The International Journal of Nautical Archaeology (2006) **35**.1: 97–103
doi: 10.1111/j.1095-9270.2005.00082.x

Sailing the Pepper Wreck: a Proposed Methodology for Understanding an Early 17th-Century Portuguese Indiaman

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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 on its return voyage from Cochin, India, on 14 September 1606. Following archaeological excavation and a tentative reconstruction of the ship's hull and rigging, the next step is the study of its structural strength and sailing characteristics using the tools of modern naval architecture. This paper presents a methodology for investigating the sailing and structural characteristics of the 'Pepper Wreck', combining archaeological, iconographic and contemporary written sources with modern naval architectural calculations.

Key words: Pepper Wreck, *Nossa Senhora dos Mártires*, Portugal, India Route, Portuguese *nau*, sailing performance.

The India Route was the longest commercial route of its time and the vessels which sailed from Lisbon, in Portugal, to Goa or Cochin in the Indian subcontinent, were the largest and strongest of their time (Fig. 1). The maritime route to India was opened by Vasco da Gama in 1497 and 1498, and during the following centuries Portuguese *naus* sailed around the African continent and into the Indian Ocean, loaded with as many as 800 passengers and crew, and enormous quantities of precious and exotic merchandise, as well as new ideas. In spite of the numerous books written about European expansion overseas almost nothing is definitely known about its ships.

Historians have a good picture of the intellectual environment in which these voyages were planned and carried out, the difficulties encountered by sailors when trying to find their way on the open sea, the instruments and calculations available to estimate a ship's position at sea, and the skills of 15th-century map-makers. Art historians have studied the tastes, artistic trends and architectural styles that determined the appearance of the cities and towns where these men planned their voyages and dreamed of power, glory, wealth, and salvation. They have a fair idea of the paintings they hung on their walls, the images they worshiped, the music they listened to, their plays, poems and favourite fiction. Their material culture is also fairly well known. Archaeologists have uncovered the artefacts of their daily life and have established chronologies for styles, trends and fashions in furniture, glasswares, tablewares, clothes, jewellery and weapons for the entire period of the European expansion overseas.

When it comes to their ships the case is unfortunately different. We know almost nothing about the ships of the Age of Discovery, the very vehicles of this expansion. Because they were built in a pre-industrial era there were no drawn plans. Because they were an inconspicuous part of the landscape nobody bothered to paint them in detail. Finally, in spite of being complex machines, their construction relied mostly on practical knowledge and tradition and they belonged to a sphere of knowledge that did not attract many scholars. For all these reasons nobody bothered to write detailed

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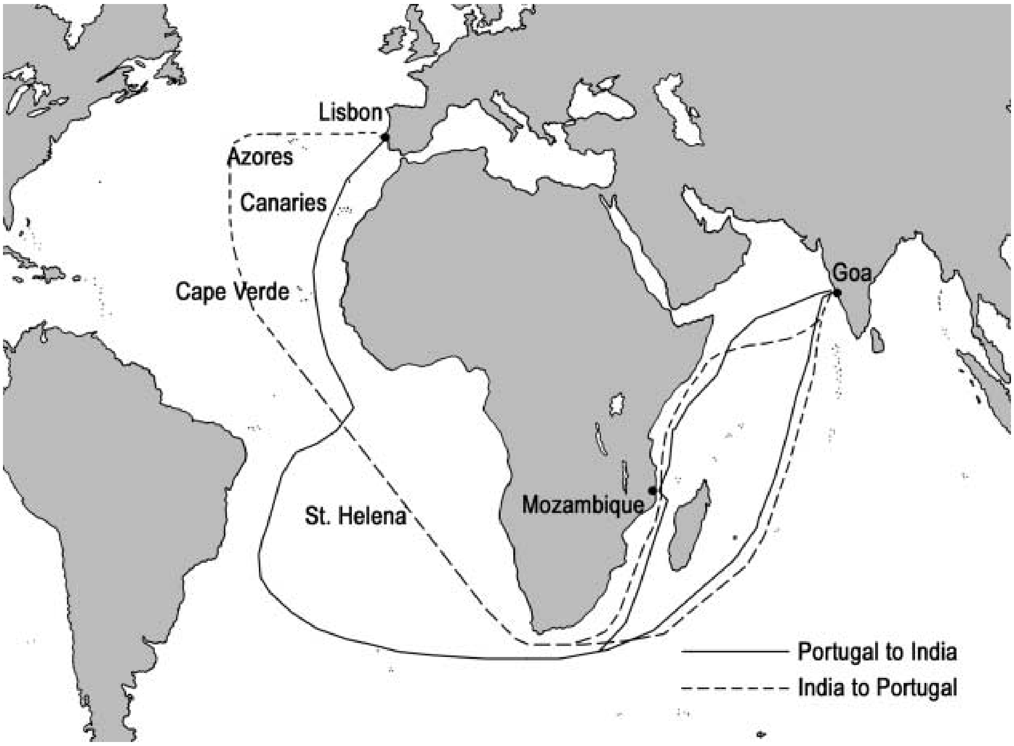

