to a height of 1.46 m. The centre of gravity would be 21.2 m forward of the aft perpendicular and 1.03 m above the baseline. This height of the ballast allows the conclusion that a substantial portion of the lower deck was still available for cargo, with a usable free height of around 2 m, after taking into account that generally a layer of wood was added on top of the rocks to smooth the surface where the cargo was to be laid.

The cargo aboard this *Nau* consisted mainly of pepper, weighting between 3000 and 5000 *quintais* (1 *quintal* equals to 58.75 kg), as indicated by Castro (2005a). Costa (1997) indicates some cargo weights for ships returning from India and 4500 *quintais* (265 t) is a usual cargo weight for ships of this size. The available volume in the hold above the ballast can be found to be 606 m^3 and, taking into account that the pepper density can be estimated to be 0.5 kg/dm^3, the volume required for the 4500 *quintais* is 530 m^3. This indicates that the estimated cargo of pepper could be carried entirely in the lower hold, which is according to the loading scheme described by Falcão (1607). The centre of gravity of the pepper can be estimated to be located 19.6 m forward of the aft perpendicular and 2.83 m above the baseline.

These results indicate that the lines plan derived from the archeological remains and contemporary shipbuilding treatises is plausible, given that the estimated ballast and cargo can indeed be accommodated inside the hold, as prescribed in Falcão (1607).

Ship floatability and stability

This section presents an analysis of the ship floatability and transversal stability. The transversal stability represents the ship's ability to recover its mean static position, or upright position, after being subjected to an inclining moment. This ability is directly related to the ship safety against capsizing.

The analysis of the floatability and stability characteristics of a ship requires knowledge of the ship mass and centre of gravity. The estimation of these properties for an early 17th century ship, whose constructive details are not known accurately, represents a major task and one bound to yield a result with some uncertainty. Furthermore, as usual, a considerable number of loading conditions are possible. Some results are presented for two loading conditions, being the first the condition at the departure from India for the return voyage. This condition is selected because the ships tended to be severely overloaded and this appears to have caused a considerable number of losses around the turn of the 16th to the 17th centuries, especially in the area of the Cape of Good Hope. The arrival condition is also considered since it is of interest to evaluate the ship's stability at the moment of the accident.

To obtain the mass and centre of gravity, the weight of the ship has been subdivided into a number of components, namely: hull, masts and yards, sails, rigging (shrouds, etc), anchors and ship's boats, artillery, ballast, cargo, crew, soldiers, passengers and supplies. The hull was further decomposed into an extensive list of components, comprising the hull planking, decks and structure, and were identified together with their individual weights and positions of the centre of gravity. The various types of wood employed in the different structural elements were also considered.

Fonseca et al. (2005) describes the sources of information, assumptions and details used to derive the distribution of masses of the whole ship and of the cargo. Figure 07-11 presents the weight distribution for the loading condition at the departure from India. For the arrival at Lisbon condition, it is assumed that weight of the water and wine, biscuit and other supplies is 10% of the corresponding weights when departing from India.

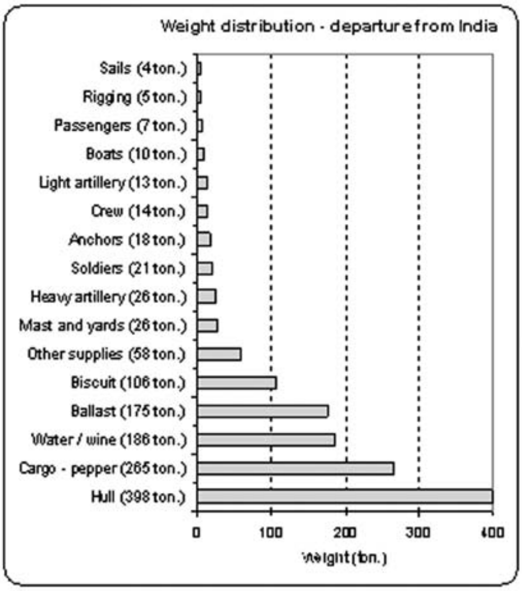

Figure 07-11 - Weight distribution for the loading condition at the departure from India

For the hydrostatic and stability calculations, the planking thickness (11 cm) was taken into consideration when defining the hull sections and the forecastle and aft superstructure were not considered watertight. Table 8 shows the drafts aft and forward, the trim of the ship, freeboard and metacentric height in the different conditions. The freeboard is defined as the distance from the waterline to the main deck, or weather deck, and it is a measure of the flotation reserve of the ship. The metacentric height is a measure of the ability of the ship to return to the upright position when subjected to a small inclination angle. The related restoring moment is given by the $W^*GM^*\theta$, where W is the ship weight, GM is the metacentric height and θ is the heeling angle.

