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Tonnages and displacements in the 16th century

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ABSTRACT

Questions associated with the size of ships suggested in historical documents are relevant to giving an idea of the volume of cargoes, the size of crews, cost of freights, or when trying to evaluate competitive advantages in war and commerce. Good estimates are often difficult to obtain from the written record, although some values concerning basic hull dimensions are sometimes mentioned. The establishment of reliable relations between registered capacity, as expressed in coeval documents, and displacement, as it is defined nowadays, would be helpful to both historical and archaeological research. This paper probes into the relations between a number of known formulas to calculate tonnages in the 16th century, and the reconstructed hull of the Pepper Wreck, an archaeologically excavated shipwreck dated to 1606.

1. Introduction

Questions associated with the size of ships mentioned in historical documents are frequently difficult to answer. Several factors tend to blur our understanding of the references to ship sizes and capacities in the records. The reliability of documents depends on the honesty and competence of their authors, and references to ships' basic dimensions, crew, or cargo capacity can be distorted for many different reasons. But to know the size of a given ship within a narrow range of dimensional values is often important, for instance when we attempt to identify a shipwreck. To know the size of ships in historical documents is important for the study of the history of shipbuilding, and the best way to understand and compare ship sizes from archival references is to establish a common scale. We have chosen displacement, as it is defined nowadays – the weight of the water displaced by the submerged volume of a given hull – and we are trying to establish relations between capacity, as expressed in coeval documents, basic hull measurements, such as beam, length of keel, or depth in hold, and the volume of a hull below the waterline.

At least from the 16th century onwards, capacity was sometimes calculated with formulas of which a small number survives, together with scattered values and equivalences of measuring units. These formulas and values can be tested against a growing body of data retrieved from shipwrecks to facilitate a better understanding of the questions related to ships' tonnages and displacements in the 16th and 17th centuries. Two factors must be weighed, however, related to the concepts of precision in the period under analysis, and the documented changes – in time and from place to place – of the values of units as important as the *ton*.

2. Precision in the 16th century

It is difficult to imagine anybody today demanding centimetric accuracy in the construction of a backyard swimming pool, as it unlikely that 16th and 17th century shipwrights concerned themselves too much with measuring the maximum beam of their ships to within a few *dedos* in width (a *dedo* in Portugal is thought to measure around 1.83 cm and in Spain 1.74 cm). If it is plausible that the *graminhos* – a set of geometric methods used to achieve fair longitudinal curves along a ship hull (Castro, 2007) – applied on the central frames to define the narrowing and rising of a ship's bottom were measured with care, possibly to less than one *dedo*, it is difficult to imagine the same care and precision being applied to the definition of a keel length. The rigor applied by Ticho Brahe to his celestial measurements, or by an astrolabe maker to his astrolabes, was certainly different from that required in the shipyards of any European country, when it came to laying a keel on the stocks. In other words, it is plausible that units used in Portuguese shipyards, such as the *palmo de vara* (22 cm) and *palmo de goa* (25.67 cm), which were defined by standards kept in municipal halls, were sometimes loosely applied in the construction of ocean-going ships through gauges made in the shipyards and copied from other gauges, possibly with accumulated errors. Several times I

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have repeated a story I heard from J. Richard Steffy, who heard it from John Patrick Sarsfield, about a shipwright from Bahia in Brazil who told him that he used a certain *graminho* gauge, but “he always gave it a little bit more”. These measurements were transferred to the timbers with inscribing tools, followed by sawyers working with large saws and sometimes under pressure to deliver the sawn timbers on time, and then modified by the shipwrights with adzes and axes to fit in the real ship, once mounted on the stocks.

This fact is clearly observed in the dimensions of timbers obtained from shipwrecks. For instance, in the case of the Pepper Wreck, believed to be the Portuguese Indiaman *Nossa Senhora dos Mártires*, lost in 1606 (Castro, 2005a), the sided dimensions of the floor timbers varied around an average of 25 cm (22–26 cm), and the side dimensions of the adjacent futtocks varied around an average of 22 cm (21–25 cm). We should not imagine, however, that ships were losely built by eye. Richard Barker cautioned us to consider that maritime cultures where locks and docks are common call for a particular care on the establishment of maximum values for beams and drafts. Still, we do not believe that even in these cultures measurements would be taken with the same accuracy as those used in the manufacture of furniture, let alone a nautical instrument, to cite just two examples.

3. Units of measurement

The second problem, related to the values of units recorded in different places and through the decades, also calls for reflection. Sometimes the value of a particular unit is difficult to estimate with any accuracy. For instance, in its origin a Baltic *last* seems to have been the volume of a cartload. The dimensional boundaries of such a concept are difficult to define, no matter what methodology is applied. In the 16th century, a *tonel* – a unit that sometimes measures weight and sometimes volume – meant different things in Portugal, Spain, France, and England.