Figure 1. The India Route (after Malhão Pereira, 2001).

descriptions of these ships, nor about the ways in which they changed, evolved, and eventually fell out of use (Castro, 2003). Written sources are scarce and laconic, iconography unreliable, and archaeology practically non-existent. These ships are shrouded in mystery and tales of lost treasures, and many of the surviving wrecks have been destroyed by treasure-hunters. The systematic depredation of archaeological sites is not a problem faced only by nautical archaeologists, but one that has yet to attract the attention of most of the scholarly community, not to mention the politicians and the media (Renfrew, 2000).

During the 20th century a number of Portuguese shipwrecks were found and either looted by local divers or salvaged by treasure-hunters. The Pepper Wreck, presumed to be the Indiaman *Nossa Senhora dos Mártires*, lost in 1606 at the mouth of the Tagus River, near Lisbon, is the only Portuguese Indiaman ever to be fully excavated by archaeologists (Afonso, 1998). Excavated between 1996 and 2000, a small surviving portion of the hull has yielded an impressive amount of information because some of its timbers had construction marks scribed on them. These have allowed a hypothetical reconstruction of the ship's hull based on the information contained in a series of contemporary texts on shipbuilding (Castro, 2005a). The texts under analysis—which establish simple proportions and rules of thumb for the design of ships' hulls and rigging—permitted the reconstruction of a plausible configuration of the hull and rigging of the ship (Castro, 2005b). This reconstructed ship can now provide a major contribution to filling an important gap in our knowledge about the performance of these ships under sail.

It is difficult to assert the sailing capabilities, maximum speeds, or best possible reaching angles of these ships. Although we have diaries of voyages and notes from the pilots who led these ships through the 6- to 8-month trips, these are personal accounts from a time when there were no instruments, and navigation was carried out by estimation of speeds, directions and times. The gap in our knowledge extends far beyond the performance of the Portuguese Indiamen of the 16th and 17th centuries. We know almost nothing about the sailing capabilities of most post-medieval ships, both merchantmen and warships. Some scholars have developed theories to explain why such ships as the *Mary Rose* or the *Vasa* capsized (Marsden, 2003; Hocker, 2005); others have carefully studied the naval diaries of the early-17th-century Portuguese India Route to assess the sailing capabilities of these ships (Pereira, 2001); a few have built full-scale replicas (Baykowski, 1994).

However, it is difficult to understand stability and sailing performance from contemporary accounts and drawings, and full-scale replicas are very expensive, not very durable, and cannot be tested for the worst weather conditions without risking accidents or endangering the lives of the crew. A theoretical study has been conducted on the Bremen Cog, entailing tests of the rigging in a wind-tunnel and the development of a mathematical model to predict the performance of this ship under sail (Brandt and Hochkirch, 1995). But the Bremen Cog was a middle-sized ship with only one mast and a square sail, and this type of analysis becomes far more complex for 3-masted ships. A group of researchers from the Unit of Marine Technology and Engineering (UETN) at the Instituto Superior Técnico, Technical University of Lisbon, Portugal, and the Nautical Archaeology Program of the Department of Anthropology at Texas A&M University, USA, is trying to establish a methodology for the testing and evaluation of sailing abilities (Fig. 2). Our long-term goal is to build a comprehensive image of these ships: how they were conceived, designed and built, how they evolved and changed over time, how their performance was perceived by the several players with stakes on their voyages, what the cultural exchanges were between the major shipbuilding powers in Europe at the time, and how they improved the shape and characteristics of the different large vessels built by these countries or regions.

The main objective of this project is to analyse the sailing capabilities and structural strength of an India *nau* reconstructed from archaeological and documentary evidence. Based on the information retrieved from the archaeological remains, compounded with the knowledge obtained from almost 100 years of studies of iconography and contemporary written sources, both literary and technical, the main objectives of this project are:

To obtain a plausible configuration for the hull, masts, spars, rigging and sail plan of an India *nau*;

To try to understand the complexities of the construction sequence and structural details, determining the fundamental characteristics of these ships in terms of total weight, weight distribution, displacement and trim;

To assess the sailing abilities under different weather conditions, in terms of stability, propulsion force, resistance, performance regarding the waves, and manoeuvrability;

To assess the ship's structural strength to extreme and fatigue loads.

