La Belle

The Archaeology of a Seventeenth-Century Ship of New World Colonization

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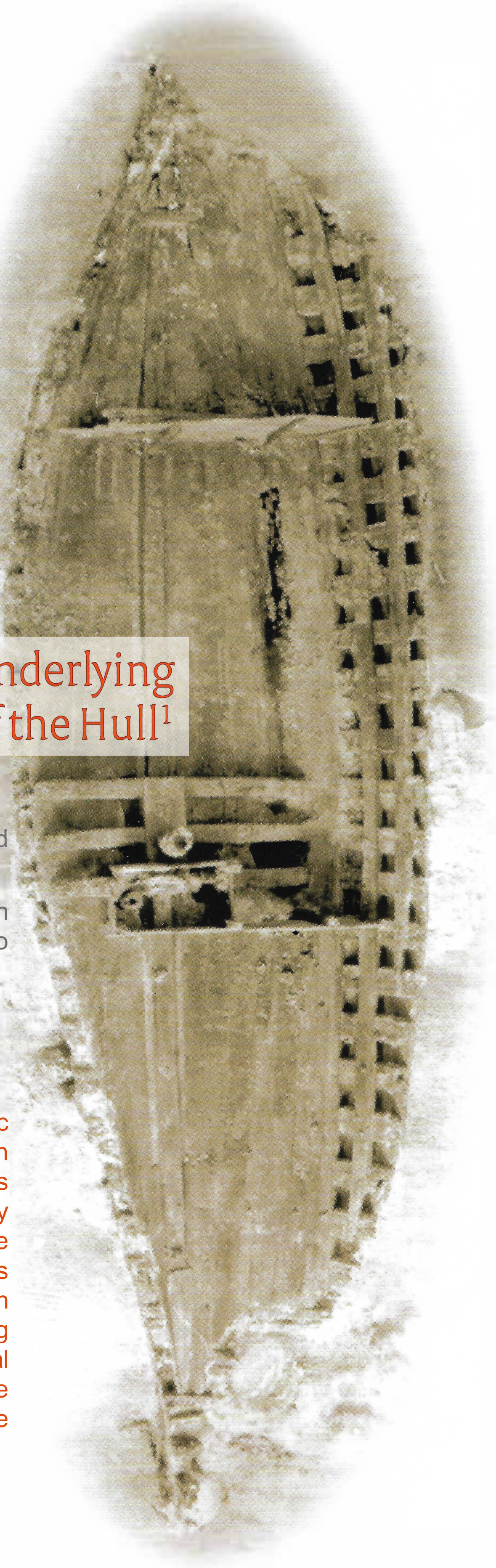

6 Capturing the Curve: Underlying Concepts in the Design of the Hull[1]

TARAS PEVNY

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"This is a very impressive piece of geometric and archaeological detective work, which shows careful attention to the fine details of the archaeological evidence. It is very much relevant to the overall question of the development of hull design, and the author's conclusion about the relationship between pre-mathematical shell-based building methods and the quantification of longitudinal curvature is extremely important. I believe that this will be a significant chapter in the book."

Fred Hocker 2010

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6 Capturing the Curve: Underlying Concepts in the Design of the Hull[1]

TARAS PEVNY

La Belle, measuring less than 20 m on deck and armed with only six 4-pounder cannons and eight swivel guns, would not have been considered a very significant naval vessel in the French Navy of the 1680s. In fact, it is among the smallest vessels listed in the surviving French naval records of that decade (Marine Royale 1688a). However, its small size does not diminish its archaeological value.

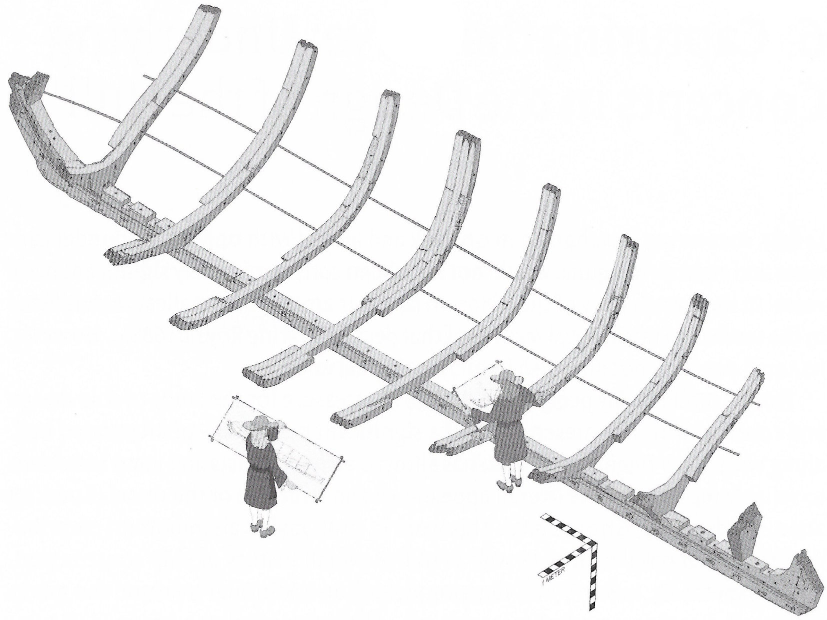
From a modern-day perspective, *La Belle* is a treasure for the study of ship design and construction. The preservation of a significant percentage of articulated hull, along with many rigging elements, has allowed archaeologists and naval historians to reliably reconstruct the overall appearance and structure of the vessel (Boudriot 2000; Corder 2007; Grieco 2003). This work in itself makes an important contribution to French naval history as well as to the overall history of ship construction. But unexpectedly, *La Belle*'s hull remains yielded an additional treasure: the marks of shipwrights that provide direct evidence of how the vessel was designed (Figures 6.1–6.3).

Throughout most of the history of shipbuilding, one of the main challenges for shipwrights has been how to quantify—capture—the complex curvature of hulls. In other words, how do shipwrights determine measurements for the curves of the vessel prior to actually defining the hull shape in three dimensions with timber? If making such a predetermination is one of the great challenges for ship construction, then determining how shipwrights accomplished this feat on the basis of archaeological remains is one of the great mysteries for ship reconstruction.

The difficulty lies in the fact that there is rarely direct evidence of the design method used. Most hull remains provide at least some direct evidence for determining the original shape of the vessel, its structural characteristics, and even its assembly sequence. How the shipwright determined or designed the shape of the vessel most often has to be deduced from the above analyses in combination with comparative archaeological and documentary evidence.

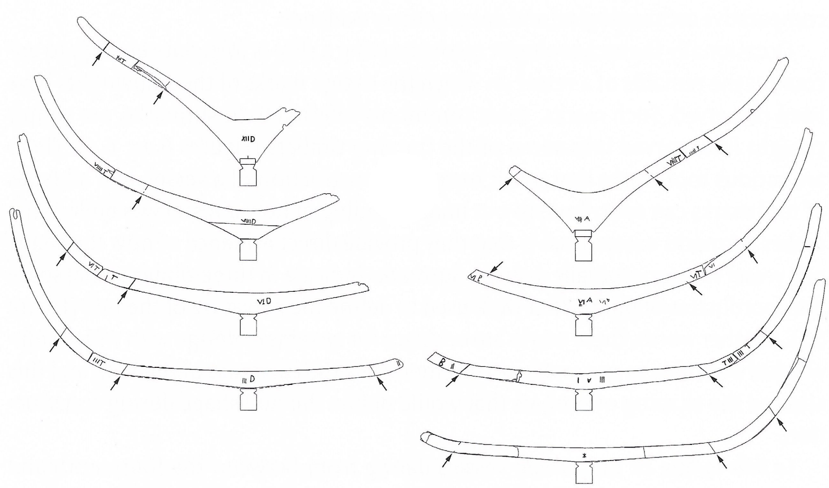
Occasionally the archaeologist reconstructing a ship is fortunate enough to encounter the remains of a vessel on which the design marks of the shipwrights have been preserved. Such marks, most commonly referred to as surmarks, are simply straight lines carved into some of the framing timbers (Figures 6.2a, 6.3). There are various tool marks that result from the construction of a vessel, and all types of tool marks can contribute to our understanding of how a vessel was built. What makes surmarks exceptional is that they provide direct evidence of how the shape of a vessel was conceptually defined. Surmarks indicate in three-dimensional space the coordinates of points that were used to define the curvature of the hull (Figure 6.1). In other words, these marks are evidence for systems of design with which shipwrights were able to generate measurements for the curvature of the hull, and this allowed the shaping of timbers that would define the hull shape during construction.

La Belle is one of only seven vessels dating from between the fourteenth and eighteenth centuries on which inscribed design marks have been discovered and documented (see Section II). Despite the rarity of archaeological design marks, they are prevalent in European documents relating to ship design from the fifteenth to eighteenth centuries (Barker 1988:550; Bellabarba 1993; Rieth 1996; 2003a; Rieth and Pujol 1998:156–159; Sarsfield 1989) (Figure 6.4a, b). From these documents it is known that surmarks were integral to the design process. Thus in the case of *La Belle*, as with the handful of other "marked" vessel remains, the fact that these marks were incised into the timbers may account for their preservation, discovery, and uniqueness. Such marks are more likely to survive than drawn or painted marks, which may have been present on other wrecks but are no longer visible.



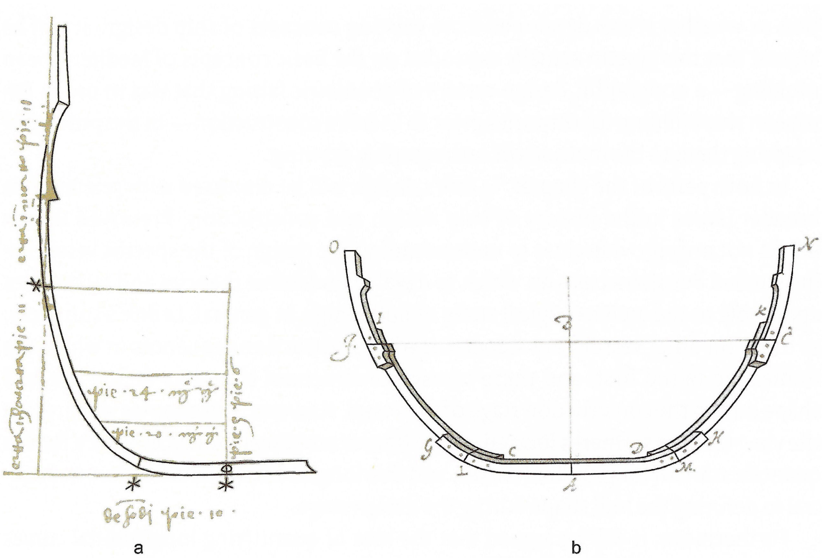
6.1. Isometric drawing of *La Belle*'s hull remains with every third frame depicted and battens positioned along the design marks. (Illustration by author.)

6.2. *(a)* The starboard end of the third floor timber abaft of the midship frame, with the location label and surmark clearly visible; *(b)* the centerline label on the sixth floortimber before amidships. (Photo (a) by the author; photo (b) by the Conservation Research Laboratory, Texas A&M University.)

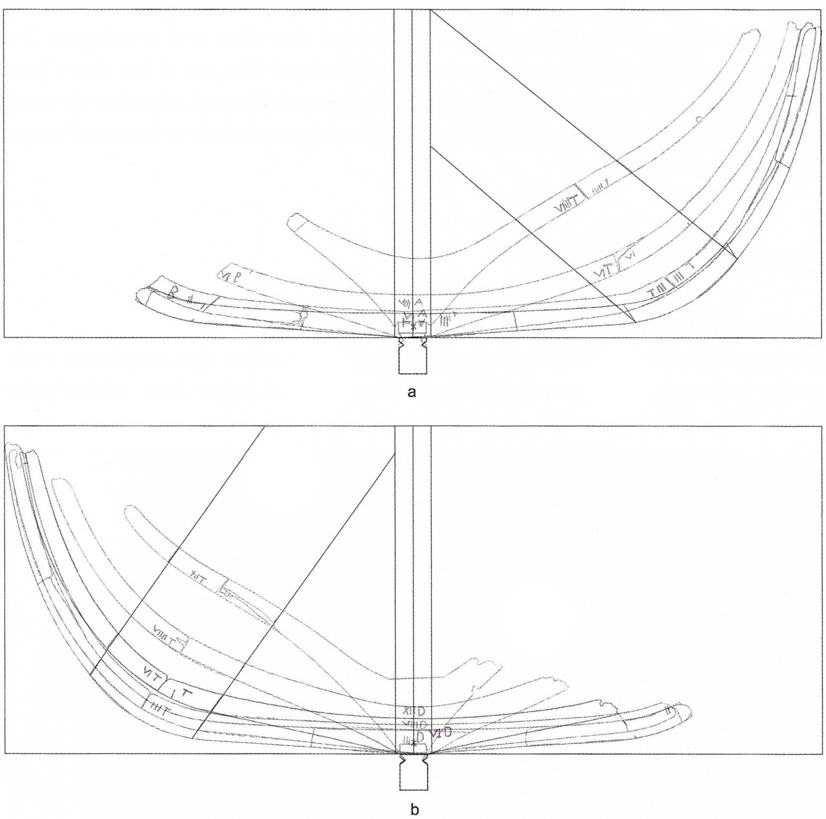


6.3. Every third of *La Belle*'s frames with arrows pointing to the design marks. Note that only frame *XIID* has a small centerline mark. Features such as filler piece notches, wane, and areas of erosion have been omitted for clarity. (Illustration by author.)

La Belle has the most extensive and complete set of such marks. It is most extensive not only in the absolute number of marks but also in the percentage of the hull shape these marks define. Furthermore, *La Belle* has two sets of surmarks along its bilges (Figure 6.3) while all other "marked" vessels have only one. When superimposed in cross section, *La Belle*'s design marks define oblique straight lines, i.e., diagonals (Figure 6.5a, b). These distinguishing features of the distribution, number, and placement of *La Belle*'s surmarks associate it with a graphic design system of "geometric fairing with diagonals," which was in use in French shipbuilding in the



6.4. Frame outlines and surmarks accentuated on illustrations from: *(a)* the fifteenth-century Trombetta manuscript (after Trombetta [1445]:fol. 46); *(b)* Lavanha's *O Livro Primeiro da architectura naval* (after Lavanha 1608:fol. 71r). (Modified by author.)

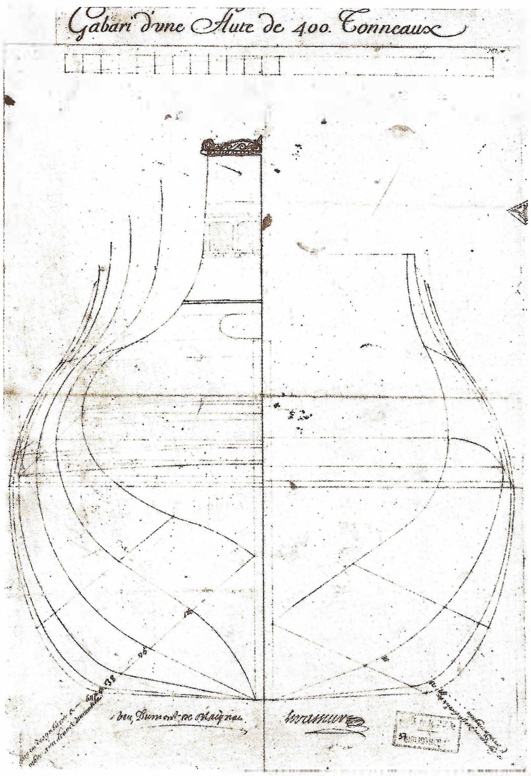


6.5. Cross-sectional drawings of every third of *La Belle*'s frames: *(a)* the frames before the midship frame; *(b)* the frames abaft of it. The starboard half of the midship frame in *(a)* is shown mirrored in *(b)*. The design marks line up to define the diagonals depicted. (Illustrations by author.)

late seventeenth and eighteenth centuries. The earliest documentary evidence for the use of this system is found in two drawings dating to 1684, the year of *La Belle*'s construction (Figures 6.6, 6.7). *La Belle* provides the earliest and only archaeological evidence for the use of this design system, and despite its small size, is an example of the "cutting edge" of French hull design at the time. In addition, *La Belle* exhibits a framing pattern that appears for the first time in French shipbuilding in the 1680s (Figures 6.8, 6.9) (L'Hour and Veyrat 1998).

Section I of this chapter presents the archaeological and documentary evidence that supports the conclusion that a graphic design system of "geometric fairing with diagonals" was used in *La Belle*'s construction. It also discusses how and which specific measurements were applied to the reconstructed design procedures to regenerate *La Belle*'s archaeologically documented hull shape.

Section II examines whether *La Belle*'s design system was a completely new inven-



6.6. *(above)* Draft of *Profond* (Rochefort, France, 1684) (PH 178893, ©Musée national de la Marine.)

tion or whether it was developed from existing concepts of ship design. It will be argued that this system actually expanded on the basic concepts of Mediterranean molding—a nongraphic design system of geometric fairing that was in use in European shipbuilding for centuries prior to *La Belle*'s construction—in the process of adapting them to the methods of orthographic drawing.

In both parts of the chapter, *La Belle*'s design will be discussed with reference to broader issues in the history of ship design and construction. Preserved design marks not only provide clues to understanding the design of the specific vessel being studied but also a basis on which to develop and refine theories and techniques applicable to the archaeological study of hull design in general. *La Belle*'s surmarks, as those on other vessels, are associated with construction sequences in which the frames are raised first, and these transverse structural elements define the hull shape during the construction stage of the vessel. However, this chapter will present the view that the surmarks located on the frames are actually direct evidence for the quantification of longitudinal curves, and this longitudinal quantification was central to defining the hull shape during the design stage.