Built by hand according to tradition, the external dimensions and capacities of barrels varied considerably, even within a small sample. We have a first hand account of this fact from Johannes Kepler who, unhappy with the way the supplier of wine for his wedding gauged the barrels he purchased, theorized the calculus of barrel capacities for three different theoretical profiles: elliptical, parabolic or hyperbolic sides (Kepler, 1615). Notwithstanding the patent variation in their capacities, barrels were used as tonnage units for several centuries. The use of formulas seems to have gradually replaced the estimation of a ship’s capacity with gauges and hoops, although the use of formulas in Portugal is not documented in the 16th century. These formulas add another difficulty to the study of ship sizes because it is not always clear where the measurements used in their calculations were to be taken (e.g. to the inner surface of the ceiling planking or inner surface of the hull planks; on the lower deck, along the weather deck, or below it, at the level of the maximum beam).

These problems call for special care in the interpretation of historical documents. The numerous replicas of Columbus’ ships built since the 1880s speak eloquently to this problem (Gay and Ciano, 1997). This troublesome issue arose as recently as 1992, when a new set of replicas was built for the commemoration of the 500 years of the discovery of the Americas and exhibited in Seville, in the World Exhibition Expo’92. Historian José Luis Casado Soto showed that the replicas had tonnages that almost doubled those of the ones sailed by Columbus on his first voyage, as indicated in coeval documents (Soto, 2006).

At this stage of our research, the best solution for the problem of determining historic ships’ sizes seems to hinge on a two-step strategy that encompasses: 1) the determination of displacements and hull coefficients of hulls archaeologically excavated; and 2) the establishment of mathematical relations between capacity and hull scantlings, as defined in contracts, shipbuilding treatises, or other reliable historical documents. Given a large enough sample, it should be possible to understand the orders of values within which a certain type of ship was built.

4. Units and regions

The Portuguese used a unit of linear measurement, possibly imported from Genoa, designated the *goa* or *côvado real*, and equivalent to 77 cm. It was related to a local unit designated the *vara*, of which a standard offered by king Sebastian (1554–1578) to the city of Tomar measured exactly 110 cm. A *goa* was divided into 3 *palmos de goa* (25.66 cm) of 7 *polegadas* each (3.67 cm), or 14 *dedos* (1.83 cm). The *vara* was divided into 5 *palmos de vara* (22 cm) of 6 *polegadas* or 12 *dedos*. The *goa* was the equivalent to half a *rumo* (1.54 m), the height of the standard *tonel*, which was the unit of capacity in use in Portuguese shipyards. The maximum diameter of this standard *tonel* was 4 *palmos de goa* (1.027 m), and its capacity was twice that of a *pipa* and four times the capacity of one *quarto* (Barata, 1996; Barreiros, 1838; Costa, 1997).

The exterior volume of the cylinder that contains this *tonel* is given by:

$$\pi \times r_{max}^2 \times h = 1.276 \ \mathrm{m}^3 \tag{1}$$

With ($\pi = 3.14159$, $r = 1.027/2 = 0.51$ m, and $h = 1.54$ m). Kepler established a method to calculate a barrel’s capacity considering the curvature of its sides elliptical:

$$1/3 \times \pi \times h \times \left(2r_{max}^2 + r_{base}^2\right) \tag{2}$$

or parabolic:

$$1/15 \times \pi \times h \times \left(3r_{base}^2 + 4r_{base} \times r_{max} + 8r_{max}^2\right) \tag{3}$$

where $\pi = 3.14159$, r_{max} is the maximum radius, r_{base} is the radius of the barrel’s base, and h is the height of the barrel.

The values obtained through Equations (2) and (3) are similar, but to obtain them we need to estimate the radius of the barrel’s base, the thickness of the staves and heads, and the height of the chimes. Data pertaining to the dimensions of barrel staves are scarce, but there are no strong reasons to suppose that these have changed drastically over the centuries. For lack of a better plausible source relating the thickness of barrel staves and the size of the barrels we have used late 19th century values and assumed that the thickness of barrels’ staves and heads was 4 cm and the chimes 5 cm. In this case, the maximum interior diameter becomes 94 cm and the interior height 1.36 m (Special Consular Reports, 1891–1892, 3–89). Varying the diameter of the base between 80% and 95% of the maximum diameter, the capacities obtained with Equations (2) and (3) present differences smaller than 1%. For diameters of the base equal to 80%, 85%, 90% and 95% of the maximum diameter of the barrel, the elliptical model determines capacities of 831, 857, 884, and 913 L, and the parabolic 828, 855, 883, and 913 L, respectively.

In a collection of *barricas* – in Portuguese *quartos* – found on the Basque whaler *San Juan*, lost in 1565 at Red Bay, Canada, and carefully studied by Brad Loewen, the average relation between the diameters of the base and the bilge (maximum value) was 89% (Loewen, 1999, 59). Considering this value, the calculated capacities are 878 and 877 L for elliptic and parabolic sides, respectively, not far from the 52 *almudes* (873.6 L) traditionally referred to in the literature, at least if we accept the value of one *almude* as 16.8 L (Lopes, 2003, 155).