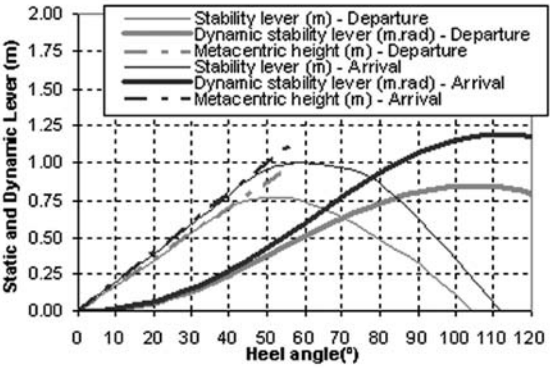

Figure 07-12 presents the righting arm and righting energy curves, as functions of the heeling angle, for the ship loading conditions when departing from India and when arriving at Lisbon. The righting arm multiplied by the ship weight results on the restoring moment, or stability moment, when the ship is heeled. While the stability lever is related to the static stability and represents how the ship reacts to a static inclining moment, the dynamic stability is related to how much the ship heels in response to a sudden and dynamic inclining moment, like for example a wind gust or a wave impact.

The graph shows that, for the departing condition, the maximum static stability moment occurs for a heel angle around 50 degrees, while the ship stability vanishes for an angle of 104 degrees. These values are slightly increased for the arrival condition, basically because the centre of gravity is slightly lower thus the stability levers are higher.

The Portuguese shipbuilders of the late 16^{th} century knew very little about ship stability, except that, for example, locating large weights high in the ship would degrade the ship's stability and that increasing the beam had good effects in the behavior and cargo carrying capacity of the ship, as mentioned by Oliveira (1580). Therefore, it is interesting to investigate if a Portuguese *nau* would comply with modern intact ship stability criteria. For this purpose we adopted the US Coast Guard (1983) criterion for large sailing vessels.

Table 8. Drafts of the ship in different loading conditions

	Draft Aft(m)	Draft Forw(m)	Trim (m)	Free-Board(m)	GM (m)
Departure from India	5.25	4.75	0.50	3.21	1.00
Arrival at Lisbon	4.68	3.74	0.94	4.0	1.13

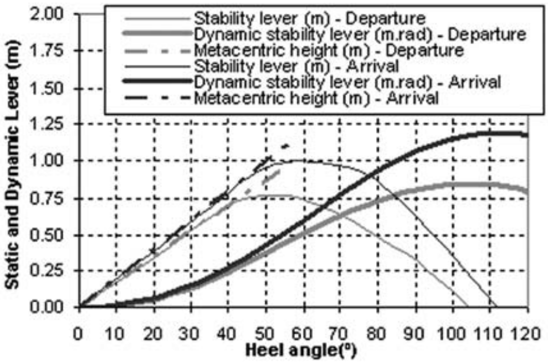

Figure 07-12 – Righting arm and righting energy curves for the departing from India loading condition.

Table 9. Stability criteria and numerals calculated for the reconstructed nau

Parameter	Minimum value (criterion)	Departure	Arrival
X	16.4	19.4	31.1
Y	18.6	21.5	18.9
Z	20.8	31.9	31.7
Angle of extinction	90°	104°	112°

According with this criterion, the ship shall have numerals *X*, *Y* and *Z* larger than given values. The *X* numeral expresses a measure of protection against water on deck. Numeral *Y* expresses the resistance against down flooding the interior of the ship and numeral Z indicates the capacity of the ship to resist a knockdown (leading to capsize). The procedure to calculate the numerals are presented in Fonseca et al. (2005), while Table 9 presents the minimum criterion requirements and the results for the reconstructed ship for the departing and arrival loading conditions.

It is observed that the ship complies with the stability criterion for both loading conditions. The general conclusion is that this ship had stability characteristics appropriate for open sea operation, at least when well maintained and correctly operated. This conclusion is valid under the assumptions of watertightness up to the main deck and of the gun holes. In practice, watertightness was often far from satisfactory and the overloading and overcrowding common practice. In fact, for instance, D'Intino (1998) indicates that the real distribution of cargo, supplies and people onboard seldom followed the theoretical scheme of Falcão (1607).

