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Rising and Narrowing: 16th-Century Geometric Algorithms used to Design the Bottom of Ships in Portugal

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Methods of designing the bottom of ship's hulls were only a small part of the process of building a frame-based ship in Portugal in the 16th and early 17th centuries, but they deserve a careful look. Using a number of geometric algorithms that were already well-known to Italian shipwrights of the 15th century, Portuguese shipwrights obtained the co-ordinates of the turn of the bilge points of the central, pre-designed, frames without the need for making drawings.

Key words: Mediterranean, 16th century, whole moulding, ship design, narrowing, rising.

Long ago I heard an anecdote about the composer George Bizet's love for gipsy music that I never forgot: one day, after listening to a group of players and singers in Spain, he said to one of the older singers: 'I understand the rhythm, the chromatic effects and the harmonies, but I don't understand how you know when to stop all at the same time'. The elder is said to have replied: 'We stopped because the song was over!'

I don't know whether this story is true or not, but I often feel like the composer when I try to understand the mind of the 16th-century shipwright. Or perhaps a little bit worse because when talking about these issues with colleagues and students I get the feeling that a few basic concepts, although very well understood by most specialists in this field, have never been thoroughly described in a way that every lay student, starting his studies of this subject, may understand fully and clearly. Without any intention of being exhaustive, this article aims solely at explaining the geometrical algorithms used in Portugal—and perhaps also in Italy, Spain, France, Greece, Morocco and Turkey—throughout the 16th century, in order to obtain the turn of the bilge points of the central frames of a ship's hull (Damianidis, 1998).

Ocean-going ships were conceived in the 16th-century Iberian peninsula as a box with two ends (Loewen, 1998). The frames that composed the central portion of the hull were designed and built using a very simple and old non-graphic system, developed in the Mediterranean, probably for the building of galleys (Anderson, 1925; Lane, 1934; Bellabarba, 1993). After mounting the keel, stem and sternposts in the shipyard, the shipwrights would erect one, two, or three midships frames, followed by the construction of the central portion of the hull, defined by a number of pre-designed, pre-assembled, and pre-erected frames, each consisting of a floor timber and two futtocks. The shape of these frames was basically the shape of the midship or master frame, as it was sometimes called, but as shipwrights moved away from the centre of the ship toward its ends, each frame's bottom was raised and narrowed a bit more than the previous one. The turn of the bilge point of each frame—a point on the outer surface of the frame where the bottom of the ship ended and the sides began—was raised and narrowed through one of a series of geometrical algorithms. After all the pre-designed frames were mounted over the keel—the forward-most and the after-most being called tail-frames—the shape of the ship's ends, bow and stern, was obtained with the help of ribbands, or *armadouras*, which were stretched from the stem to the sternpost and ran over precisely-determined points on the pre-designed frames, extending the curves generated through the geometrical algorithms mentioned above (Fig. 1).

As a general rule the basic dimensions of the hull were obtained by simple proportions and