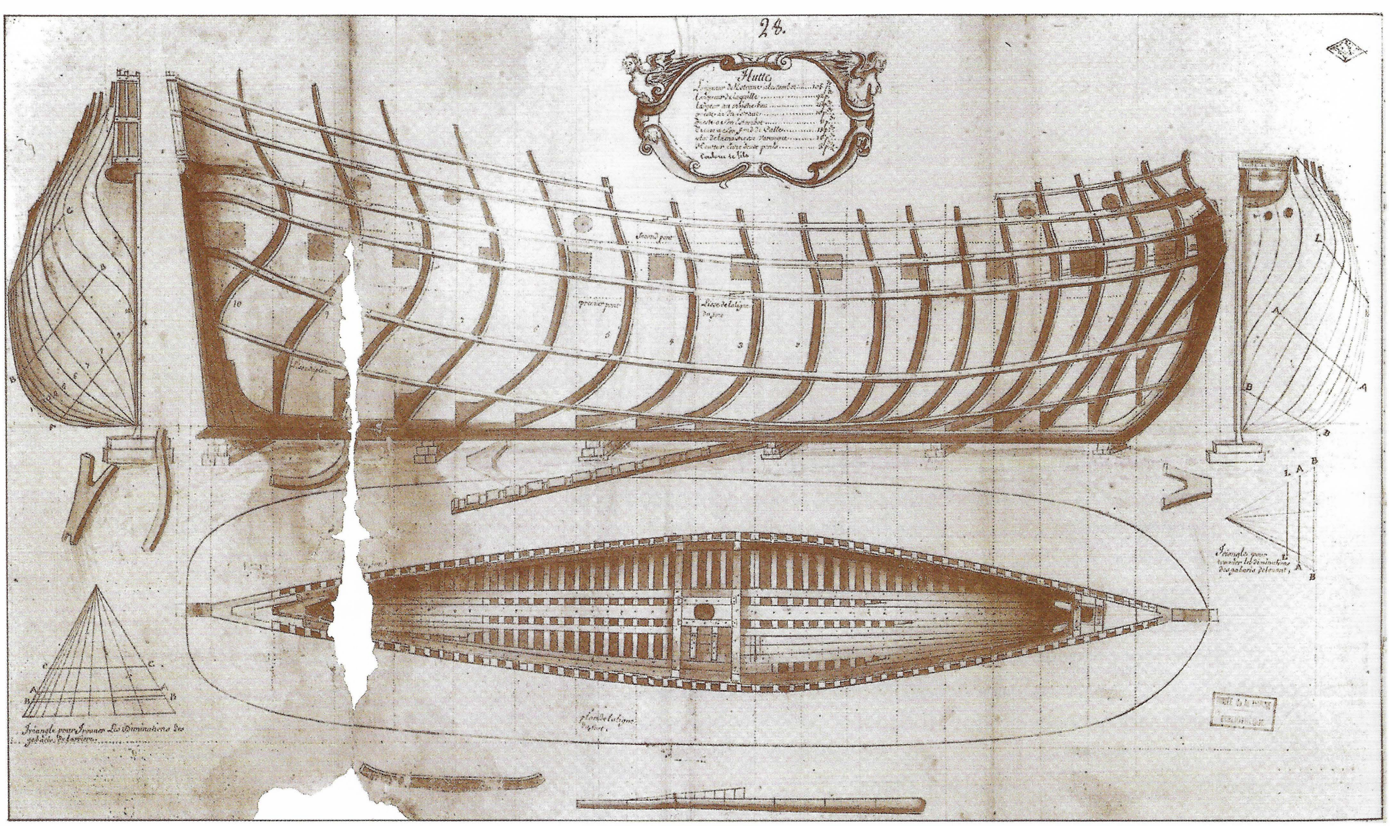
Furthermore, it will be argued that the idea of quantifying longitudinal curves originated with adjusting and regulating curvature along the runs of planks or ribbands at transitional points on the shell of the hull. This difference in emphasis has potentially important repercussions for how one views and investigates the transition from shell-first to frame-first construction. The use of key plank runs for regularizing or even regulating hull curvature in shell-first construction (Pomey 1998) may be an existent design concept that was adapted to enable the transition to frame-first construction.

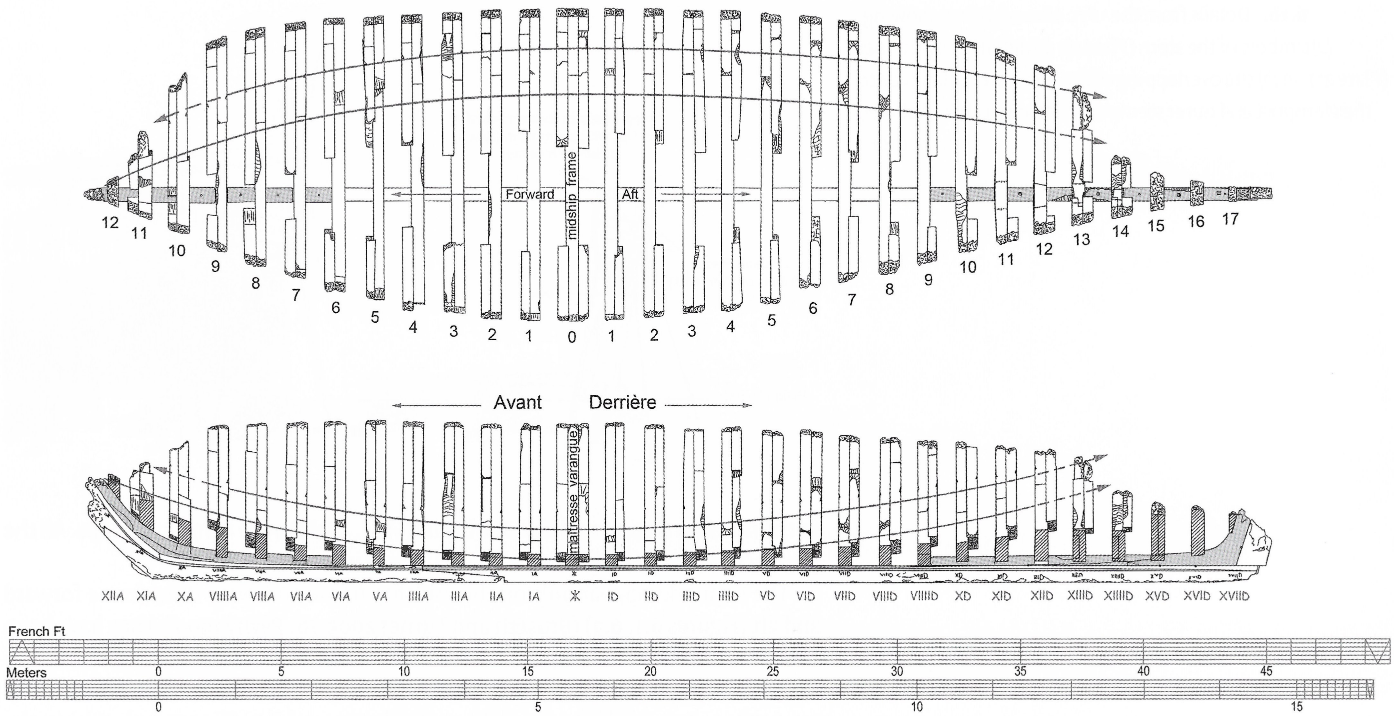
Section I

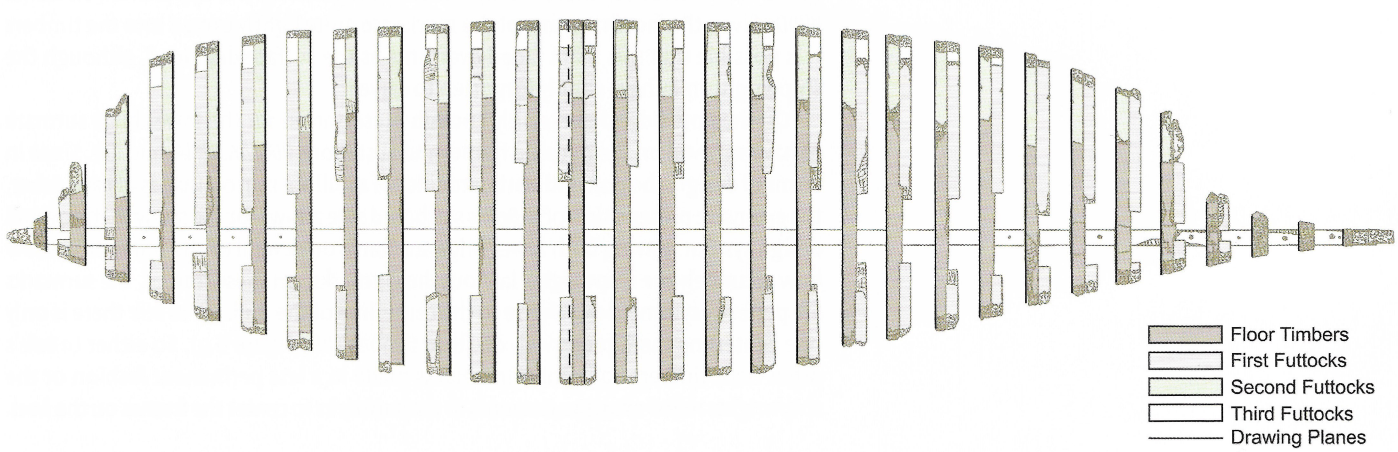
Design Marks and Location Labels

During the cleaning and recording of *La Belle*'s timbers, it was discovered that some of the framing timbers had distinct angled lines carved across their vertical faces

6.7. *(below)* Draft of a French flute by François Coulomb (son) (Toulon, France, 1684) (PH 39810, ©Musée national de la Marine.)





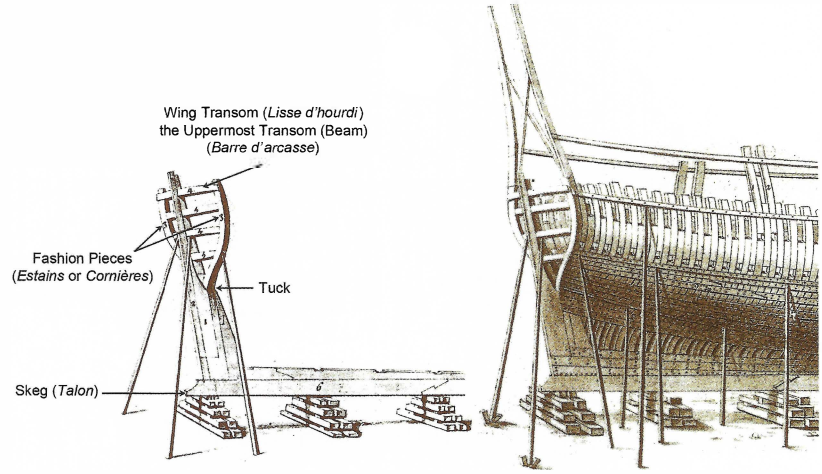


6.8. (*top*) The system underlying the labeling of the frame positions on *La Belle*. The superimposed curves are drawn joining the surmarks on the starboard side of the vessel. The deadwood before frame *VIA* and abaft of frame *VIIIID* is shaded. (Illustration by author.)

6.9. (*bottom*) Plan view of the framing of *La Belle* with the various categories of timbers shaded differently. The dark lines indicate the continuous design planes at the open faces of the floor timbers and second futtocks. The location labels and surmarks on all the frames other than the midship frame are along these planes. (Illustration by author.)

(Figure 6.2a). Early on in the reconstruction process, it became apparent that these lines are design marks commonly referred to in English as surmarks (Barker 1988:549–550, 1991:65–67; Rieth 1996:155, 2003a).

For discussing the locations of these marks and other features along the length of the hull, the original labeling system used by *La Belle*'s shipwrights will be used for reference. In addition to the surmarks, *La Belle*'s shipwrights carved an extensive series of location labels on the hull timbers (Figures 6.1–6.3). Along the longitudinal centerline, the labels for the frame positions (frame stations) appear on the port side of the keel (Figures 6.1, 6.8). These labels follow a very logical pattern based on frame positions relative to the widest point in the hull (Figure 6.8). The starting point of the numbering sequences is the midship frame position, which is marked by a star representing the number "0." In total there are 29 additional frames preserved, 12 frames before and 17 frames abaft the midship frame. Together these represent all the frame positions for *La Belle*'s design other than that of the fashion pieces of the transom at location 18 aft, which were not preserved (Figure 6.10). All the frame stations before and abaft the midship station are consecutively numbered with Roman numerals moving away from amidships. In addition, these numbers are accompanied with a letter designating forward or aft in French; *A* for *avant* and *D* for *derrière*. Thus the frame stations forward are labeled *XIIA*, *XIA*, *XA*, *VIIIIA*, *VIIIA* . . . *IA* up



6.10. Details from the 1670 *Album de Colbert* showing: *(a)* timbers of the stern (Plate 2); *(b)* details of the rabbet (Plate 21). In *(b)* the overlapping of the two lowest planks onto the sternpost and outer sternpost is clearly visible. (Labeled by author.)

to the midship station and *ID*, *IID*, *IIID*, *IIIID*, *VD* . . . *XVIID* away from amidships. All the Roman numerals are additive; e.g., *IIIID* is used instead of *IVD*.

The surmarks appear only on the midship frame and every third frame forward and aft (Figures 6.1, 6.3) (Bruseth and Turner 2005:76; Pevny 1999). They have been documented on frames *IIIA*, *VIA*, and *VIIIIA* forward and *IIID*, *VID*, *VIIIID*, and *XIID* aft. On *La Belle*'s better preserved starboard side, almost all the frames listed above have two surmarks—one on the lower and one on the upper bilge (Figure 6.3). Within the limits of preservation, there is only one surmark missing: the upper mark on frame *VIIIID*. Given the fact that some of the marks are quite lightly carved into the timbers it is possible that this mark faded over time as the surface degraded, although the shipwrights may have simply forgotten to carve it.

On the port side, there is only enough preservation for the lower bilge surmark to have survived on the midship frame, and at stations *IIIA*, *VIA*, *VIIIIA*, and *IIID*. Since in terms of design, the port and starboard sides of a hull are mirror images of each other, the extensive preservation of *La Belle*'s starboard side allows for the study of the overall design system. Having both lower bilge surmarks on several of the frames did show how accurately the shipwrights laid out the surmarks; on these frames, the surmarks are perfectly symmetrical relative to the centerline of the hull. On *La Belle* there is only one centerline mark preserved, on floor timber *XIID* (Figure 6.3). So either *La Belle*'s other floor timbers had centerline marks made in a less permanent fashion or the shipwrights relied on measurements to the surmarks to center the frames on the keel.

Surmarked Frames Raised First

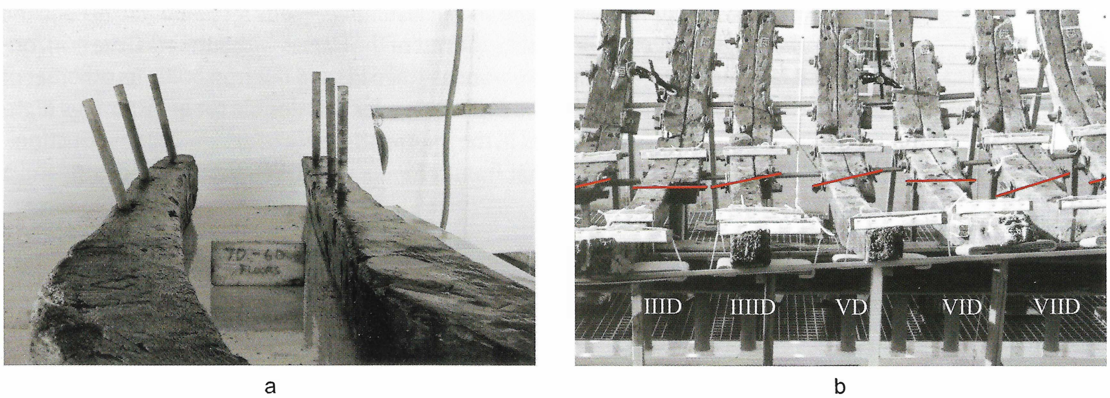
Every third of *La Belle*'s frames is distinguished from the rest of the frames by the presence of design marks, and there is also strong evidence supporting the conclusion that these surmarked frames were raised first in the construction sequence.

Other than between the lower ends of the first futtocks, *La Belle*'s frames consist of two continuous layers of adjoining timbers, i.e., double framing (Figures 6.8, 6.9). The inline floor timbers and second futtocks, which butt up end-to-end, are held in alignment by being bolted to the first futtocks that adjoin and overlap them. The third futtocks would have similarly been bolted to the second futtocks and presumably to the top timbers that have not been preserved. The midship frame has three layers of timbers with first and third futtocks attached both before and abaft the floor timbers and second futtocks. This partial double, or in the case of the midship frame triple, framing arrangement first appears in French shipbuilding around the time of *La Belle*'s construction (L'Hour and Veyrat 1998).