Life aboard

One of the most interesting approaches to the study of this type of ships is the simulation of life aboard conditions in particular situations, such as under storms of various magnitudes, becalmed at sea, taking water through different parts of the hull, or maneuvering.

How did the enormous crowd that populated theses ships sleep, cook, eat, work, spent their idle moments, or handle their children, their women and their sick companions? How did they discipline the crews? Where? How did they move heavy weights around, such as the ship's boats or the provisions?

This avenue of research is still pending the elaboration of a more refined computer model, one with a tentative separation of spaces and a detailed distribution of cargoes, provisions, weapons, personal items, or livestock. Not to mention the ship's fittings, such as the capstan, windlass, or bitts, as well as the ship's operational areas, such as cable lockers, spare spars' room, or even the carpenter's shop.

An Iberian ship type?

Another interesting avenue of research is the definition of an Iberian Atlantic type (Alves 2001). Such a study will entail a comprehensive comparative study of all deep sea cargo ships of the broad period under analysis, compounding historical, iconographic and archaeological information. Some characteristics consistently found in Iberian shipwrecks seem to indicate that there was a well-defined type, typical from Portugal and Spain (Figure 13). There are (many) reasons to believe that the long sea traders built in the Iberian Peninsula during the 16th century are therefore a particular blend of both Mediterranean and North Atlantic shipbuilding traditions. Nevertheless, only further studies will be able to assert how much of the shape and size of the Portuguese India naus resulted from imported models, and how much was developed and perfected in Portugal, and if so how, when, and by whom.

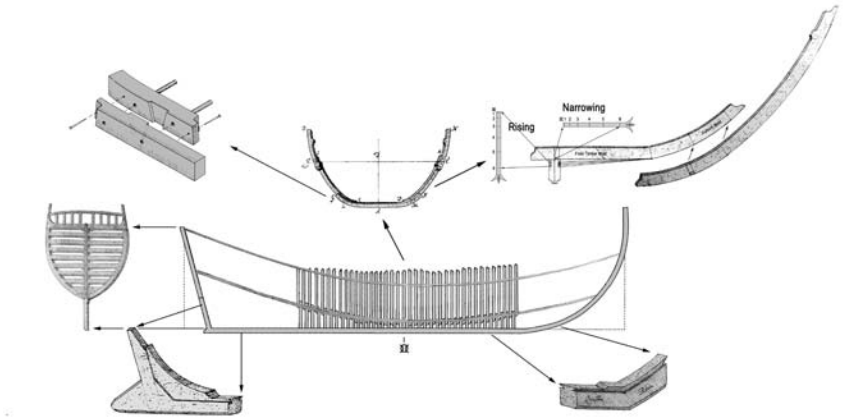

Figure 07-13 – Schematic representation of the most common structural characteristics found in Iberian shipwrecks: knees connecting the keel to the stem and sternpost, pre-designed central frames rising and narrowing the turn of the bilge points according to old Mediterranean algorithms, floors and first futtocks connected with dovetail scarves, and deep flat stern panels.

Conclusion

This project is just starting and its possible outcomes are diverse and exciting (Castro and Fonseca 2006). The ultimate goal is to understand these ships in a number of ways:

a) as inhabited places, wandering around the world with a microcosm of Portugal's 16th and 17th century society in their bellies;

b) as sailing machines, a solution to achieve a number of tasks;

c) as an artifact, complex, large, expensive, and mobile, conceived by an almost certainly illiterate community, based on experience and rules of thumb imported from the Mediterranean world, whose meaning was perhaps forgotten;

d) as a synthesis of several cultures at play in the nexus between the Atlantic and the Mediterranean seafaring worlds;

e) as an expression of power, a symbol of the will of the Portuguese monarchy, expressed perhaps in much more things than the crosses painted on the sails (at least in the first half of the 16th century); and

f) as an engineering project, built from an idea, almost certainly without plans, tuned as they were built, their measurements derived from a small number of fundamental dimensions.

We are sure that there will be many more ideas as the project develops. It will ultimately depend on the amount of resources that the authors will be capable of gathering.

One last word for the use of virtual reality, which is perhaps one of the most exciting avenues of research when we consider the outcomes of such a project, mostly when it comes to the diffusion of the results to the scholarly community as well as to the general public.

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