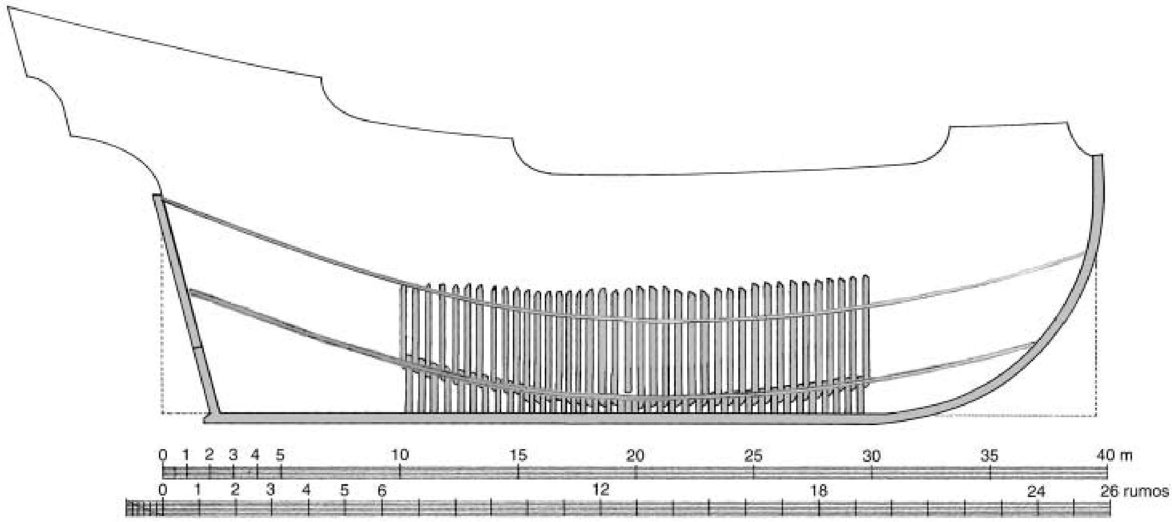

Figure 1. Ribbands or *armadouras* running over the pre-designed frames. (Filipe Castro)

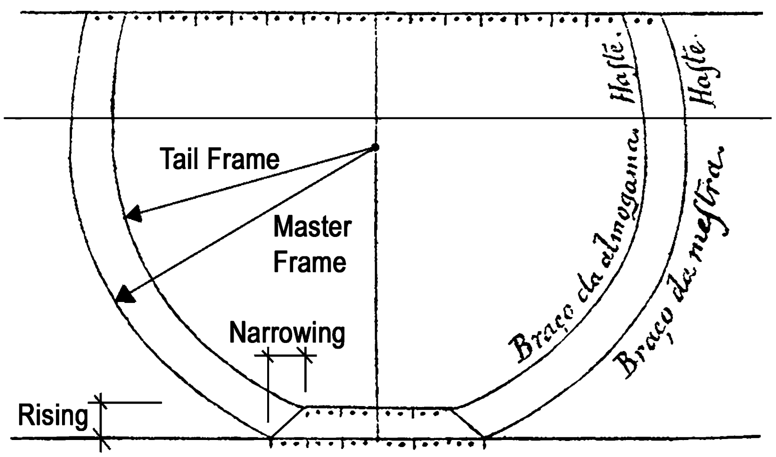

Figure 2. Narrowing and rising lines. (after Fernando Oliveira)

the total values of the rising and narrowing of the bottom were often simple fractions of the basic values of the midships frame or of the room-and-space. The rising and narrowing of the bottom of a ship are actually geometrical abstractions and consist of the projections, on a vertical and a horizontal plane, of the co-ordinates of the turn-of-the-bilge points (Fig. 2). Particularly interesting about this method is the fact that it is non-graphic. In other words, shipwrights did not need any drawings to obtain the shape of each one of the pre-designed frames (Rieth, 1996). All tasks were achieved with the help of two moulds and a variable number of gauges (Fig. 3). From the shape of the midship frame the shipwrights would deduce the shape of the tail-frames by adding the total rising and subtracting the total narrowing of the turn-of-the-bilge points. The length of the total rising or narrowing to be distributed along the pre-designed frames was called *compartida* in Portuguese. The gauge with the incremental values, to be added to or subtracted from each of the frames, was called *graminho*. The word *graminho* may lend itself to confusion because it designated both the gauge and the method, or algorithm, used to obtain the incremental values or co-ordinates of the curves.

Some of these geometric algorithms were described in 16th- and 17th-century Portuguese treatises on shipbuilding, under designations like *meia lua*, *besta*, *saltarelha*, *brusca*, and *rabo de espada* (Barata, 1989). However, the first written descriptions of these methods date from 15th-century Italian texts. The earliest seems to be the 1445