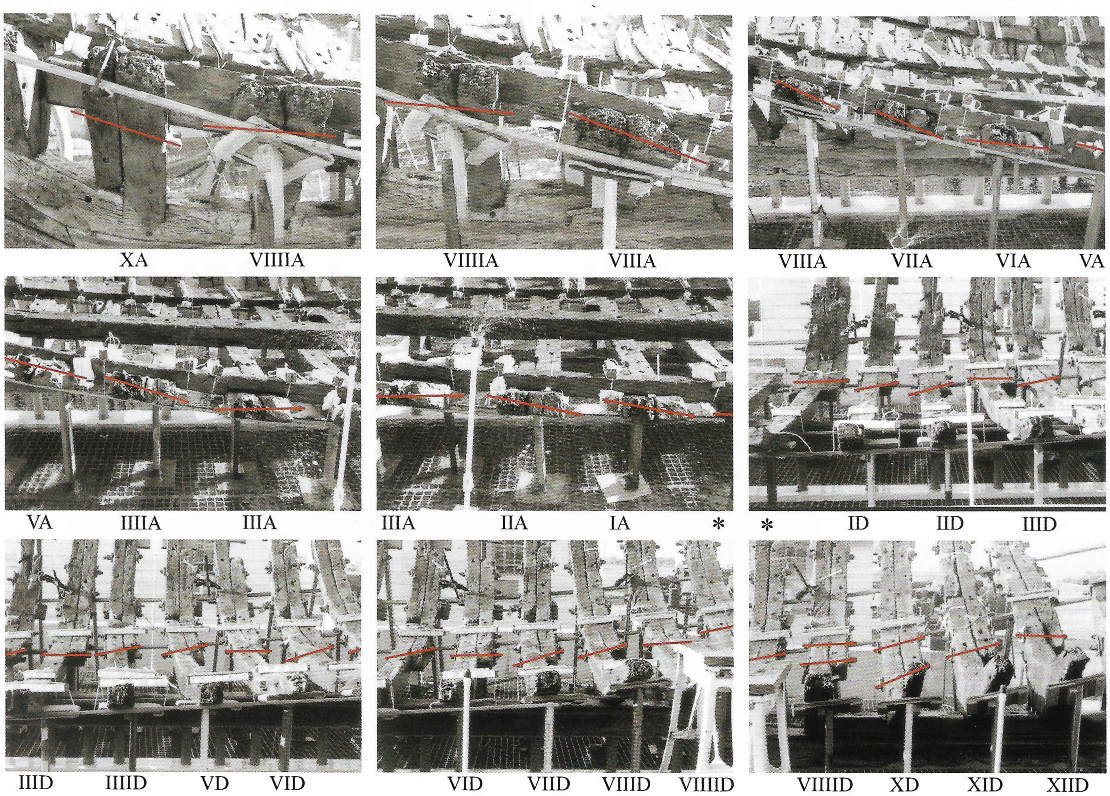
The fore and aft framing bolts provide definitive proof that *La Belle*'s frames with surmarks were erected prior to the intervening frames. All of *La Belle*'s frames have similar scarfs between their components, and they are all fastened together with square-shafted iron bolts driven into round holes. The edges of the bolts barely cut into the perimeter of the round holes; thus they would have been relatively easily driven into the holes and yet provided a tight and strong alignment. Despite this overall similarity, distinct differences in the number and angles of these fastenings distinguish the surmarked frames from the others.

In general, within the limits of preservation, almost all the surmarked frames have three fastenings per scarf for joining the first futtocks to both the floor timbers and second futtocks. Frame *VIA* has only two bolts for each of its floor timber and first futtock scarfs, but it has three bolts in the preserved first and second futtock scarf. The arms of the floor timber at frame *VIA* extend slightly less beyond the lower surmark than those of the other surmarked floor timbers, and this may have left insufficient room for the third bolt. Frame *VIIIID* has only two through fastenings joining its first and second futtocks, but it has a third blind fastening that only partly enters the first futtock. All the frames without design marks have only two bolts joining the first and second futtocks, and fewer than half of them have three bolts joining the floor timbers and first futtocks. Thus the extra number of fastenings in the frames with design marks already begins to distinguish them. What definitively proves that the surmarked frames were erected prior to the intervening frames is the angles at which the bolts are driven.

On the surmarked frames the bolts are driven essentially perpendicular to the vertical faces of the timbers; viewed from the side of the vessel, they would appear to run horizontally (Figures 6.11, 6.12). Given the existing frame spacing, these fasten-



6.11. Differing orientations of the fore and aft fastenings on frames without design marks versus those with: *(a)* starboard arms of floor timbers *VIID (left)* and *VID (right)*; *(b)* red lines indicate the angles of the fastenings. (Photos by author.)



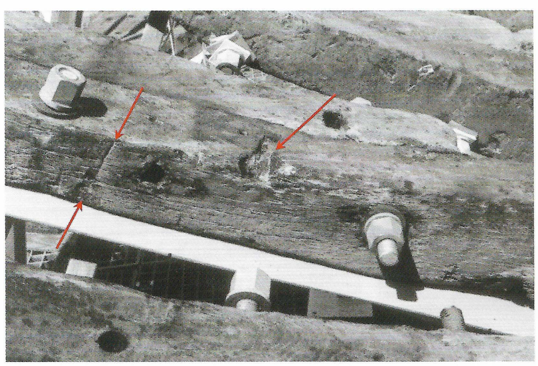
6.12. Fastening angle pattern illustrated for all the preserved frames. (Photos by author.)

ings are too long to have been practically driven with the adjacent frames in place. At the very least each sequential component timber of the frames with the design marks had to be raised and secured in place prior to the erection of the intervening timbers of the adjacent frames. The bolts in the intervening frames are driven at angles that clear at least one of the adjoining frames (Figures 6.11, 6.12). Thus the pieces of these frames could be assembled with the surmarked frames already raised. The fastenings on the frames without surmarks generally have the same orientation but a greater inclination than the curvature of the hull at a given frame location. In the upper hull some of the fastenings have the opposite orientation but still clear at least one of the adjacent frames.

Additional evidence that the pieces of the frames without surmarks were fastened in place sequentially is furnished by several mistakes made by the shipwrights. They had to cut a notch in the floor timber of *VIIIID*, one of the surmarked frames, because they needed additional clearance for one of the fastenings for frame *VIIID* (Figure 6.13a, b). The fact that the floor timber of frame *VIIID* also has such a notch in it is an indication that all the floor timbers of the intervening frames may have been in place prior to the insertion of their first futtocks.

The pattern distinguishing every third frame revealed by the surmarks and the angles of the fore and aft fastenings holds true for all *La Belle*'s frames with sufficient preservation for analysis. Initially frame *VIIIIA* presented a problem because it has two almost complete sets of fore and aft fastenings—one set perpendicular and the other angled (Figure 6.14). Unlike the rest of the frames with surmarks, the horizontal fastenings in frame *VIIIIA* are wooden treenails and not iron bolts. Its other set of fastenings is angled bolts. The explanation for this double set of fastenings highlights several important issues in the interrelationship of design and construction.

It is a structural reality that frames have a width, the sided dimension, and a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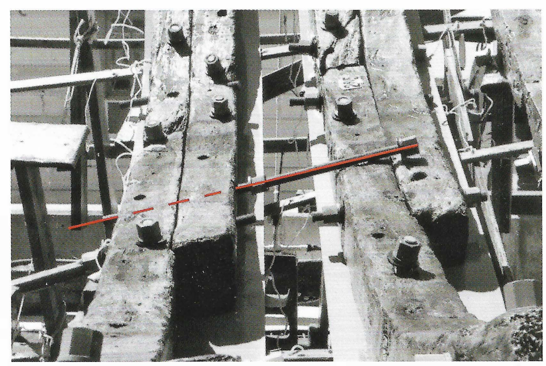
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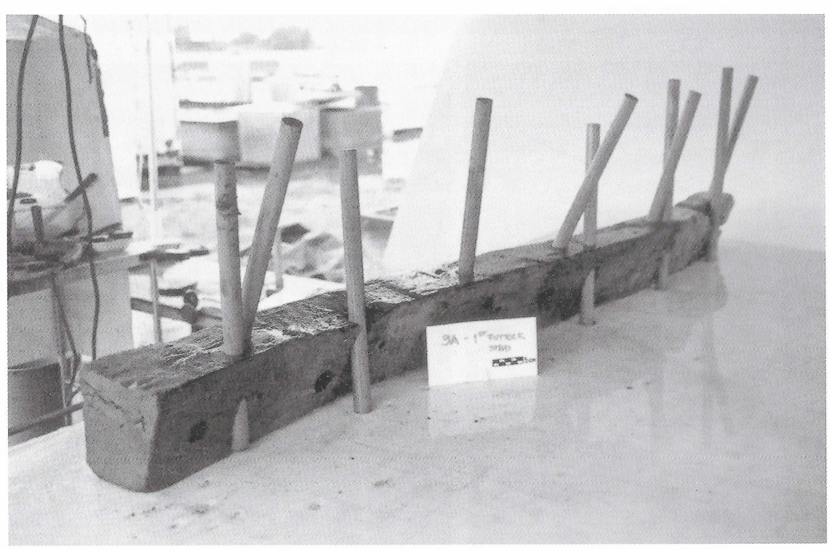
6.13. Frame *VIIIID*: *(a)* a design mark and notch cut into the floor timber; *(b)* this notch lines up with one of the fastenings that extends from frame *VIIID*. (Photos by author.)



6.14. Starboard first futtock of frame *VIIIIA* with two sets of fore and aft fastenings. The inserted modern fastenings were used during the reassembly of the hull in the conservation lab. (Photo by author.)

thickness, the molded dimension. Since the sides of the hull curve inward before and abaft the midship frame, to conform to the shape of the hull the inboard and, most critically, the outboard faces of the frame timbers have to be angled or beveled. Due to beveling, the shipwrights had to carefully determine the placement and inclination of fore and aft frame fastenings in such a way that their ends did not exit on the outboard face instead of on the opposite forward or after transverse face of the frame. Protruding ends of iron bolts would greatly interfere with planking a hull.

To accurately determine bevels becomes increasingly difficult toward the ends of the vessel, where the change in curvature becomes more pronounced. Unlike in some other shipbuilding traditions, the French did not adjust the orientation of the frames, or canting, in the bow to reduce the amount of beveling required (Ollivier 1992a:67). Frame *VIIIIA*, which is not canted, is located far forward in *La Belle*'s hull, and its bevel angles are large. The shipwrights did not risk using iron bolts that would interfere with cutting the bevels on *VIIIIA*. Instead they used treenails for the initial fastening of its components. Like the bolts in the other surmarked frames, treenails in frame *VIIIIA* are perpendicular to the forward and after faces of the timbers.

These treenails in *VIIIIA* were cut through in the process of finishing the beveling of the assembled frame. In fact, on the starboard first futtock they are almost completely exposed on the outboard face (Figure 6.14). Once the beveling was completed, holes for additional bolts were bored at angles that avoided exiting on the outboard face. For the floor timber to first futtock joint only one additional bolt was added because the treenails were less compromised. For the first to second futtock joint the shipwrights added an additional three bolts.

While the evidence that every third frame on *La Belle* was raised first is unequivocal, how these frames were initially secured in place on the keel is uncertain. The pattern of bolting the floor timbers to the keel does not conform to the every third surmarked frame pattern, and there is no evidence for the use of temporary fastenings such as nails or spikes to hold the floor timbers in place prior to boring for the centerline bolts.

La Belle's floor timbers are fastened to the centerline timbers with round bolts that either go through only the floor timber and keel or that go through the keelson, floor timber, and keel. Frames *VIA*, *IA*, *ID*, *IIID*, *VD*, *VIID*, and *VIIIID* are just bolted to the keel. Thus between *IA* and *VIIIID*, every second floor timber was independently fastened to the keel. The midship frame is notably not one of these frames. Although the floor timber of frame *IIIA* has two bored holes, its bolt extends from the top of the keelson to the bottom of the keel and thus breaks the pattern of independently fastening every second floor timber. Floor timber *VA*, what would be the next frame in the pattern, is not fastened to the centerline timbers in any manner. Other than the frames beyond the ends of the keelson, all the other frames have bolts that extend from the top of the keelson to the bottom of the keel. Frame *XIIA* is so far forward that it is bolted directly to the stem timber (Figure 6.8). In addition, the keelson is held in place with large square-shafted spikes driven into the tops of some the floor timbers. The floor timbers do not have any additional fastenings to secure them in place. In fact, there are no major fastening holes in any of the centerline timbers that cannot be accounted for by *La Belle*'s specific assembly sequence.

A correlation between the centerline fastening pattern and that of every third surmarked frame was not discovered. However, since none of the frames provide evidence of how they were held in place prior to boring for the centerline holes, this does not cast doubt on the proposed sequence of raising the frames. Clearly the shipwrights had some temporary means of holding the raised frames in place prior to inserting the centerline bolts. The surmarked frames must have been held in place with some combination of clamps, shores, ribbands, and possibly even removable centerline fastenings. Other than a desire to have a different centerline fastening pattern for structural reasons, the delay in permanently fastening the floor timbers in place gave the shipwrights the flexibility to adjust frame positions in order to assure a fair hull shape.

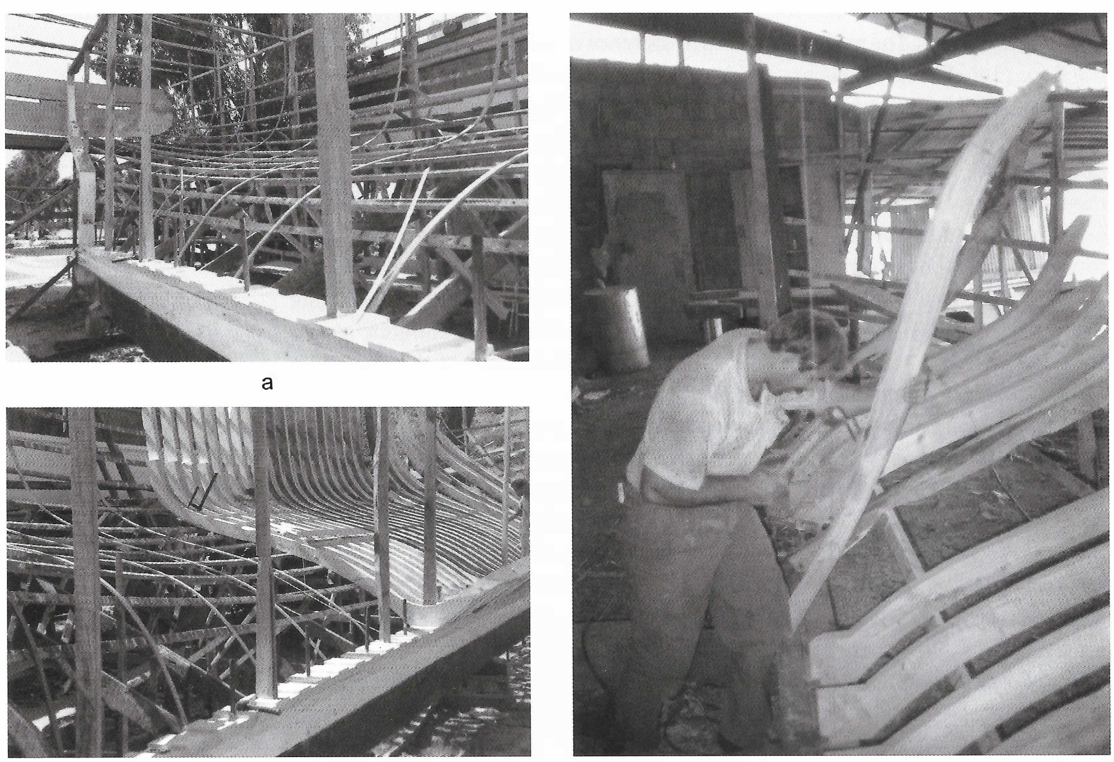
Frame First Design?

The archaeological evidence presented thus far suggests that surmarks are integrally associated with frames that were raised first in the construction sequence. Indeed, during actual construction, by raising these frames on the spine timbers, the hull shape would be defined in three-dimensional space. However, in order to build a vessel by raising the frames first, there has to be some way of determining the shapes of at least some of the frames prior to the actual start of construction. This may at first glance seem like an absurdly obvious statement and thus demands some justification.

Nautical archaeology has made great progress in uncovering the evolution of ship construction in various shipbuilding traditions since antiquity (Greenhill 1995; Hocker and Ward 2004; Steffy 1994). One of the most dramatic discoveries has been the realization that, in various shipbuilding traditions prior to the partial or complete adoption of frame first construction, hull curvature was defined by first shaping the shell of the hull with planks that were temporarily or permanently edge joined (Casson 1963, 1964, 1971; Hasslöf 1963, 1972). In design and construction based on the shell, the shipwright judges or "sees" the developing hull curvature with the longitudinal plank runs (Pomey 1998, 2009; Steffy 1995). Subsequently the shipwright can shape and insert transversely oriented framing timbers to conform to the hull shape defined by the shell of planks.

With frame first construction, only a few widely spaced frames or transverse templates can be raised along the length of a hull prior to establishing some longitudinal relationship between them, which will assure smooth curvature along the length of the vessel. Ship hulls are complex curved surfaces characterized by continuous smooth curvature that changes in all directions, and frames simply do not provide a continuous surface that can be progressively bent or carved into a desired hull shape.