This project entails 13 separate tasks:

1. Design of the hull lines, sail and rigging plan

Improve the lines drawing that resulted from the reconstruction of the Pepper Wreck hull remains with special three-dimensional software, develop the masts and spars plan, sail plan and rigging plan. This may entail the creation of several different models with plausible variations in the hull shape and the rigging, since there was no such a thing as a standard India *nau*, and there are several possible arrangements for the sail area, mast positions and height and width of the yards.

2. Design of the ship's structure

To create a three-dimensional plan of the ship's structure, including internal subdivisions, and input the weights and centres of gravity of each timber piece, having in mind the different specific densities of the various kinds of timber used. This also includes the identification of the connections between structural timber elements, which will be important for assessing the ship's structural strength. This task is especially important because the definition of the interior spaces will also allow estimation of the cargo capacity, weight and distribution, and ballast requirements for each loading configuration. An additional objective is to characterize the design and fabrication processes that were used to build this these ships.

3. Stability analysis

This comprises assessment of the floatability and stability of the ship for several loading conditions. Firstly the intact stability will be investigated by modern computational methods (Santos and Guedes Soares, 2001), including small-angle and large-angle stability. The results will be compared to current stability criteria for large sailing vessels, allowing an estimation of the actual safety of the ship. Secondly, the stability during and after flooding (damaged stability) will also be investigated, using state-of-the-art methodologies, which will permit conclusions to be drawn with regard to the ship's survivability, effectiveness of the crew counter-measures and of simple subdivision of the ship (Santos *et al.*, 2002).

4. Hydrodynamic model tests in tanks

One scaled hull-model will be built based on the computer model obtained upon completion of tasks 1 and 2, and a series of tests will be carried out in a towing and sea-keeping tank (Fig. 3). Three groups of tests are planned: resistance tests, where the model is towed in still water at several speeds to measure the resistance to the advance; sea-keeping