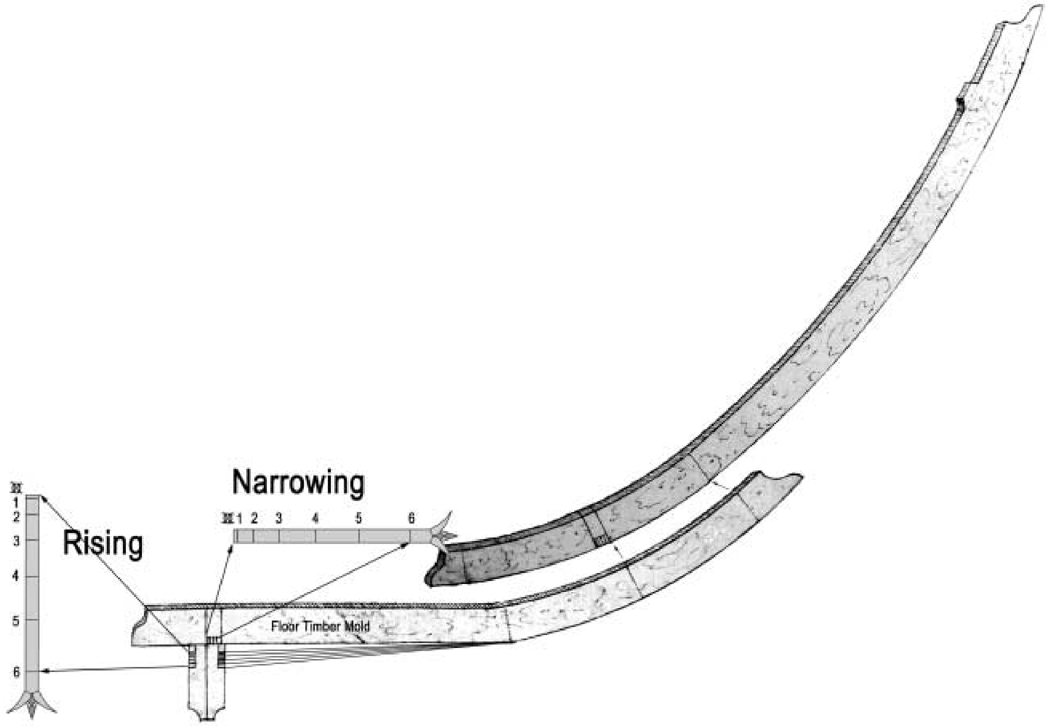

Figure 3. Mediterranean whole moulding. (after João Baptista Lavanha)

manuscript of Giorgio Trombetta, and refers to two of these methods: the *mezzaluna* and the so-called incremental triangle (Bellebarba, 1993; McManamon, 2001). The influence of Italian shipwrights in Portugal is well documented, and it comes as no surprise that Portuguese texts on shipbuilding refer to similar ways to generate smooth two-dimensional curves relating a certain length, the *compartida*, to the distance between the midship frame and the tail-frame (Ciciliot, 1998; Ciciliot, 2000; Barker, 2001). In spite of the fact that these methods are very simple and well understood by most scholars studying this subject they do not seen to have been described in detail in any language other than Portuguese (Barata, 1989). It is worth therefore presenting them below as concisely and clearly as possible.

Meia lua

The *meia lua* method, or *besta*, as Fernando Oliveira calls it, is referred to in Italian texts from the 15th century onwards—where it was called *mezzaluna*—and consists of a quarter of a circle with a radius equal to the *compartida*. The quarter circle is divided into as many equal parts as the number of offsets required or, in other words, as many equal parts as the number of pre-designed frames to be placed from the midship frame to the tail-frame in any particular vessel. The offsets can be obtained by the expression: $X_i = 1 – SIN\ \alpha_i$ when α_i is the angle of the radius that touches point *i* on the quarter of the circle. However, the traditional way to obtain these values is graphic and much simpler, consisting of adding another quarter of a circle, mirroring the first one, and passing lines horizontally across, connecting the correspondent points. The resulting scale was directly engraved on a wooden gauge from the 1/1 scale drawing (Fig. 4).

Saltarelha

The *saltarelha* method, or *brusca*, as it is called by Oliveira and mentioned in Italy, is sometimes called 'infinite stick' in English and consists of a simple line where the *compartida* is marked and divided in as many parts as the pre-designed frames in the following way: with a divider they would mark one space for the first frame, two spaces for the second, three for the third and so on, in an arithmetical progression, for all the pre-designed frames (Fig. 5). There are several possible progressions but the most common consists of adding simple incremental values: $N_{(i+1)} = N_i + (i–1)$, resulting in 1, 2, 4, 7, 11, 16, etc., or $N_{(i+1)} = N_i + i$, which results in 1, 3, 6, 10, 15, etc. If after adding the last interval the total length was too short or too long in relation to the total rising or narrowing required (*compartida*), the shipwright would start again and repeat the task until he had a perfect match.