During construction with only a few frames raised, whether by bending on actual hull planks or ribbands as temporary substitutes, the longitudinal curves have to be defined (Figure 6.15a, b). Once they are shaped and positioned, these longitudinal timbers provide the shipwright with guide points for shaping additional frames (Figure 6.15c). A shipwright visually judging the characteristics and smoothness, or



a b c

6.15. Traditional wooden boat construction on the Bodrum peninsula, Turkey (1996): *(a)* the shape of the port side of a vessel defined with ribbands; *(b)* raised frames cut to match the shape defined by the ribbands. The starboard side was cut to mirror the port side. Traditional wooden boat construction in Istanbul, Turkey (mid-1990s); *(c)* a shipwright trimming a frame template to fit the hull shape defined by ribbands. (Photos *[a]* and *[c]* by author; photo *[b]* by John De Lapa.)

fairness, of curvature defined by planks, ribbands, or splines is known as visual or free-form fairing (Nowacki 2009:37; Rabl 1941:28). The tendency of planks to bend in fair curves as a result of their material resistance to such bending is a great aid in the evaluation of fairness.

On *La Belle*, other than the spine timbers, there is no evidence that any longitudinally oriented timbers were in place prior to raising the surmarked frames. The double set of fastenings on *VIIIIA* supports the conclusion that even the main shape of the most forward preserved surmarked frame was determined independently of the use of ribbands during construction. If the shape of the hull was already defined in three dimensions with ribbands, the shipwright would have been able to measure the bevel angles, and frame *VIIIIA* would display the same fastening characteristics as frames *VIIIA* and *XA* that lack surmarks. Instead, *La Belle*'s shipwrights must have had some method of determining the shape of frame *VIIIIA* as well as the other surmarked frames prior to construction—a design method that, like the use of longitudinal planks or ribbands, could provide guide points for defining the frame shapes by delineating the change in longitudinal curvature.

Diagonals

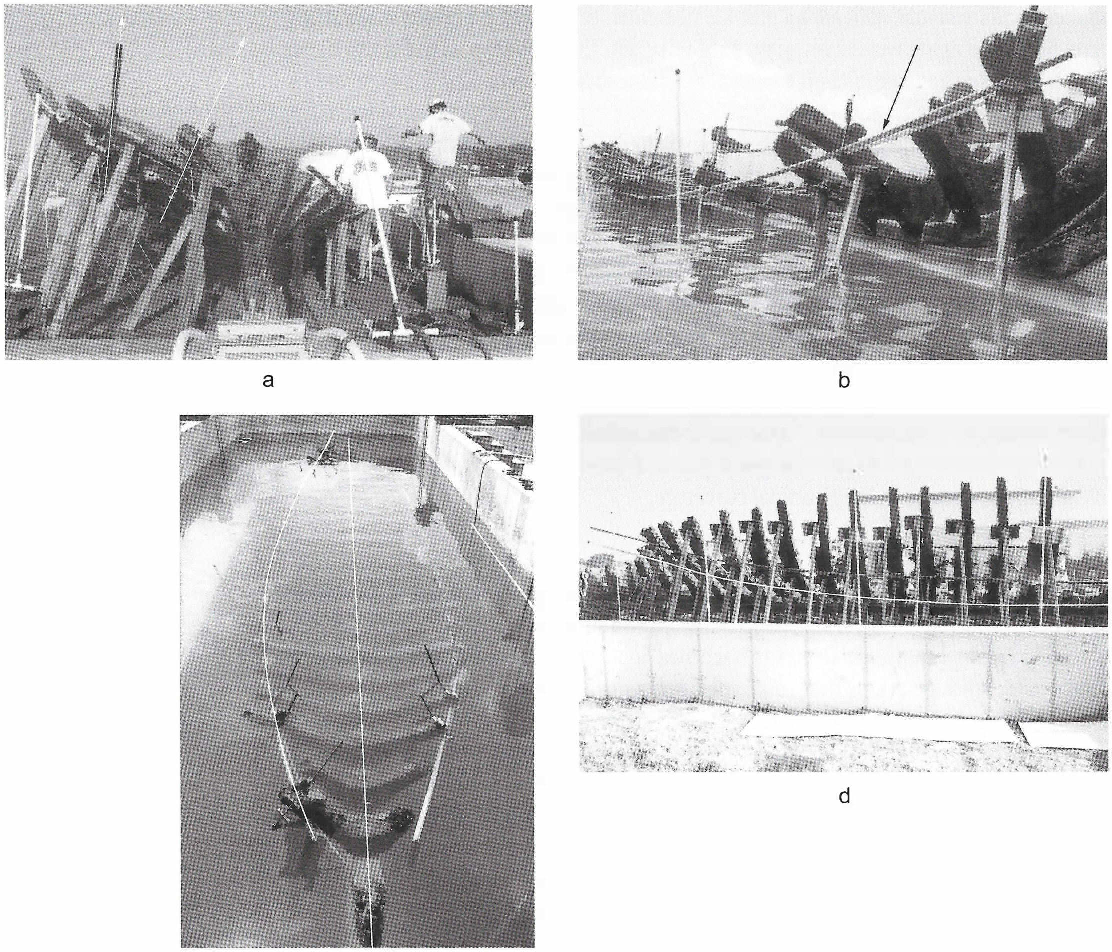
La Belle's surmarks are carved onto transverse structural elements, i.e., the frames. However, when the interrelationship between the surmarks on all the frames is explored, a strong longitudinal feature becomes apparent. A distinguishing characteristic of *La Belle*'s surmarks is that when the frames are superimposed in cross section, the surmarks align along two oblique straight lines, i.e., diagonals (Figure 6.5a, b) (Pevny 1999). Not only do the surmarks define points on these lines, they are actually carved into the timbers at the angles of these diagonals. There is one anomaly: the upper endpoint of the upper surmark on *VIA* falls on the diagonal, but the rest of the mark is exactly at the angle of the after diagonals.

The surmarks define straight lines only in a cross-sectional view. In the two-dimensional space of a flat drawing, this view is dominated by the curved shapes of the frames that are transversely oriented across the width of the hull. In real three-dimensional space, there is no superposition of all the frame shapes in one flat plane, and when the same surmarks are joined along the length of the hull, it becomes evident that they actually delineate fair longitudinal curves (Figures 6.1, 6.8). A fair curve is a smooth curve without any unintentional bumps or hollows.

To illustrate this concept, as well as to help in the proper positioning of the frames, colored ribbon and then narrow wooden ribbands were secured along the surmarks during the reassembly of *La Belle*'s timbers in the Conservation Research Laboratory (CRL) at Texas A&M University. These ribbands were then photographed from various angles (Figure 6.16). Only when viewed from the ends of the vessel, as in the cross-sectional view or body plan of a ship drawing, do these ribbands line up on diagonals (Figure 6.16a). Viewed from any other position, the ribbands appear not as straight lines but as smooth curves running the length of the vessel (Figure 6.16b–d). The view from above in Figure 6.16c shows how the lower ribband narrows along the length of the vessel and would appear in the plan view or breadth plan of a drawing (Figure 6.8). The view of the hull in Figure 6.16d, although somewhat obstructed by the conservation tank wall, shows how the lower ribband rises along the length of the after part of the vessel and would appear in the profile or sheer view of a drawing (Figure 6.8). The longitudinal nature of the surmarks brings up the possibility that although the transversely oriented surmarked frames defined the shape of the hull during construction, the actual definition of hull curvature in the conceptual design stage was based on defining these longitudinal curves. But how was this done?

Insights from Documentary Sources

The above discussion, presenting the conclusion that every third of *La Belle*'s frames was erected first and that the surmarks carved on these frames define diagonals, is written mostly from an archaeological point of view. Establishing which parts of the surviving hull the shipwrights predetermined is just one aspect of reconstructing



6.16. *La Belle*'s hull remains during reassembly at the Conservation Research Laboratory at Texas A&M University *(a–d)*. These photos show how battens attached along the surmarks appear from various viewpoints. The runs of the battens are accentuated in white in *(a)*, *(c)*, and *(d)* and the centerline in *(c)*. (Photos by author.)

the design of a vessel. Discovering how the original architect or shipwright generated the measurements needed to achieve such predetermination is a more elusive aspect.

Progress in the archaeological study of ship design has depended to a great extent on insights gained from documentary evidence. Without the aid of historical documents, there would be much greater uncertainty in deciphering design from archaeological evidence. The earliest historical documents that begin to provide some insight into how shipwrights quantified hull curvature are from fifteenth-century Italy (Alertz 1995, 2009; Bondioli 2003; Dotson 1994; McGee 2009; McManamon 2001; Rieth 1996). Italian documents dominate till the appearance of English, Spanish, and Portuguese works in the late sixteenth to early seventeenth centuries and then a proliferation of works in various European shipbuilding traditions through the course of the seventeenth and eighteenth centuries (Anderson 1924; 1947; Dotson 1994). The earliest French documents relating to ship design also appear in the seventeenth century (Boudriot 1994:10–14; Rieth 2001:260–261, 2003b:75).

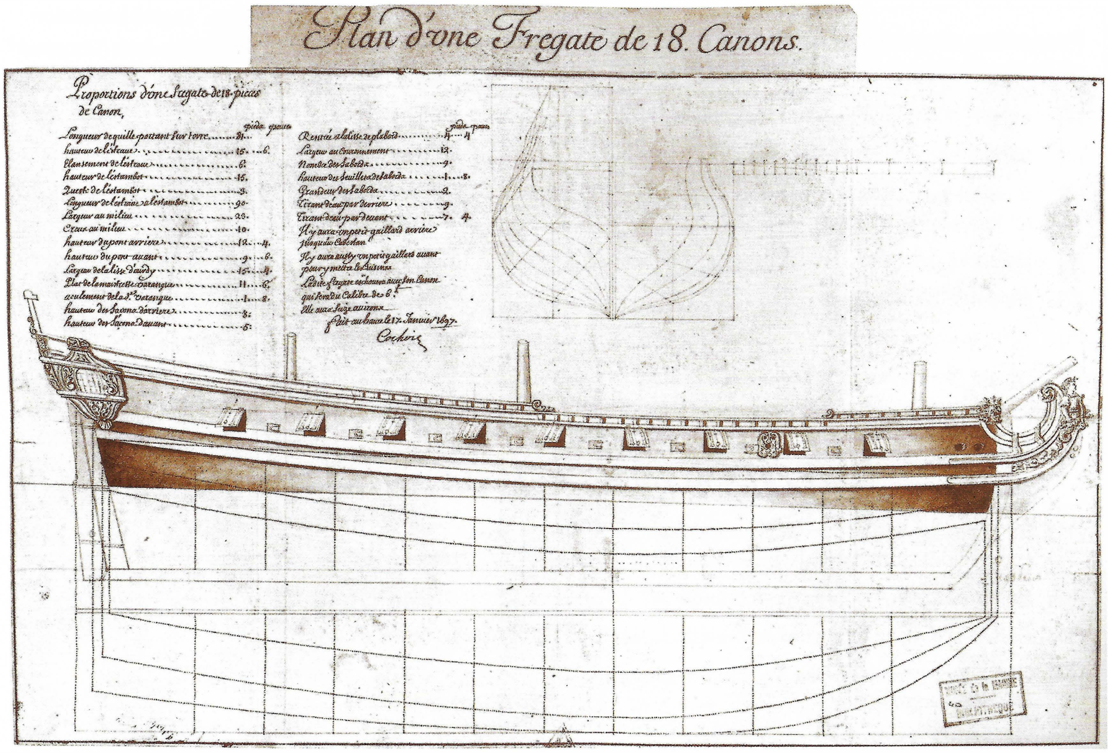
Once the hull remains were positively identified as those of *La Belle*, historical records such as naval archives and correspondence were searched for documents specifically relating to its design and construction. One particular document discovered by John de Bry (Bruseth and Turner 2005:66) is extremely important in reconstructing *La Belle*'s original shape and system of design. Known in French as a *devis*, this document lists 18 of *La Belle*'s key dimensions and is signed by several shipwrights and naval administrators at Rochefort (Figure 6.17) (Boudriot 2000:36–37; Bruseth and Turner 2005:66–67, 69–70; Levasseur 1684). This devis not only provides an opportunity to compare the historically recorded measurements with the archaeological remains, but it also gives critical information for reconstructing the hull beyond the levels of preservation.

Proportion of a barque named *La Belle* that was built at the port of Rochefort during the months of May and June 1684, of 40 to 50 tons		
[1]	Length of the keel treading the ground	45 feet
[2]	Length from stem to sternpost	51 feet
[3]	Breadth from outside to outside [of frames, i.e. molded]	14 feet
[4]	Height of the stem	12 feet
[5]	Height of the sternpost	11 feet 1/2
[6]	Wing transom length	9 feet 4 inches
[7]	Height [depth] from the bottom of the hold	7 feet 3 inches
[8]	Rake of the stem	4 feet 6 inches
[9]	Rake of the sternpost	1 foot 6 inches
[10]	Flat of the master floor timber	9 feet 4 inches
[11]	Height of the line of maximum breadth in the middle [amidships]	6 feet 3 inches
[12]	Height of the line of maximum breadth aft	9 feet 4 inches
[13]	Height of the line of maximum breadth forward	13 feet 6 inches
[14]	Depth [from the top of the keel] to the straight line of the master beam	7 feet 1/2
[15]	Tumblehome in the middle [amidships]	12 inches
[16]	Tumblehome at the top of the fashion piece [in the stern]	3 feet 2 inches
[17]	Height of the run [the floor diagonal/ribband at the sternpost]	5 feet 6 inches
[18]	Height of the entrance [the floor diagonal/ribband at the stem]	3 feet 6 inches

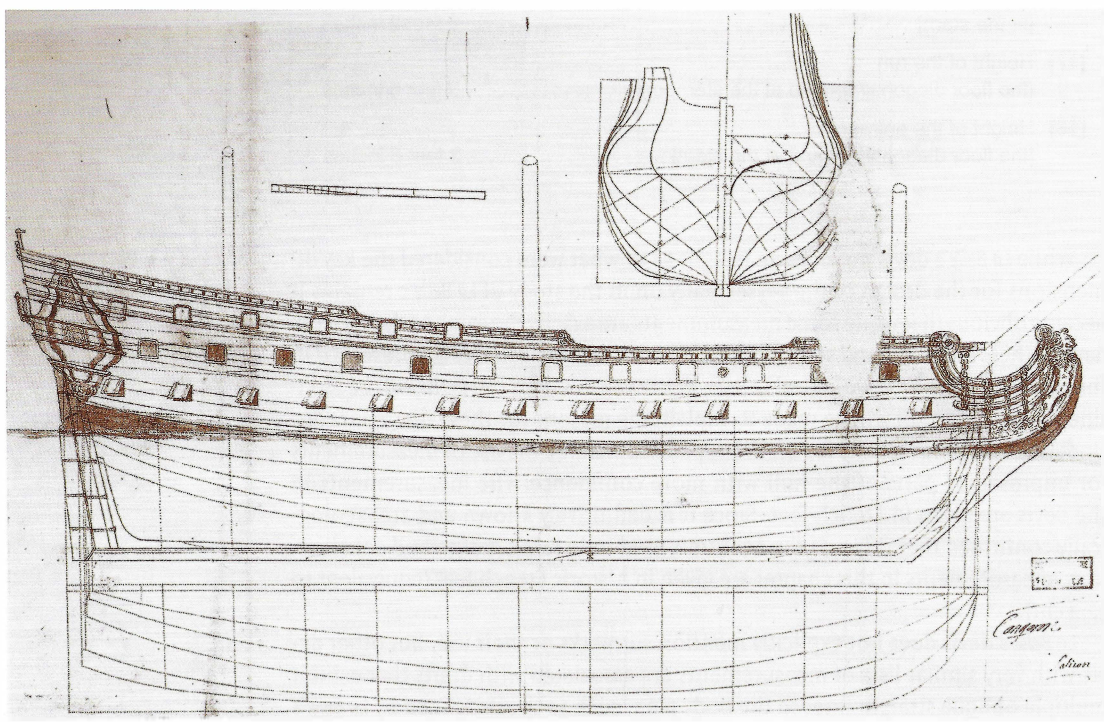
6.17. English translation of *La Belle*'s devis (Levasseur 1684). (Translation by author.)

While *La Belle*'s devis provides an insight as to what were considered the key dimensions for the design of the vessel, early on in the study of *La Belle*'s remains it became obvious that while some measurements are exactly the same as those of the devis, others are close, and some are completely different. The design presented in this study is of the archaeological *La Belle*; discrepancies with the devis will be identified and an attempt will be made to explain the reasons for these discrepancies. Understanding the reasons for the discrepancies enabled the use of measurements for unpreserved parts of the hull with more confidence. The measurements in the devis are given in French feet. Since it is definitively known and archaeologically confirmed that this was the base unit used in *La Belle*'s design and construction, measurements in this chapter are given in historic French feet (equivalent to 32.4 cm).

La Belle's devis does not explicitly mention surmarks or their use, but other devis with very similar lists of measurements are associated with drafts that exhibit multiple oblique straight lines in the body plan, such as those defined by *La Belle*'s surmarks. Multiple diagonals in the body plan depicted as narrowing and rising curves in the breadth and sheer views of a ship drawing are defining features of a design method that is first documented in early French drafts from the 1680s and 1690s (Figures 6.6, 6.7, 6.18, 6.19). In fact, the two earliest French drafts with multiple diagonals in the body plan both date to the year of *La Belle*'s construction, 1684. The first, for which only the body plan exists, is of the 400-ton flute *Profond* (Figure 6.6) (MnM 1684a:PH 178893). Like *La Belle*, it was built in Rochefort in 1684, and its devis follows that of *La Belle*'s in the official records (Levasseur 1684:89r–90v; Boudriot 2000:41). The second depicts a French flute built in Toulon (Figure 6.7) (MnM 1684b). Both vessels depicted in these drafts are much larger than *La Belle*; however, they still have only two bilge diagonals per side for defining the lower hull. Later drafts from



6.18. A 1697 draft by Cochois of an 18-gun frigate, Le Havre, France (J9e/7374, ©Musée national de la Marine.)



6.19. A late 1680s French draft signed by Salicon and Langeron (J9e/7373, ©Musée national de la Marine.)

the 1680s and 1690s that display the same general characteristics are more developed. Once again, they mostly depict large vessels; however, a draft from 1697 is of a small frigate much closer in size to *La Belle* (Figure 6.18) (MnM 1697). It has the same arrangement of lower diagonals as *La Belle*, and these diagonals are clearly depicted in the breadth and sheer views. While the frigate has only two diagonals per side in the lower hull, for some of the larger vessels one or two additional diagonals were added below the maximum beam (Figure 6.19) (MnM [1690]).