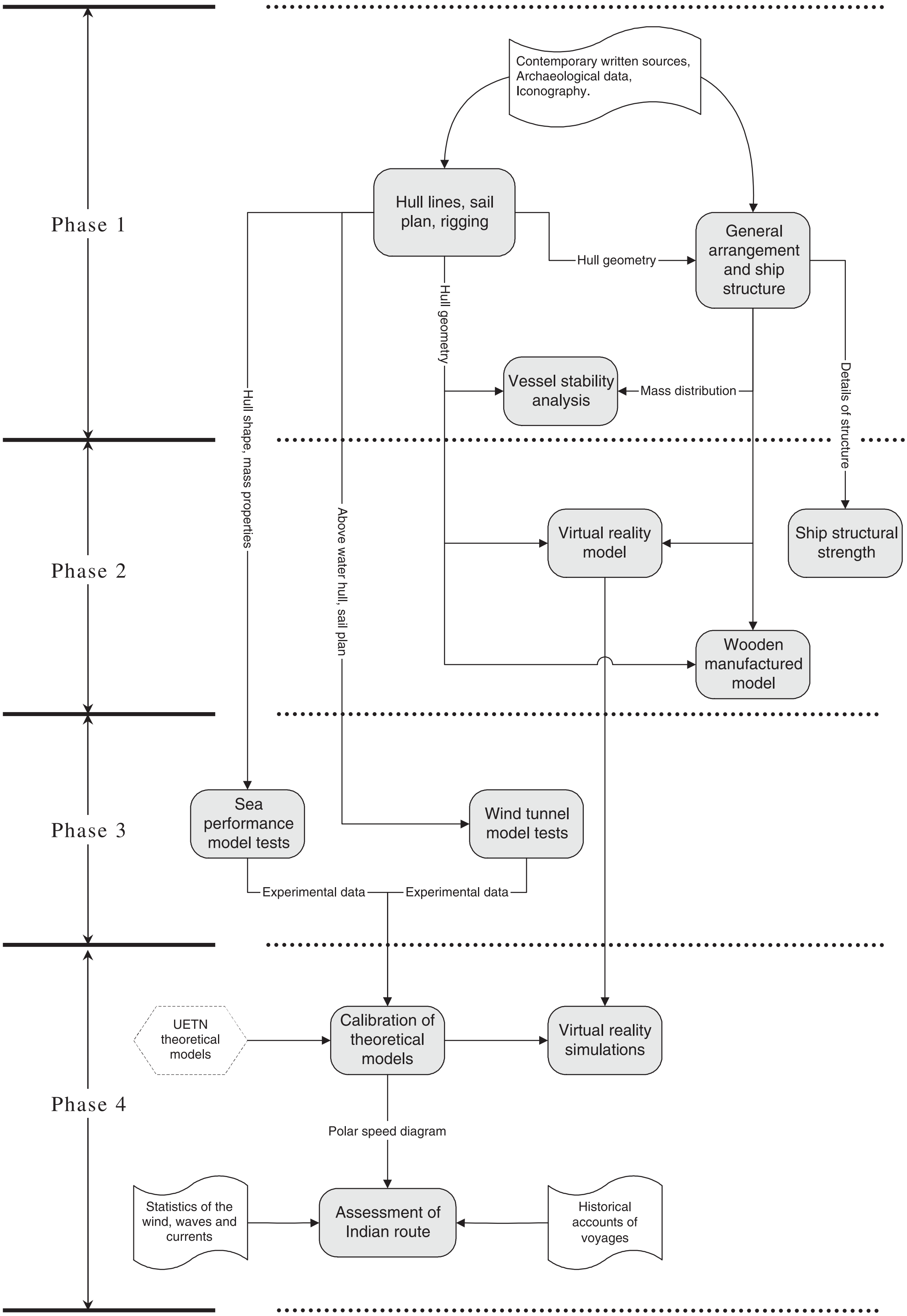

Figure 2. Chart with the planned tasks.

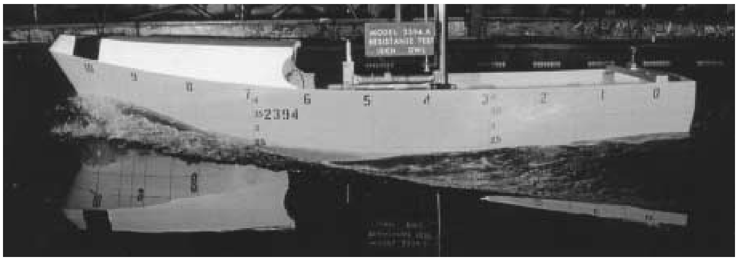

Figure 3. Seakeeping tank at the El Pardo Model Basin, Madrid, Spain. (Nuno Fonseca)

tests, where the model is towed in regular and irregular waves to measure the induced motions and added resistance to the advance due to the waves; and manoeuvring tests where forced horizontal motions are imposed to the model to obtain the hull manoeuvring characteristics.

5. Aerodynamic tests of sail-model in wind-tunnel
A model of the hull's upper works and rigging will be built, based on the data gathered in tasks 1 and 2, and tested in a wind-tunnel, with different wind conditions and directions. These tests will be carried out considering only the sails (in several configurations) and the sails together with the hull's upper works, since it is known that the size of the fore and stern castles of these ships influenced their performance under sail. These tests will allow the determination of the intensity of the force applied on the ship and its application point for each wind condition considered. This force will be then resolved into the directions that will determine the advance of the ship (longitudinal), the fall to leeward (transverse) and the heeling (heeling moment). The results will be used to calibrate the theoretical model built in task 6.

6. Calibration of the theoretical models for ship dynamics
UETN has developed and implemented software based on several theoretical models that calculate the dynamic behaviour of ships at sea. These models solve the following problems: resistance to advance, seakeeping in waves (Fonseca and Guedes Soares, 1998; Centeno *et al.*, 2000), manoeuvring (Sutulo *et al.*, 2002) and sailing performance (Bettencourt *et al.*, 2003). However, these models are at present adequate for modern conventional ships and vessels. In this task, those models will be calibrated and validated to represent the dynamics of the Pepper Wreck, by systematic comparison of results with tank and wind-tunnel data. Combining the calibrated models it will be possible to describe the fundamental sailing characteristics of the *nau* designed in tasks 1 and 2.

7. Calculation of the polar diagram of speeds
This task will consist in the calculation of the polar diagram of speeds, a graphic that indicates the speed attainable for each direction and wind-force combination. In addition to the sailing speed and direction, UETN software (Bettencourt *et al.*, 2004) will find the heeling, drift and rudder angles, while sailing in equilibrium for each situation of wind intensity and direction and sail configuration.