Although to the experienced shipwright this was a far simpler procedure than it may sound today, it is strange that the scaling triangle is not mentioned in any of these early treatises. Barata (1989) seems to imply that it was used in Portugal but does not indicate the sources from which he took this idea. During the 17th century this scaling triangle was extensively used to scale up or down all sorts of gauges (Fig. 6). According to Fernando Oliveira the *brusca* method generated sharp curves and was only suited for smaller craft. There is, however, some confusion about this designation because both in Portugal and in Italy the words *saltarelha* and *brusca* are sometimes used in the general sense of a template or wooden gauge, as happens with the word *graminho* in Portugal (Sarsfield, 1985). Curiously, Bartolomeo Crescenzio wrote the opposite opinion in his *Nautica Mediterranea* (1607), that the *mezzaluna* did not yield fair curves and the *brusca* was preferable for generating fair curves, compatible with the curvature of the ribbands before and abaft the tail-frames (Crescenzio, 1607; Bloesch, 1983). One must keep in mind that when they expressed their opinions about this method the first author was thinking of round ships and the second of galleys.

Incremental triangle

One well-known variation of the *brusca* is the 'incremental triangle' described in Trombetta's

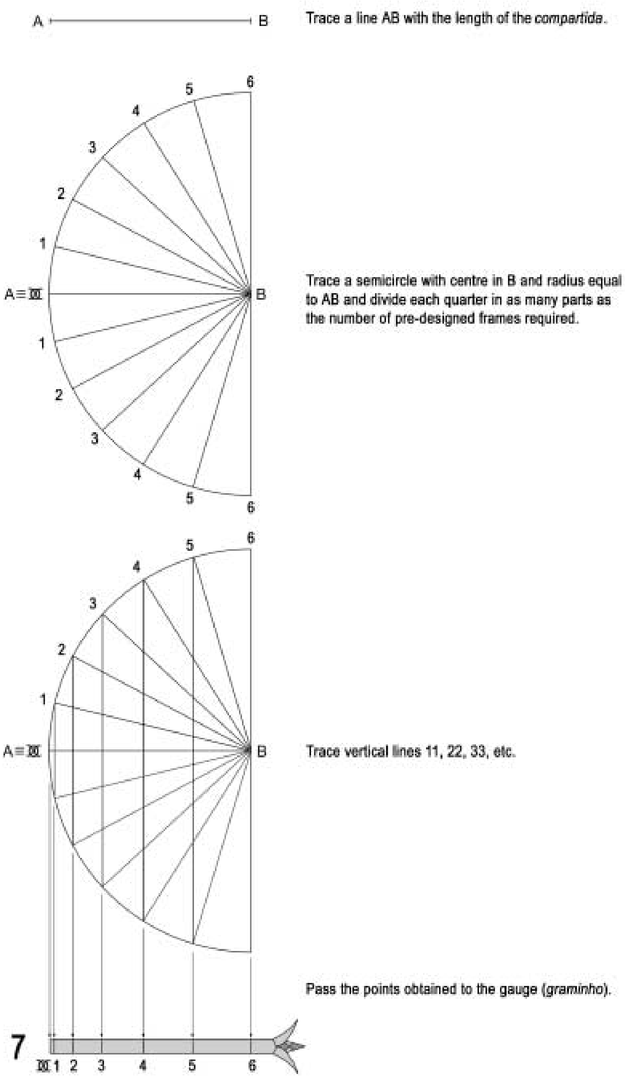

Figure 4. *Meia lua* or *mezzaluna* method. (Filipe Castro)