While most of these drafts are technical drawings, the drawing of the 1684 Toulon flute is an illustration of the basic concept of this design method—the subdividing of the diagonals by mathematically generated increments to define smooth longitudinal curves, i.e., offsets (Figure 6.7). This draft is very useful for studying and discussing *La Belle*'s design since there are no written descriptions of this method contemporaneous with *La Belle*. In fact, this method is mentioned for the first time in Paul Hoste's 1697 treatise *Théorie de la Construction des Vaisseaux* (Hoste 1697:145–149, Pl. I liv. 3; Rieth 1997:208, 2001:261); all documents describing this method in detail date to the eighteenth century. For example, this method figures prominently in Duhamel du Monceau's treatise on ship design and construction (Duhamel 1752, 1758). Overall, *La Belle*'s innovative design system is more representative of the design techniques described in French treatises from the eighteenth century than the nongraphic design method of Mediterranean molding, which predominated in the seventeenth century (Boudriot 1998a; Rieth 1997, 2001).

Design Reconstruction Methodology

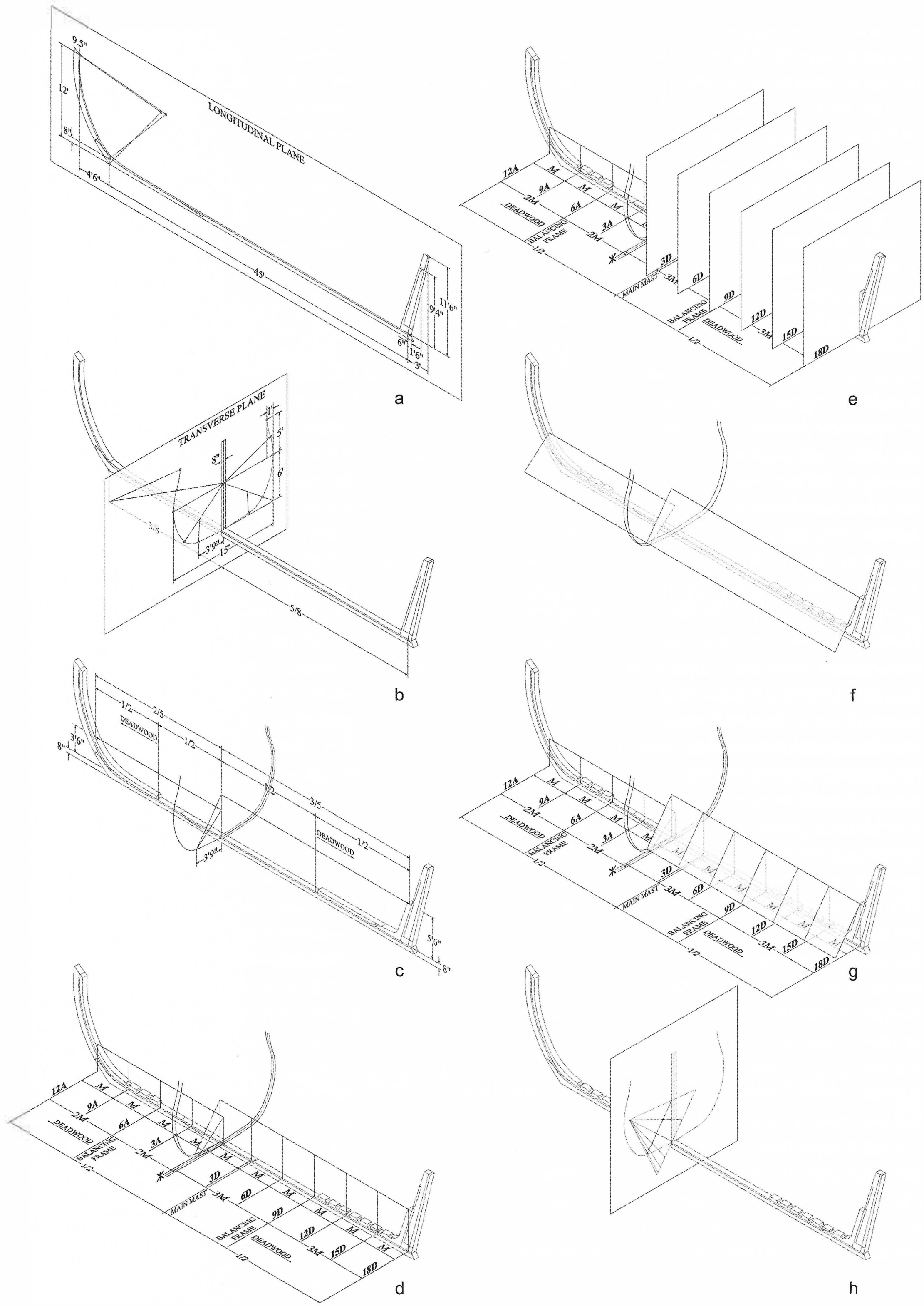
Since the same characteristics are apparent in *La Belle*'s archaeology as in the earliest French drafts, one might presume that *La Belle* was designed by the same method used to create these drafts. However, before attributing any perceived consistencies or patterns in the archaeologically preserved dimensions or curves of *La Belle*'s hull to the designer of the vessel, it is deemed essential to determine how they could be accounted for in a reconstructed design sequence. The author found it useful to periodically remind himself that the designer of a hull begins with a blank sheet of paper or uncut timbers, while the archaeologist begins with the remains of the finished product.

The rest of Section I presents, in as linear a manner as possible, the logic of *La Belle*'s design method from the point of view of the designer (Figure 6.20a–x). In reality, the design reconstruction was a continual back and forth process of conducting a geometrical analysis of the preserved timber shapes, formulating hypothetical design steps based on historical procedures, graphically investigating these steps within the parameters of the archaeological data, and repeating this process until it spiraled down toward the most plausible design reconstruction. While guided by contemporary treatises that offer corroborating evidence for French drafting practices, the reconstructed design method strictly adheres to the archaeological evidence, such as the preserved timber shapes, fastening patterns, and surmark locations.

Any progress in uncovering the original design logic for a vessel can greatly aid in reliably reconstructing the original shape of the preserved hull remains as well as in reconstructing the hull beyond the level of preservation with greater confidence. In fact, deciphering the original design method aids the archaeologist reconstructing the original hull shape similar to how the design method originally helped the shipwright define that shape. Therefore, knowing how a vessel was designed is a critical part of understanding the shipbuilding process from conception to construction.

The reliability of the archaeological reconstruction of the design of a vessel is greatly dependent on the quality of the documentation of the hull remains, both in terms of the individual timber shapes as well as specific construction features such as tool marks and fastenings. *La Belle*'s articulated hull remains were systematically dismantled with recording of the hull by both electronic (total data station) and traditional plumb bob and tape measure methods. In addition, 1:1 recordings were made of the individual timbers, and these drawings were subsequently digitized. All this documentation provided a wealth of data for reconstructing the ship on paper and ultimately the reassembly of its remains in a conservation vat at the CRL.

Preliminary reconstruction work included generating lines drawings of the hull shape both in its as-found configuration and, after accounting for any deformation, generating a lines drawing of the hull remains in a hypothetical as-built configuration. For this work, sections were generated for all the frames and not just the surmarked frames, although only the surmarked frames are included in the final presentation drawings. The original graphic investigations of the design method were not simply based on the reconstructed outlines of the frame sections; instead, composites of scaled-down recordings of the original timber components were

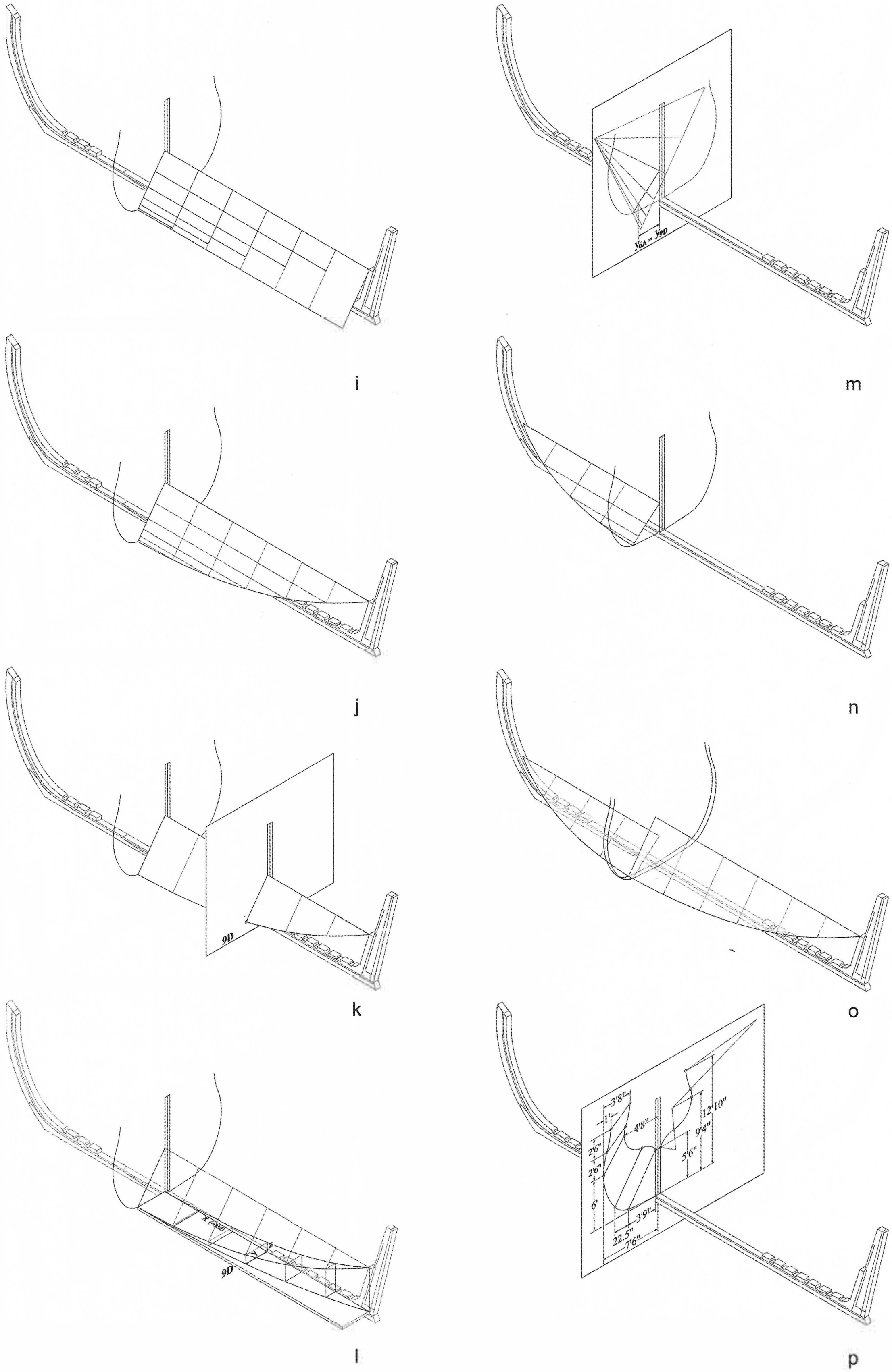


6.20. Isometric drawings illustrating the concepts underlying the graphic design system of "geometric fairing with diagonals" as reconstructed for *La Belle*. See the text for a complete explanation of the drawings. (Illustrations by author.)

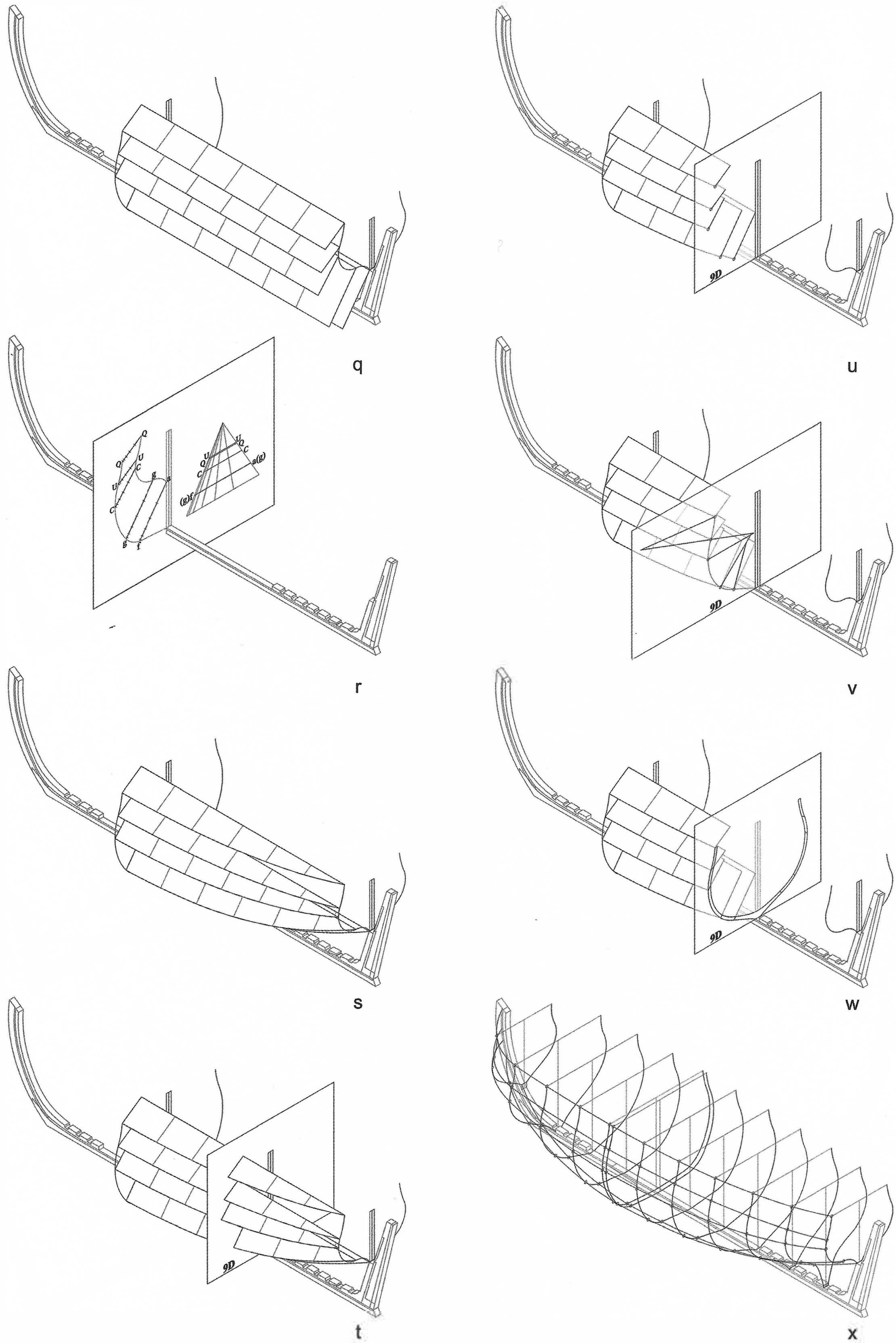
used for all such work. This was done to minimize any departure from the original curves cut by *La Belle*'s shipwrights. Furthermore, to assure accuracy, these drawings and all subsequent graphic research was done at a 1:10 scale.

The study of *La Belle*'s design and construction was greatly facilitated by the high percentage of the original hull preserved and its distribution. The better preserved starboard side represents 49 percent of the complete original starboard side of the vessel as reconstructed. Relative to the hull below the reconstructed level of

6.20. *(continued)*



6.20. *(continued)*



maximum beam, preservation goes up to 71 percent. Since most of the change in curvature on a hull occurs below the maximum beam, this high percentage should correlate with the reliability of the reconstructed hull shape. These percentages take into account the sides of the hull, the centerline timbers as well as the area of the transom, but they do not include the surface area of the upper decks. Decks represent a large area, but, once the run of a deck is determined, its general shape and structure are relatively easily reconstructed with the help of historical records.

Although the preservation of *La Belle*'s hull falls off at the forward and after ends of the vessel, several features of its distribution benefit the process of hull reconstruction. The percentage of preservation declines from amidships forward and aft fairly gradually and evenly until abruptly falling off after frames *VIIIIA–XA* forward and frame *XIIID* aft (Figure 6.8). As a result, the curvature of the bilge is preserved along most of the vessel's starboard side. Even with an abrupt reduction in preservation at the extreme ends of the vessel, at a minimum the bottoms of all of *La Belle*'s original frames, with the exception of the fashion pieces, are preserved. Furthermore, there is sufficient preservation of the lower ends of both the stem and sternpost to project their as-built shapes with great reliability.