8. Assessment of the India Route possible paths
Considering the patterns of wind and currents for the Atlantic and Indian Oceans during the periods in which these ships sailed, and the sailing qualities of the *nau*, an attempt will be made to simulate a full round voyage and determine the speeds and times achieved during each leg. A critical analysis will be performed in order to assess whether the route chosen by the Portuguese pilots was in fact the best possible solution given the ship's characteristics and the time restrictions imposed (related to the harvest and cure of the return cargo of peppercorns, the prevailing winds of each monsoon, and the pathway of the cash flows that fuelled the commerce. The results obtained from this task will be compared with the historical accounts of voyages to assess the 16th- and 17th-century estimations of the longitude and distances sailed noted in the sailing logs. The methodology is based on procedures previously developed to investigate the sea-keeping performance of modern ships in terms of the climatology of the ocean areas where the ships operate (Guedes Soares *et al.*, 1998, Fonseca and Guedes Soares, 2002).

9. Assessment of the ship's structural strength
The model built in tasks 1 and 2 will be used to study the structural strength of these ships. Almost

nothing is known about this subject other than that the scarcity of suitable shipbuilding timber at this period makes these ships very interesting subjects of study from the optimization-engineering point of view. Structural loads imposed by severe weather, transmitted to the hull structure both by large waves and by the rigging will be analysed and compared with the structural strength expected for the model, given the timber sections utilised, the types of connections, scarves and fastening patterns. Fatigue will also be analysed since these ships were subjected to violent and repetitive stresses during long periods—frequently over one month—during their 6- to 9-month trip. One of the most interesting aspects will be to assess the influence of heterogeneity of timber, as a construction material, in the final strength of the ship.

10. Creation of a virtual reality model

A 3-dimensional virtual model will be designed by computer to provide both the investigators and the target public a better understanding of the interior space distribution, living conditions, sailing performance and manoeuvring. The user will be able to observe a realistic ship-model including hull-form, rigging and sails, general deck arrangement, internal subdivision and relevant structural details. A 'fly-through' camera will be implemented, allowing the user to navigate around the virtual environment of the ship (Varela *et al.*, 2004). Additionally, to navigate inside the ship, a 'first person' camera will also be implemented with collision detection feature.

11. Virtual reality simulations

The virtual model will be utilised together with the mathematical models to recreate a series of typical situations routinely encountered by an India *nau*, such as: manoeuvring, including reaching; beating, changing tack, and stopping; the dynamics of the ship under different sailing conditions; the inflow of water which might result in sinking, including the measures taken by the crew; simulation of the construction process; the operation of launching; the careening of the ship.

***12. Construction of a scale model of a* nau**

This task consists in the construction of a wooden scale model of an India *nau* following the processes and construction sequence of the late 16th century. There will be no full understanding of the construction process without this experimental phase in which the scientists get to understand the real possibilities of the timber utilised, the most important aspect being the simulation of bending directions of the wales, stringers, planking strakes, and the influence of this practical knowledge—today completely lost—on the conception and design of these ships. Each construction phase will be documented in video and digital photography.

13. Dissemination of the results

Dissemination of the results to two main target publics: the scientific community and high school teachers and students. This task will encompass: publication of articles in academic journals; publication in magazines aiming at a wide public; a documentary for television; involvement in the Portuguese public project 'Ciência Viva' (living science), aiming at the involvement of high school students in the investigation activities.

This project will add to our understanding of the design and construction of the ships that opened the Asian markets to Europe. It is not possible to state in advance how close to the real ships our model will be, but once we have run all the tests encompassed in this project we will have a very precise idea of what needs to be refined. Moreover, this study is of particular interest should another Portuguese Indiaman ever be found and excavated by archaeologists. By comparing the data obtained in this study with the data archaeologically retrieved from another Indiaman this model could be improved with only marginal costs.

Conclusion

Being well aware of all the difficulties related to the reconstruction of such a complex machine as a Portuguese Indiaman, we think that this exercise, as academic and theoretical as it may be, is an important first step for our basic understanding of these ships. Although theoretical, the reconstruction of the Indiaman under analysis is not another romantic reconstruction, such as the ones made in the early 20th century, in commemoration of European discoveries. Ours is an educated guess based on precise overall measurements stated in contemporary technical texts. What we expect to get from this project is not a perfect model of an India *nau*, but a solid understanding of the ranges of values at play, for instance, when we consider the basic stability of these ships. We must keep in mind that these ships were designed and built to carry massive volumes of light cargoes, such as peppercorns and cotton bales, in their holds, while bearing heavy yards and crow's nests with guns.

We have no doubts that the best source of knowledge for the understanding of these ships is the archaeological record. However, these studies will provide archaeologists with a better understanding of the ships under study and will allow them to ask more precise research questions in future archaeological excavations.

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