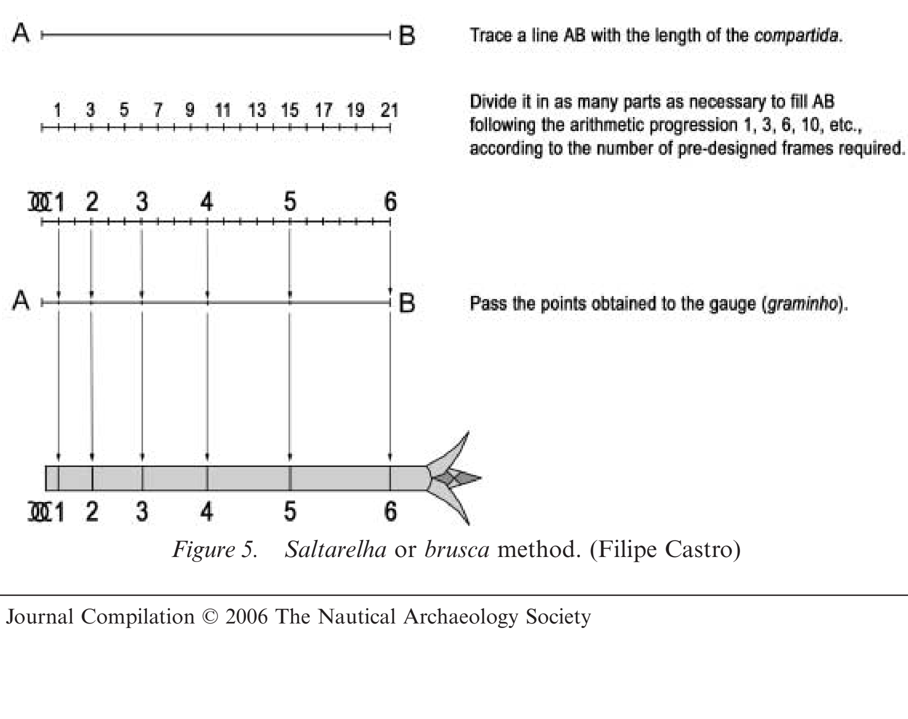

Figure 5. *Saltarelha* or *brusca* method. (Filipe Castro)

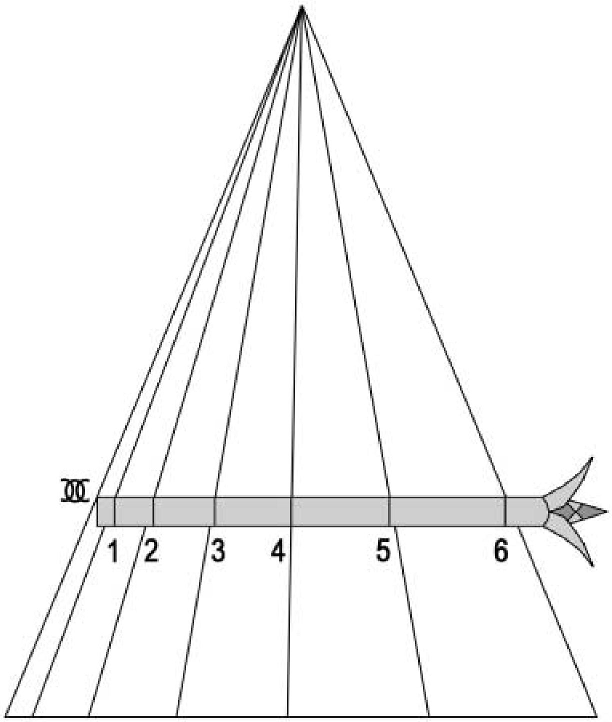

Figure 6. Scaling triangle. (Filipe Castro)

manuscript. This produced exactly the same curve as the *brusca* or infinite stick methods, and consisted of a series of isosceles triangles with the same apex (Fig. 7). The triangle's base was as long as the *compartida* and its height was equal to the sum of the total incremental values generated by the progression selected to construct the gauge. The next step would be to mark the values of the progression at the height of the triangle, after which horizontal lines would be traced at each value of the height. These horizontal lines were the increments to be marked on the gauge.

Rabo de espada

The third method mentioned by Oliveira does not seem to be mentioned anywhere else and is called by him *rabo de espada*. Again it relies on practice and the final gauge is obtained by trial and error. After tracing a horizontal line with the exact length of the *compartida* the shipwright traced one perpendicular line at one of the ends of that line with a chosen length, from which he was to derive the entire gauge (Fig. 8). At the other end he traced another perpendicular line,