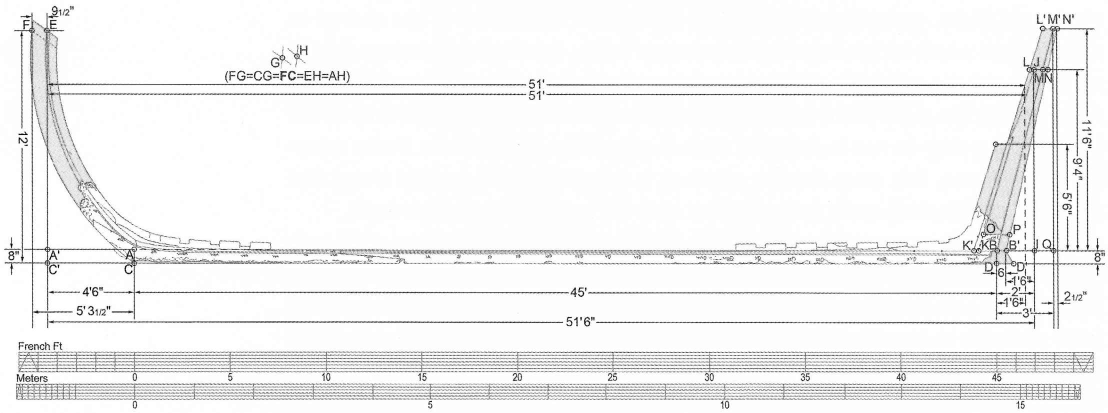
When uncovered, *La Belle*'s spine had a general twist along its length and was cracked at the keel scarf with the forward section depressed downward. Furthermore, the hull was pushed upward where it rested on the starboard bilge, and the upper part of the hull forward was splayed out and pulled aft. These various deformations were fairly easy to identify and account for in re-creating the as-built orientations of the timber remains. Three partially preserved bulkhead partitions as well as a forward hull platform served as useful checks for reconstructing the transverse shapes of the hull as well as the curvature of the lower hull forward. The hull remains were reassembled in an as-built orientation at the conservation lab; this served as an additional check on the graphic reconstruction work and provided the opportunity for further detailed investigation of such features as fastening angles as well as surmark alignment. In general, the CRL staff enabled the study of *La Belle*'s design and construction to become an integral part of the reassembly process. Particularly, acknowledgement for the collaboration and support in this effort goes to fellow archaeologists Peter Fix, Peter Hitchcock, and Jim Jobling.

Two-Dimensional Design

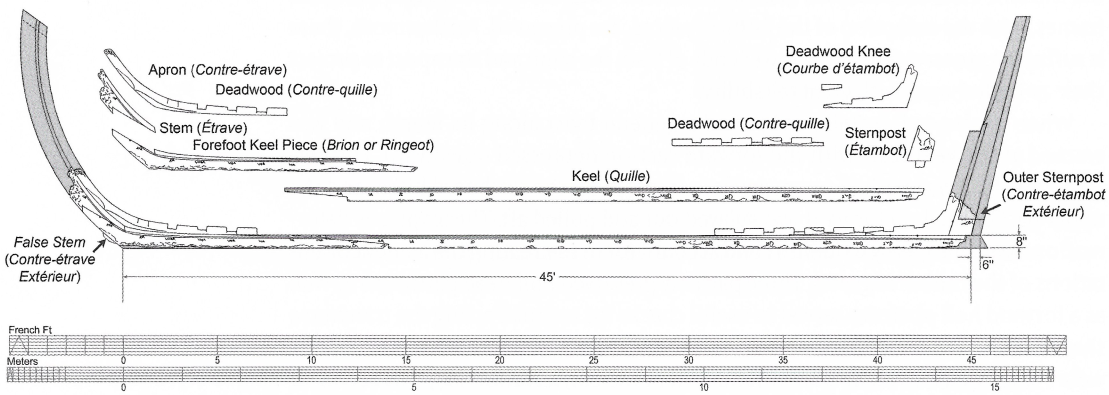
La Belle's design process begins with the relatively simple task of establishing the two-dimensional contours of the centerline timbers and the midship frame. These contours define the main proportions of the vessel's length and width, and thus it is not surprising that 12 out of the 18 key measurements in *La Belle*'s devis relate to them (Figure 6.20a, b).

The Centerline Profile

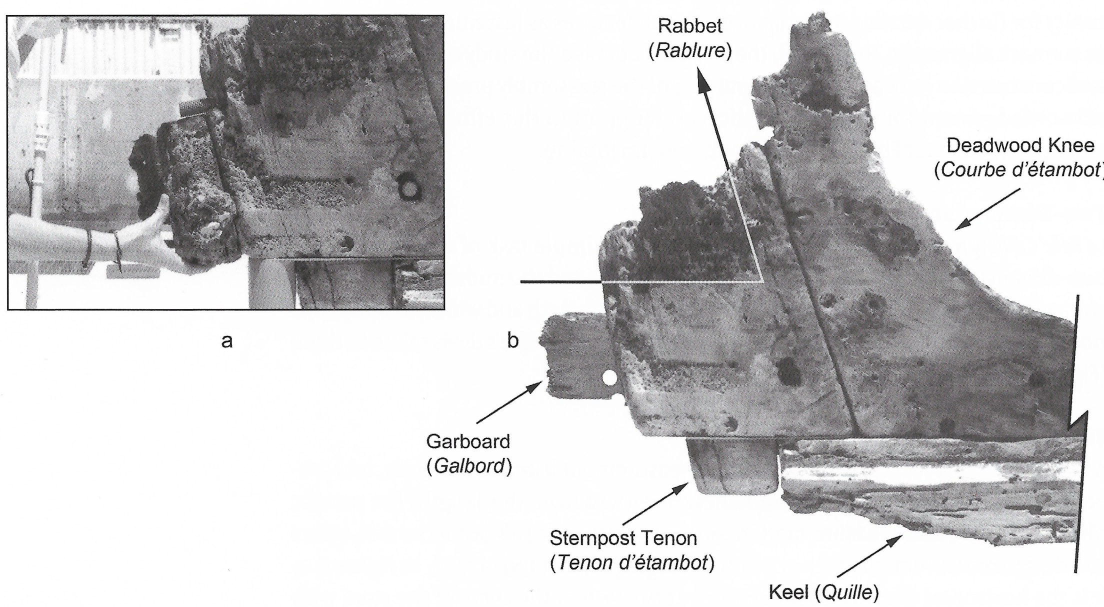
A keel length of 45 ft (14.62 m) is the first measurement listed in the devis, and several of *La Belle*'s other basic measurements are derived from this length. The specific phrasing for the keel measurement in the devis, *longueur de quille portant sur terre*, refers to a design measurement and not a timber length (Ollivier 1992a:362). In Figure 6.21 it is the horizontal distance between the intersection of the curve of the stem with the bottom of the keel, point *C*, and the intersection of the after side of the sternpost with the top of the keel, point *B*. The two timbers that comprise the keel actually extend beyond these points both forward and aft. The forward piece of the keel, referred to as the forefoot in this chapter, incorporates part of the lower curve of the stem (Figure 6.22) (Ollivier 1992a:357). In the stern the keel is not preserved past the after face of the sternpost, but pieces of the outer sternpost and an overlapping garboard plank survive (Figure 6.23a, b). These timbers indicate that the top of the keel extended 6 inches (16.24 cm) past the sternpost and probably even further on the bottom due to an angled skeg (Figures 6.10, 6.21). Over most of its length the keel is 6 inches (16.24 cm) sided (wide) and 8 inches (21.66 cm) molded (high). Thus for design the above information gives two parallel lines (*AB* and *CD*) that are 8 inches (21.66 cm) apart (Figures 6.20a, 6.21).



6.21. The design measurements for *La Belle*'s longitudinal profile. (Illustration by author.)



6.22. *La Belle*'s spine timbers. (Illustration by author.)



6.23. The components of *La Belle*'s sternpost assembly: *(a)* remains of the main piece of the outer sternpost are being held in place; *(b) La Belle*'s stern timbers with nomenclature. In both figures the partial remains of the port garboard are visible extending beyond the sternpost. (Photos by author.)

The devis provides three other measurements that relate directly to the length of the vessel. The total length between the stem and sternpost is given as 51 ft (16.57 m), the rake of the stem as 4 ft 6 inches (1.46 m), and the rake of the sternpost as 1 ft 6 inches (48.73 cm). The given length measurement of 51 ft (16.57 m) is simply the two rake measurements added to the keel length, and therefore it does not independently give any additional information. Both the rake measurements are ratios of the keel length. The stem rake is one-tenth the keel length and the sternpost rake is one-third the stem rake or one-thirtieth the keel length.

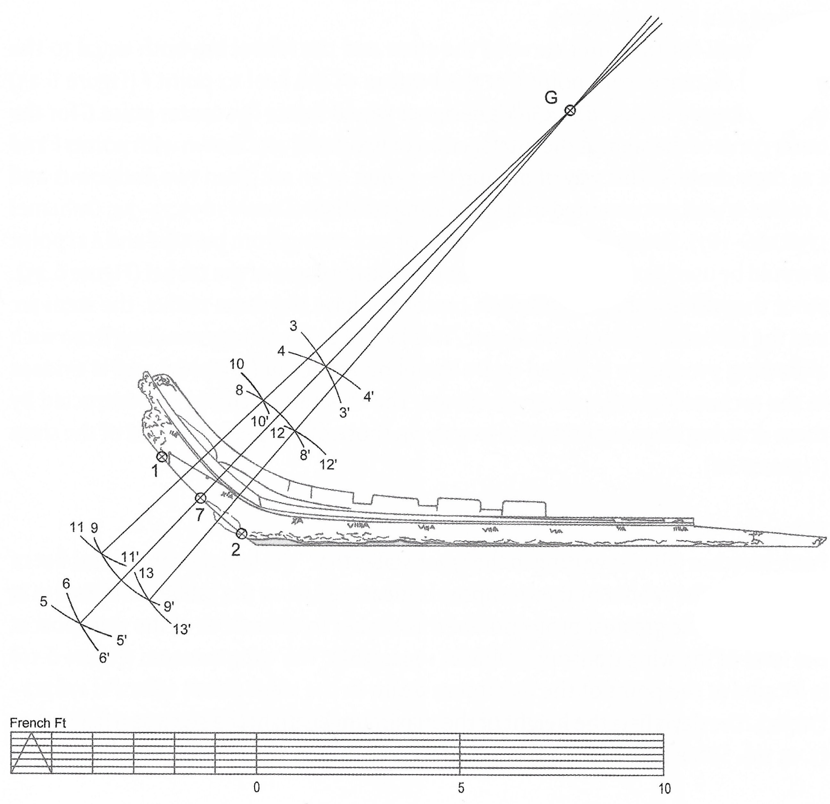
Based on the terminology used in the devis, the rakes should be the horizontal distances from the ends of the design keel, points *C* and *B*, to vertical lines dropped from the outside top corners of the stem and sternpost—points *F* and *M′* in Figure

6.21. Both the stem and the sternpost are sufficiently preserved to indicate that the rakes to the outside of *La Belle*'s endposts were greater than those given in the devis. Reconstructing in detail how the stem and sternpost were originally drawn gives a very plausible explanation for the apparent discrepancies with the devis that does not simply discard them as mistakes. These measurements may be for the rakes to the rabbets—grooves cut into the stem and sternpost for fitting the planking.

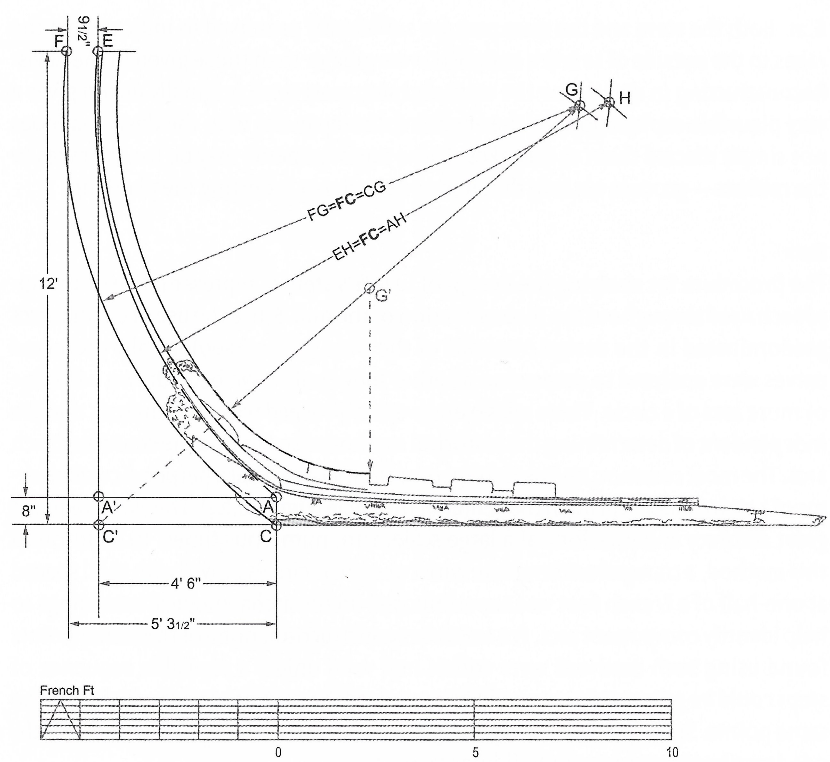
Stem

The procedure for studying the design of *La Belle*'s stem is representative of the approach used throughout the reconstruction of the hull. Since the use of circular arcs predominated in the design methods of the time, all archaeologically preserved curves were analyzed to determine whether they could have been drawn with one or more arcs of a circle. There are several ways to proceed with this analysis that are independent of determining the historical methods used to find the centers of such arcs. The most common one uses the geometric theorem that a perpendicular bisector of a chord passes through the center of the circle (Figure 6.24). This work requires great accuracy and was done at a large scale, 1:10, numerous times. In addition to this method, a transparent template with concentric circles drawn with radii spaced at one-half of a French foot was superimposed on the archaeological recordings to help identify component arcs. For *La Belle*'s reconstruction, none of the center points found using such methods were considered valid unless a plausible sequence of steps could be presented that would have allowed the original designer to locate the same points. Such "plausible design sequences" were derived from historical methods described in various shipbuilding treatises.

Geometrical analysis of the remains of *La Belle*'s stem indicated that two separate center points, *G* and *H* in Figure 6.25, were used to draw the curves of the outboard face and rabbet. However, the radii for these two arcs are identical and they have a very specific relationship to the height of the stem (12 ft [3.90 m]) listed in the devis. Point *E* in Figure 6.25 is located on a perpendicular line raised 12 ft (3.90 m) at point *C′*, 4 ft 6 inches (1.46 m) beyond the end of the keel. These 4 ft 6 inches (1.46 m) are the rake measurement, and the stem height (12 ft [3.90 m]) is measured from the bottom of the keel (Dassié 1695:73; Duhamel 1758:165–166; MnM 1686:PH11393,



6.24. Finding the center of the outer curve of *La Belle*'s stem using the perpendicular bisector of a chord method. (Illustration by author.)



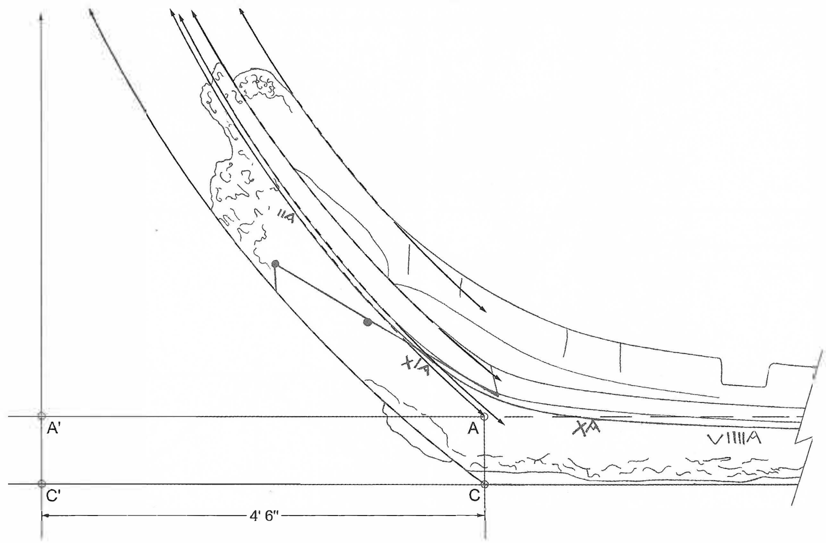
6.25. The reconstruction of the original design of the stem superimposed on the archaeological recording of the stem. The stem height is taken from the bottom of the keel and the rake measurement relative to the top of the rabbet. (Illustration by author.)

11409–11410). The shipwright located point *F* away from point *E* by the desired timber dimension for the stem beyond the rabbet. In Duhamel du Monceau's treatise from the mid-eighteenth century, where the length is given between rabbets, he confirms that a necessary step in the sequence of drawing the stem is to establish how much the stem projects beyond the rabbet (Duhamel 1758:164). In *La Belle*'s reconstruction, that distance was determined to be 9.5 inches (25.71 cm). There is enough flexibility in the reconstruction that it is suspected a distance of 10 inches (27.07 cm) was laid off by the designer, resulting in a rake to the outer face of the stem of 5 ft 4 inches (1.73 m).