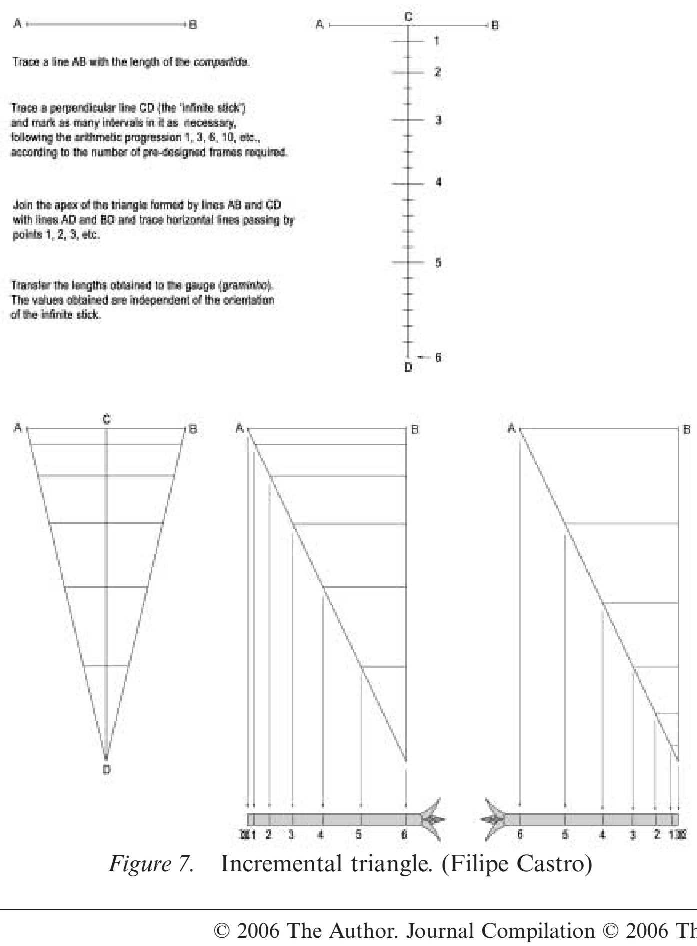

Figure 7. Incremental triangle. (Filipe Castro)

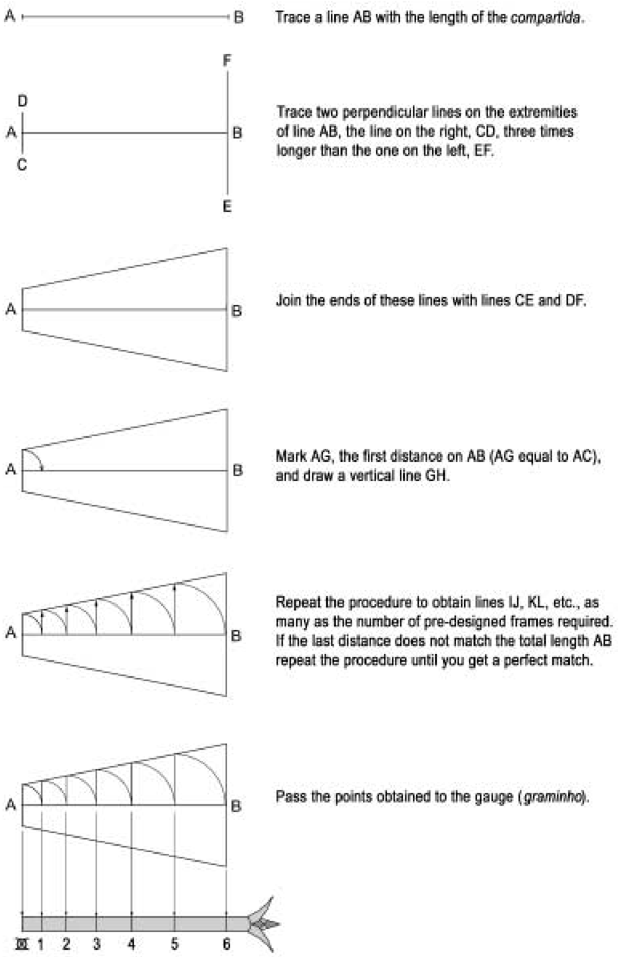

Figure 8. *Rabo de espada* method. (Filipe Castro)

three times the size of the first one. Then, with a pair of dividers, he transferred the height of the shorter line to the *compartida* line and raised a vertical line). Again, using a pair of dividers, he repeated this step, until he reached the longer vertical line. If the length obtained by adding these lines was shorter or longer than the *compartida* he had to start again.

Comparison of the methods

These algorithms were probably not the only ones in use throughout the Mediterranean and there must have been many variations to each one of them. Moreover, there is no guarantee that shipwrights were always faithful to their own gauges. Richard Steffy told me once that one of the Brazilian shipwrights building the *saveiros* at Baía de Todos os Santos told John Patrick Sarsfield that 'he always gave it a little bit more rising than the gauge indicated' (Sarsfield, 1985; Sarsfield, 1991). A comparison of the values obtained through the three methods described above is presented below, based on a fixed value for the rising or narrowing (the *compartida*) of exactly 100 cm, and distributed over six pre-designed frames. The results replicate almost exactly the results obtained analytically by Barata (1989) and show how the *rabo de espada* method differs from the other two (Fig. 9).

Conclusion

The design of the bottom of a ship's hull was just a small part of the conception and construction of a ocean-going vessel in Portugal during the 16th and 17th centuries. Similarly, the narrowing and rising of the ship's bottom were just two of the defining lines. As with the Mediterranean galleys, the turn-of-the-bilge points only defined

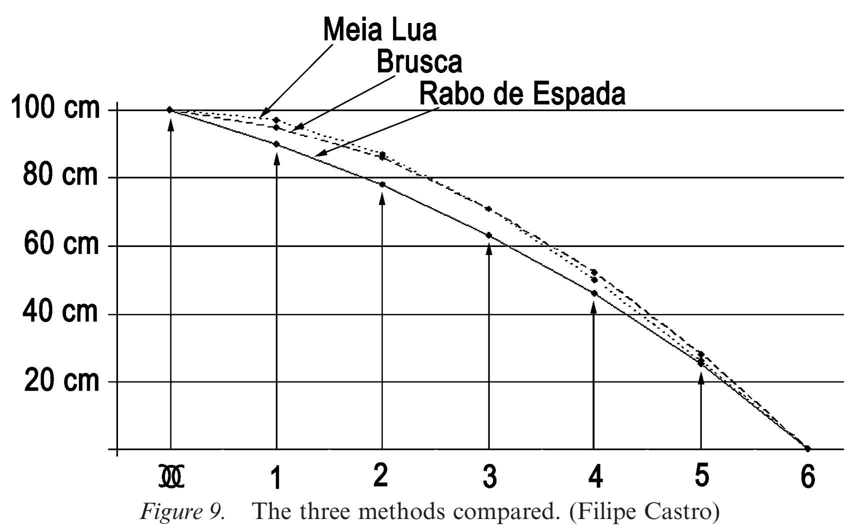

Figure 9. The three methods compared. (Filipe Castro)

a portion of the hull's lower bottom. The runs of the deck clamps were the other important longitudinal lines in the definition of a hull's shape and, together with the wales, provided support to the upper futtocks, which were not fastened to the frames. Evidence suggests that there were probably as many recipes to build ships as there were shipwrights, both in terms of the number of pre-designed frames mounted over the keel and in terms of the geometrical algorithms used to determine the rising and narrowing of a hull's bottom. Both historical and archaeological sources indicate a vast array of possible solutions for the design of fair hull shapes.

As most shipwrecks excavated so far only have a small portion of their hulls preserved, there is far less archaeological evidence for the methods used in the shaping of the upper hull. We know, however, from contemporary written sources, that the first futtocks were tilted outwards to create more deck space before and abaft the midship frame, in a process called *ramo* in Italy, *espalhamento* in Portugal and *joba* in Spain. A variant of this process was known in Italy as *scorer del sesto*, in France as *trébuchement*, and in England as 'hauling down of the futtocks'. Another variant of this process was recorded in Brazil by Sarsfield (1985), and consisted in bevelling the bases of the floor timbers to be placed before the master frame, in order to make them tilt forwards and create more deck space towards the bow (Bellabarba, 1993; Reith, 1996; Loewen, 1998).

But we are still far from fully understanding all the concepts, the rules of thumb, the construction sequences, the control measurements, and so many other tricks of the trade. As it is unlikely that a lot of texts on shipbuilding will surface during the next decades it seems that only archaeology can give us a better insight in this important part of the history of the technologies.

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