The radii for the outer curve of the stem and the rabbet are both equal to the diagonal distance from point *C* at the bottom of the keel to point *F* (Figure 6.25) (Marine Royale 1691:5–6). *La Belle*'s designer would locate the center point *G* for the outer curve of the stem at the intersection of two small arcs drawn with points *F* and *C* as their centers. This way of finding the center of an arc given two endpoints and a radius is well documented in shipbuilding treatises (Dassié 1695:73–74; Duhamel 1758:166–167). Similarly, the intersection of arcs swung from points *E* and *A* at point *H* would be used as the center point for the outside curve of the rabbet (Figure 6.25). Since they do not share a common center but have the same radius, the stem arc and the rabbet arc are not concentric. This lack of concentricity resulting from such a drawing procedure is noted by Duhamel du Monceau (1758:167) and is evident in the archaeologically preserved curves. The theoretical curves reconstructed by these drawing steps superimpose exactly on those of the preserved part of the stem (Figure 6.26).

Sternpost

French author Ollivier writing in the 1730s states that "the length from the rabbet of the stem to the rabbet of the sternpost is measured from the rabbet of the stem at the point of the greatest projection of this timber to the rabbet of the sternpost at the level of the wing transom" (Ollivier 1992a:362). The wing transom (Figure 6.10) is located at the point of the maximum beam in the stern (MnM 1680:PH 178712–178715). The devis lists the height of the maximum beam in the stern as 9 ft 4 inches (3.03 m). Since part of the rabbet is preserved on the sternpost remains it can be



6.26. Detail from a large reconstruction drawing of the stem design method illustrated in Figure 6.25. The reconstructed curves superimpose exactly on the archaeologically recorded curves. (Illustration by author.)

projected upwards to point *J* at a vertical height of 9 ft 4 inches (3.03 m) (Figure 6.21). Unlike for the stem, the heights for *La Belle*'s sternpost reconstruction are measured from the top and not the bottom of the keel. In fact, other than for the stem height, the top of the keel is the baseline for all of *La Belle*'s design dimensions. Such a switch in baselines is well supported by parallels in shipbuilding treatises and surviving drafts (Dassié 1695:73; Duhamel 1758:165,168; MnM 1686:PH 11393, 11409–11410).

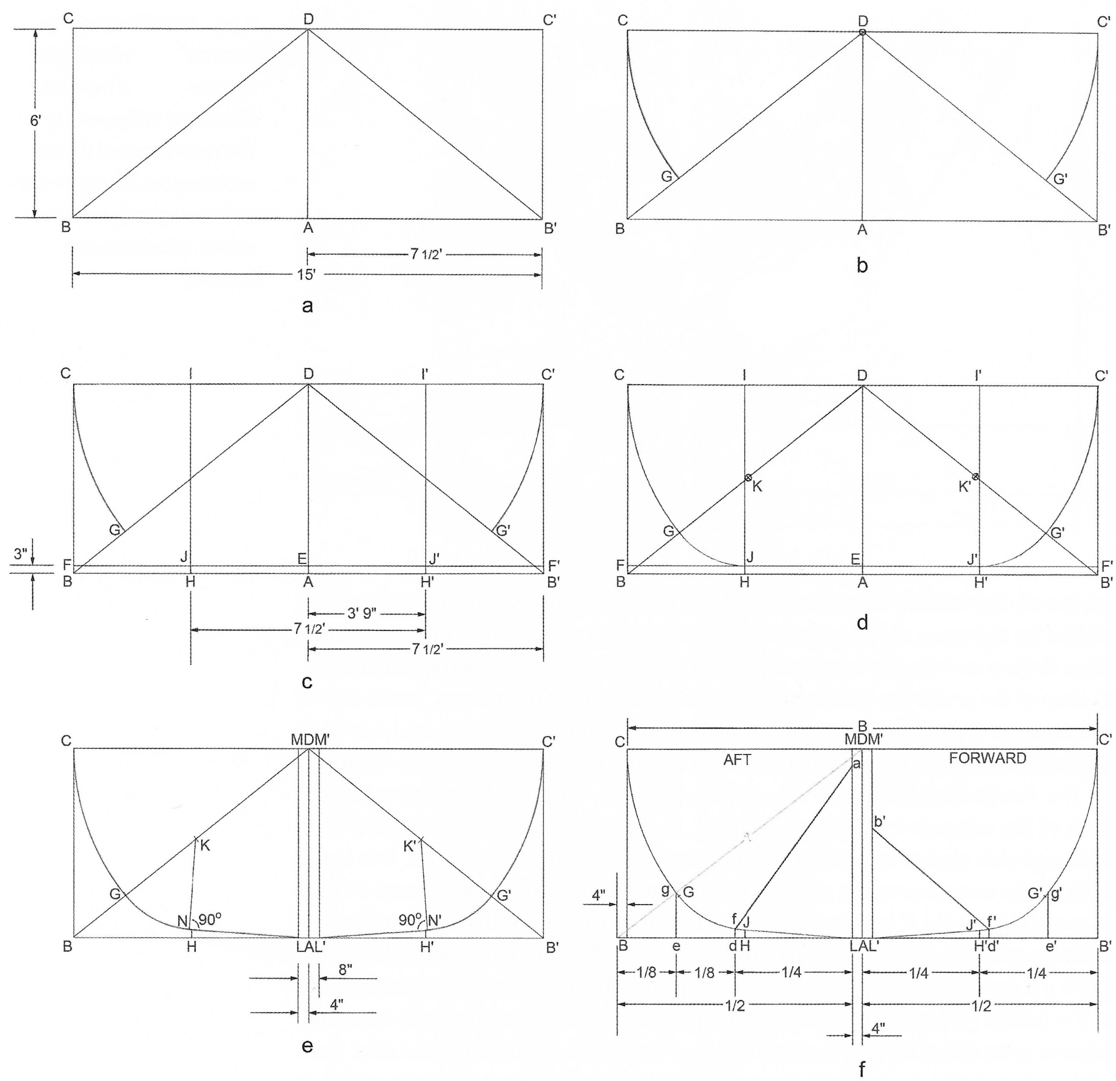
The horizontal distance *IB′*, from a vertical line dropped from point *J* to the back of the reconstructed outer sternpost, is 1 ft 6 inches (48.73 cm) (Figure 6.21). Although this measurement corresponds to the one listed in the devis, it is to the back of the outer sternpost and not the sternpost itself. However, it must be kept in mind that point *B′* is also the after endpoint of the top of the keel timber. The distance to the sternpost measured this way (*IB*) is 2 ft (64.97 cm), and to the rabbet (*IK*) is 3 ft (97.45 cm) (Figure 6.21). Furthermore, when the sternpost is extended to 11 ft 6 inches (373.57 cm), the vertical height listed in the devis, its rake measured relative to its after face (*BQ*) is also 3 ft (97.45 cm). Since the forward and after faces of the sternpost and outer sternpost are not parallel to each other or the rabbet, it is suspected that all of the points associated with these measurements were used by the shipwright to lay out these timbers. In terms of design, identifying point *J* at the height of the wing transom is the most important, and the 1.5 ft (48.73 cm) rake measurement to the back of the outer sternpost and the keel timber is consistent with the above analysis for the rake of the stem.

The Midship Frame

Having defined the longitudinal profile of the hull, the transverse limits were established with the midship frame. Deciphering the design of the midship frame was complicated not only by discrepancies with measurements in the devis but also with apparent inconsistencies within the archaeological evidence itself.

As in the case of the stem, the archaeologically documented curvature of the midship frame was analyzed geometrically to determine what if any component arcs were used in its design. This work indicated that the lower part of the midship frame was defined on each side by two arcs with centers at points *D* and *K* (*K′*) (Figures 6.27d, 6.28a). Extending the arc centered at point *D* upwards a little beyond the level of preservation results in a maximum beam at the midship frame of 15 ft (4.87 m) at a height of 6 ft (1.95 m) above the top of the keel (Figures 6.27a, d, 6.28a).

Starting with these initial findings, experimentation followed with various known historical approaches to designing the midship section to determine a drawing procedure that would yield the same midship shape as *La Belle*'s. The drawing procedure illustrated in Figure 6.27 is essentially the same as one described in La Madeleine's manuscript, *Tablettes de Marine*, from ca. 1712 (Rieth 1996:56–57). In this



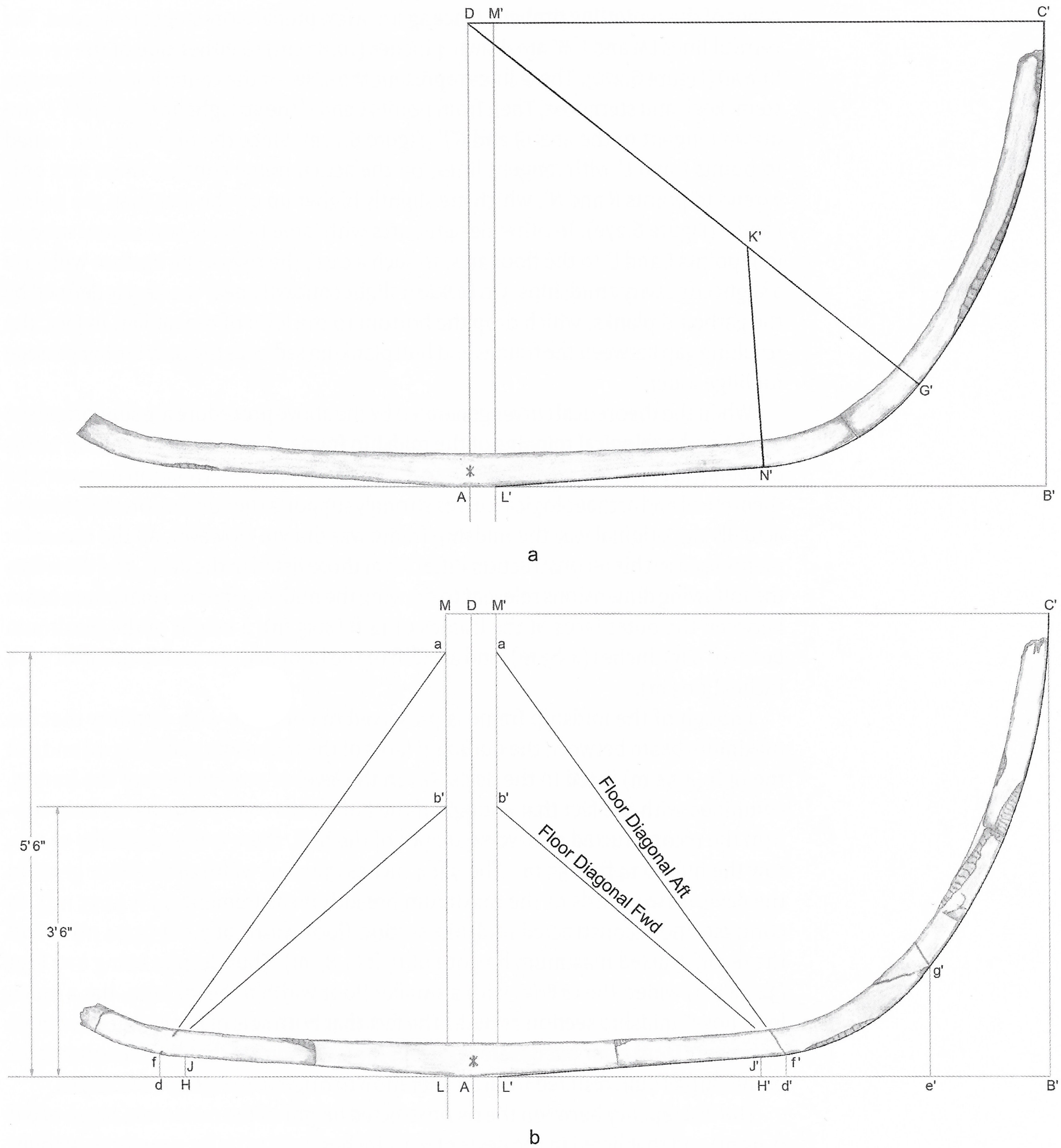
6.27. Reconstructed drawing procedure for the lower part of *La Belle*'s midship section. See the text for a complete explanation of the drawings. (Illustrations by author.)

procedure the shape of the midship frame is mainly defined by two sets of arcs: the lower breadth arcs *CG* and *C′G′* with a common center *D* and the floor arcs *GJ* and *G′J′* with centers *K* and *K′* (Figure 6.27d).

The complete lower midship section is contained within the rectangle *BB′C′C*, the width of which is equal to 15 ft (4.87 m) at *BB′* and *CC′*—the maximum beam of the vessel between the outboard faces of the frames (Figure 6.27a). This width is one-third the keel length of 45 ft (14.62 m). The height of the rectangle at *BC* and *B′C′* is 6 ft (19.49 m). This corresponds to the height of the maximum beam above the level of the top of the keel at line *BB′* and is two-fifths the beam width (Figure 6.27a).

In order for point *C* to be at the maximum beam of the vessel, the breadth arc has to be tangent to line *CB* at this point. Therefore the center point of this arc has to be located on line *CC′* which is perpendicular to line *CB*. With a common center at point *D* the radius of the lower breadth arcs is 7.5 ft (2.44 m), which is equal to half the beam (*DC* = *DC′* = 7.5 ft = half the beam). If a larger radius were chosen the midship section would be fuller, while a smaller radius would result in a finer section. From the maximum beam points the lower breadth arcs (with point *D* as the center and a radius of 7.5 ft [2.44 m]) are swung with a compass downwards to points *G* and *G′* that lie on the diagonals *DB* and *DB′* (Figure 6.27b). These diagonals, unlike the surmark diagonals, are simply temporary construction lines created as a preliminary step to aid in drawing the midship section (Figure 6.27a).

A few additional preliminary steps have to be taken before being able to draw the floor arc. First, it is necessary to divide each of the rectangles, *ABCD* and *AB′C′D*, on either side of the centerline, *AD*, in half with the vertical lines *HI* and *H′I′*. Note that



6.28. The reconstruction of *La Belle*'s midship section superimposed on the archaeological timber recordings: *(a)* floor timber and second futtock; *(b)* floor timber with the after first and third futtocks. (Illustrations by author.)

the distances *AH* and *AH'* are equal to one-fourth the total beam and the distance from point *H* to *H'* is equal to half the beam (Figure 6.27c). Next, a parallel line, *FF'*, is drawn 3 inches (8.12 cm) up from the baseline *BB'*. This line crosses the centerline *AD* at point *E*, thus *BF* = *AE* = *B'F'* = 3 inches (8.12 cm) (Figure 6.27c). The line *FF'* intersects the lines *HI* and *H'I'* at points *J* and *J'*. The width between *JJ'* is the same as that between *HH'*, which as was noted above equals half the beam. In this particular case this distance is the width of the floor at the midship frame.

Finally, in order to draw the floor arcs, using a compass successively set to various widths one must "discover," through trial and error, points *K* and *K'* on the diagonals *DB* and *DB'* that will serve as center points for arcs, with a radius of *KG* = *K'G'*, that will intersect line *FF'* at points *J* and *J'*. There will be only one radius measurement that will allow the drawing of arcs *GJ* and *G'J'* (Figure 6.27d). The center of the floor arc, *K*, is located on the same line, *DG*, as the center for the breadth arc, *D*. Therefore these arcs are tangent where they touch at point *G*. Only with the center point at *K*, "discovered" by trial and error, would an arc drawn from point *G* intersect line *IH* at point *J*. This procedure of "discovering" a center point for a tangent arc given another predetermined point off that line is common in French ship design (e.g., Duhamel 1758:209).

To complete the lower midship section, the floor arcs must be joined to the edges of the centerline timbers. Once again, a few preparatory steps are needed. The vertical lines *LM* and *L′M′* are drawn 4 inches (10.83 cm) to either side of the centerline *AD* (Figure 6.27e). These lines represent the sides of the centerline timbers: the stem, keel, and sternpost. Then from points *L* and *L′* the straight lines *LN* and *L′N′* are drawn tangent to the arcs *GJ* and *G′J′* (Figure 6.27e). Since the floor arcs are joined to points *L* and *L′* with tangent lines, on the actual frame contour these arcs only extend to points *N* and *N′*, which are slightly higher up on the arcs than the points *J* and *J′* (Figure 6.27e). In other designs, arcs with large radii are sometimes used to join points *L* and *L′* to the floor arcs. In such a case, the rise of the bottom will have a slight concavity amidships. On *La Belle* a slight concavity near the keel is defined by the garboard planks, which drop the bottom to the level of the rabbet. In fact, the resulting gap between the frames and hull planking serves as the only limber passage for bilge water.

When the theoretical curves generated by the above procedure are superimposed on the archaeological remains of the midship frame, the correspondence in terms of overall curvature is excellent (Figure 6.28a, b). The close correlation between the theoretical and archaeological curves strongly supports the conclusion that this was actually the original way the midship frame was drawn. However, all the measurements used in this reconstruction differ from those listed in the devis. The devis lists the following dimensions relevant to drawing the midship frame: a maximum beam between the outer faces of the frames of 14 ft (4.55 m); a height of the maximum beam of 6 ft 3 inches (2.03 m); and a width of the floor at the midship frame of 9 ft 4 inches (3.03 m).

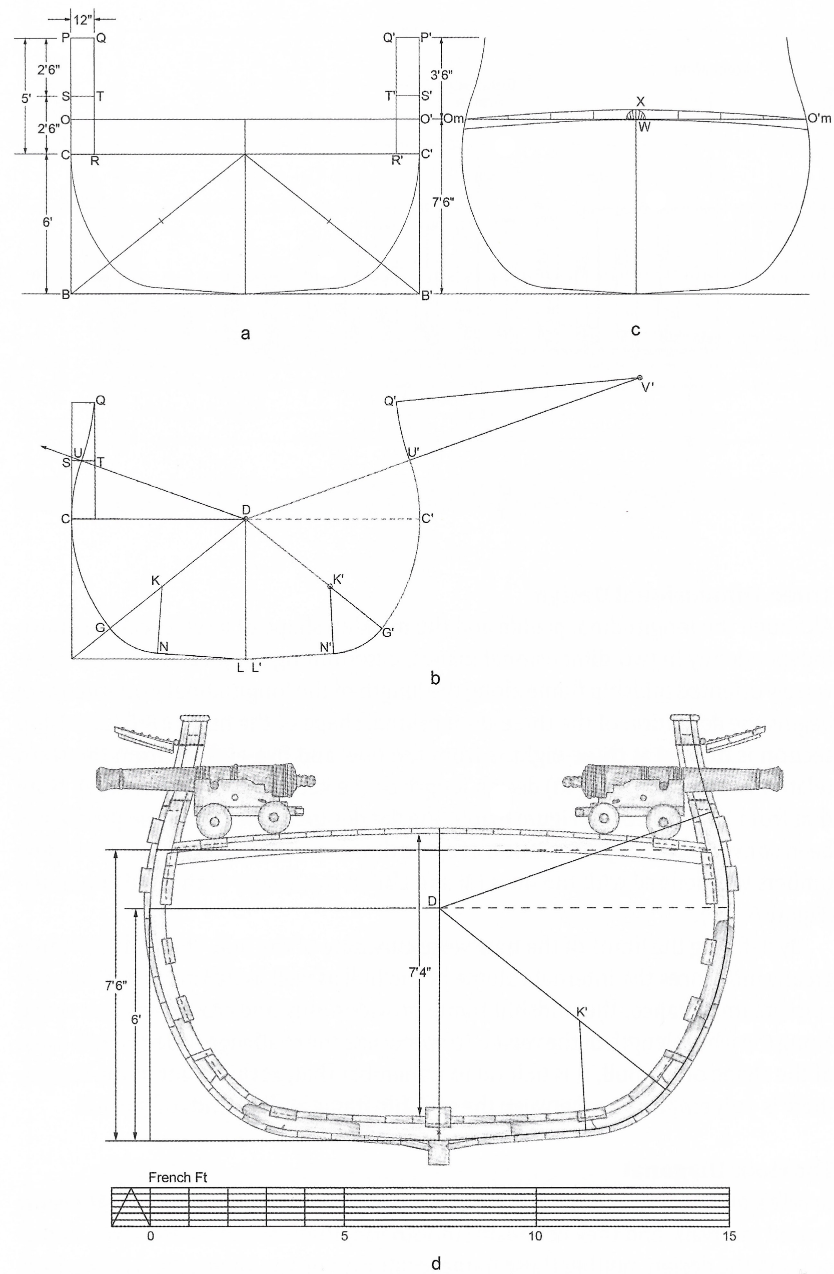
Enough of the midship frame is preserved to conclude with certainty that the maximum beam between the outboard faces of the frame was 15 ft (4.87 m) and not the 14 ft (4.54 m) listed in the devis. Given the level of preservation of the frames, combined with the fact that enough of the bulkheads were preserved to help confirm the reconstructed transverse shapes of the hull, there is no possibility to narrow the hull to 14 ft (4.55 m). The 9 ft 4 inches (3.03 m) width of the floor given in the devis is two-thirds of the maximum breadth measurement (14 ft [4.55 m]). In contrast, the reconstructed midship section floor width of 7.5 ft (2.44 m) is half the reconstructed maximum breadth of 15 ft (4.87 m). Thus despite being one foot (32.48 cm) wider, the *La Belle*, with a smaller floor width to beam ratio, has a much less "boxy" midship section as built. The fact that both sets of beam and floor measurements form clear but different ratios seems to indicate that the measurements of the ship as built resulted from an alteration to original design specifications.

The discrepancy between the reconstructed height of the maximum beam of 6 ft (1.95 m) and that listed in the devis of 6 ft 3 inches (2.03 m) is far simpler to account for. In the reconstruction, 3 inches (8.12 cm) is the dimension for the rising between the baseline and the floor line (Figure 6.27c) (Boudriot 1994:40; Rieth 1996:40–42). Six feet (1.95 m) is the reconstructed distance between the maximum beam line and the baseline, not the floor line (Figure 6.27a). In other devis, such as that of the light frigate in the draft by Cochois (Figure 6.18), the rising is listed separately from the height of the maximum beam (MnM 1697:PH 90251). It is believed that in *La Belle*'s devis the two may have been added together and listed as one measurement of 6 ft 3 inches (2.03 m).

The Upper Midship Frame

In terms of the design of the vessel, all the major changes in curvature occur below the maximum beam, and the shape of this part of the hull is vital to the overall performance of the ship. Nonetheless, in terms of the everyday life of a functioning vessel, the design of the upperworks impacts on the handling of armament, sail, and cargo as well as the comfort of officers, crew, and passengers.

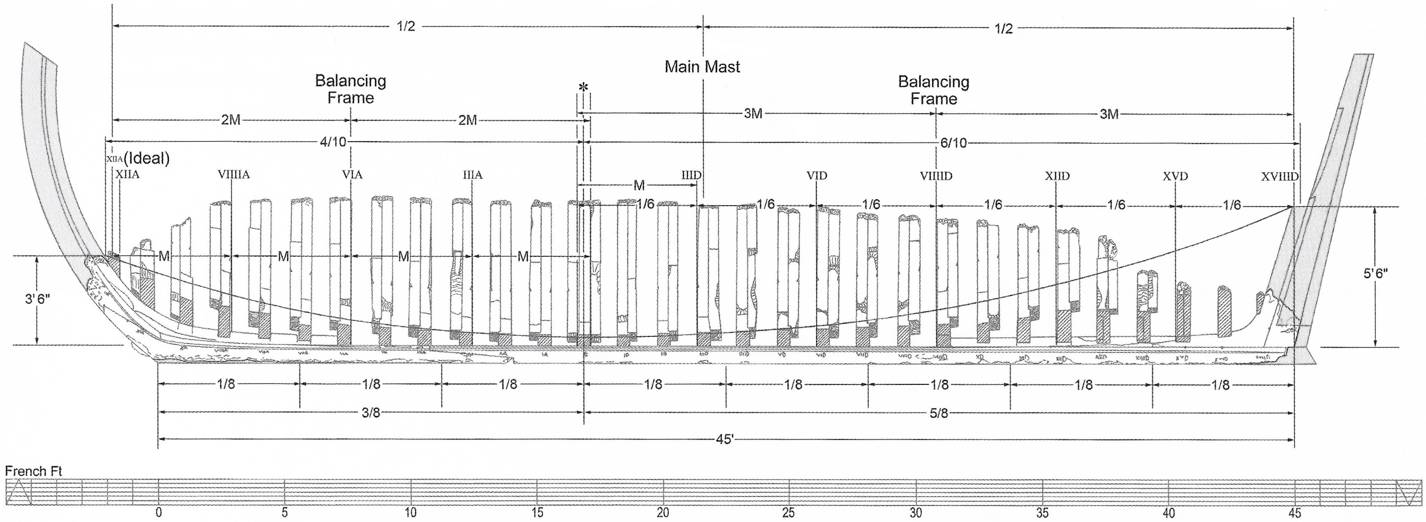
The devis provides several measurements for defining the midship section above the maximum beam: the tumblehome or the amount the hull curves inward from maximum beam is listed as 12 inches (32.48 cm); the height of the deck beam in a straight line as 7 ft 6 inches (2.44 m); and the depth of hold as 7 ft 3 inches (2.36 m).



6.29. Reconstruction of the design of *La Belle*'s complete midship section. See the text for a complete explanation of the drawings. (Illustrations by author; cannon and gunport configurations after Grieco 2003:52.)

Although the devis does not provide the height of the midship frame above the maximum beam, comparative documentary evidence enabled the reconstruction of the design of the complete midship frame (Figure 6.29) (Boudriot 1993:52–53; MnM 1684a:PH 178893; 1697:PH 90251). In addition, the work of Glenn Grieco and the historical research of Jean Boudriot and Jean-Claude Lemineur provide excellent information for the reconstruction of the overall structure of *La Belle* (Boudriot 2000; Grieco 2003).

The reconstruction of the complete midship section from the viewpoint of the designer takes into consideration the physical requirements of the functioning of the vessel (Figure 6.29d), such as clearance for *La Belle*'s 4-pounder cannons. The 1 inch (2.71 cm) discrepancy between the 7 ft 4 inches (2.38 m) depth of hold in the reconstruction and the 7 ft 3 inches (2.36 m) given in the devis can be easily reconciled by giving the beam slightly less camber. Since the design of the upperworks relies heavily on documentary evidence and cannot be compared in detail to the articulated portions of *La Belle*'s hull remains, it will not be discussed in further detail in this chapter.



6.30. *La Belle*'s longitudinal profile with the various measurements relating to the positioning of frames. The curve is the profile view of the floor diagonal. (Illustration by author.)

Three-Dimensional Design

Although the longitudinal profile and the midship shape of a vessel can be drawn independently in two-dimensional planes, determining the location of the transversely oriented midship frame along the length of the longitudinally oriented keel begins the definition of the three-dimensional shape of the hull. *La Belle*'s midship section is located at three-eighths from the bow and five-eighths from the stern relative to the 45 ft (14.62 m) design length of the keel (Figures 6.20b, 6.30). Note that from Figure 6.20a to Figure 6.20b, the flat design of the centerline profile has been converted to a representation of spine timbers. The sided dimension of spine timbers was defined with the lines *LM* and *L′M′* in the design of the midship frame (Figure 6.27e).

By defining the limits of the transverse curvature of the hull, the midship frame greatly influences the internal volume of the hull as well as its lateral stability. Despite its importance, the midship frame provides only one cross-sectional shape along the whole length of the vessel. To appreciate the challenge of defining the rest of the shape of the hull, it is helpful to remember that, at this point in the design, there is only empty space between the midship frame and the ends of the hull.

The Floor Diagonal

La Belle's archaeologically documented surmarks are located on frames at evenly spaced intervals, and they delineate smooth longitudinal curves. However, at this point in the design, neither these frame locations nor any longitudinal curves have been defined. This all begins to change by the creation of the floor diagonal.

In other drafts, like that of *Profond* and the Cochois frigate, the floor diagonals at amidships begin at the ends of the floor width (Figures 6.6, 6.18). On *La Belle* the distance between the documented locations of the lower surmarks, *ff′*, for the floor diagonal is 8 ft 2 inches (2.65 m), which is 8 inches (21.66 cm) greater than the 7.5 ft (2.44 m) between point *J* and *J′* in the midship frame reconstruction (Figure 6.27f). The clue to arriving at an explanation for this 8 inch (21.66 cm) discrepancy came from reconstructing the complete length of the lower diagonal both forward and aft. The survivingsurmarks define oblique straight lines, and these lines can easily be extended to the centerline of the vessel. The devis states the height of the floor diagonal in the bow should be 3 ft 6 inches (1.14 m) and its height in the stern 5 ft 6 inches (1.79 m). At the centerline of the vessel, the extended floor diagonal both forward and aft is just a few inches higher than these devis measurements. However, 4 inches (10.83 cm) to either side of the centerline, the heights correspond with those in the devis (Figures 6.27f, 6.28b). The interpretation that these 4 inch (10.83 cm) offsets added together represent the 8 inch (21.66 cm) theoretical sided dimension of the centerline timbers overcomes many of the difficulties in deciphering *La Belle*'s design.

The sides of the centerline timbers are represented in the midship frame reconstruction as lines *LM* and *L′M′*. In the reconstruction of the midship frame, one-fourth of the beam, 3 ft 9 inches (1.22 m), was measured to either side of the centerline, *AD*, to establish the lines *IH* and *I′H′* and the endpoints of the floor width, *J* and *J′*, on these lines (Figure 6.27c). However, when positioning the floor diagonals, it is proposed that the same distance was laid off from the lines *LM* and *L′M′* and not the centerline (Figure 6.27f). This same offset of 4 inches seems to have affected the positioning of *La Belle*'s upper bilge surmarks (Figure 6.28b) at points *g* and *g′* as well (Figures 6.27f).

There is one problem with this explanation. The actual timber dimensions of the preserved keel are 6 inches (16.24 cm) sided and 8 inches (21.66 cm) molded. However, there is comparative documentary evidence to support the proposed larger square-sectioned design keel, and the disparity in scantlings can be attributed to timber availability or selection during construction (AN 1679:Marine D1–15; MnM 1684a:PH 179610–179613). In terms of *La Belle*'s scantlings, it should also be noted that the sided dimension of *La Belle*'s keelson is on average 8 inches (21.66 cm), the same as the proposed sided dimension for the centerline "design" timbers.

Frame Spacing

It is important to highlight that consistent with conventions of orthographic drawing, the upper points *a* and *b′* of the floor diagonals *fa* (*f′a*) and *fb′* (*f′b′*) (Figures 6.27f, 6.28b) actually represent points on the endposts. In relation to the design sequence, this concept is illustrated in Figure 6.20c and in relation to the archaeological remains in Figure 6.30. Comparison with French drafts from the 1680s, as well as analysis of the archaeological evidence, suggests that the frame spacing on *La Belle* was determined relative to the horizontal distance between the endpoints of the floor diagonal on the endposts. In all the French drafts from the 1680s presented in this chapter (Figures 6.6, 6.7, 6.19), the last frames both forward and aft whose shapes are developed are located at the ends of the floor diagonal. The last frames with surmarks on *La Belle* are *VIIIIA* forward and *XIID* aft. Since surmarks are found on every third frame, it is reasonable to speculate that frames *XIIA* and *XVD* and *XVIIID* might have also borne surmarks. Since the areas where the surmarks would have been located are not preserved, there is no definitive proof that these marks were there. However, the endpoints of the floor diagonal at the 3 ft 6 inches (1.14 m) and 5 ft 6 inches (1.79 m) heights do fall at the locations of the remnants of frame *XIIA* and, assuming one more equivalent frame spacing, at the location of *XVIIID* (Figure 6.30).

Relative to frame locations *XIIA* and *XVIIID* at the ends of the reconstructed floor diagonal, the midship frame is located two-fifths the length of the diagonal from its forward end and three-fifths from its stern end (Figures 6.20c, 6.30). As mentioned, the midship section is also at three-eighths the design keel length from the forward end of the keel and five-eighths from its stern end. If both these ratios were used, then somehow the designer or shipwright had to coordinate them. This may have been accomplished by locating frame *XVIIID* exactly in line with the after endpoint of the design keel length.

What is certain is that the length between the floor diagonal endpoints was a primary consideration for establishing the frame spacing. The floor timbers of the surmarked frames are evenly spaced along this length (Figures 6.20d, 6.30). The spacing from the labeled face of any surmarked frame floor timber to the corresponding face on the next surmarked frame floor timber is 4 ft 9 inches (1.54 m), and the room and space between any two adjacent floor timbers is 1 ft 7 inches (51.43 cm). In the bow, frame *XIIA* is actually fastened 3 inches (8.12 cm) aft from where the regular spacing of the other surmarked frames would theoretically place it. Either the positioning of this frame on the steep curve of the stem gave the shipwrights difficulty or they intentionally altered its position to adjust the curvature in the bow. Two large shims placed between the frames and the hull planking on both sides of the lower bow indicate that the shipwrights did indeed have trouble fairing out the shape in this area. Since in reality the curves of the diagonals extend to the rabbet a little further than the theoretical design planes at *XIIA* and *XVIIID*, there had to be some practical adjusting of the curves at the ends of the vessel during construction. Such problems with deviations between the design method and actual construction were overcome as design methods were refined in the late 1680s and 1690s.

During construction, establishing the frame spacing allowed the shipwrights to carve the frame location labels on the port face of the keel (Figures 6.1, 6.8). The labels were definitely carved once the two component timbers of the keel were already joined because the label *IIIA* is carved across the seam of the scarf between the forefoot and the after part of the keel (Figures 6.8, 6.22). Label *XIIA* is actually on the completely separate stem timber, which is scarfed to the forward end of the forefoot part of the keel. If there had been a label for *XVIIID*, it would have been on part of the sternpost that has not survived.

The arrangement of the centerline timbers further highlights the central role of the floor diagonal length and the surmarked frame locations in the overall design. Toward the ends of the vessel where the hull becomes more V-shaped, additional longitudinal timbers, known as deadwoods, are added on top of the keel (Figure 6.22). They begin before and abaft two surmarked frames, *VIA* and *VIIIID* (Figure 6.8). The spacing between the surmarked frames is the same before and abaft the midship frame; thus the distances to frame positions *XIIA* and *XVIIID* are quite different. Nonetheless, in both cases the deadwood begins at half the distance from each of these frame positions (*XIIA* and *XVIIID*) to the midship frame (Figure 6.30). It is important to note that there are surmarked frames further forward and aft than frames *VIA* and *VIIIID*. In all other "marked" vessel remains there are no surmarked frames over the deadwoods, if such timbers are present.

Although frames *VIA* and *VIIIID* are not the last surmarked frames, they do have the same width between the port and starboard floor timber surmarks at the same proportional distance from the midship frame. Thus, they help "balance" the forward and after volumes of the hull (Duhamel 1758:174–175, 230–233). In fact, in French shipbuilding these frames are referred to as balancing frames, *couples de balancement*. As will be discussed below, these frames play an important role in determining the measurements for the longitudinal curves situated before the midship frame.

In addition to the deadwoods, the mainmast is positioned relative to the length of the floor diagonal. The base of the mainmast is located over the floor timber of frame *IIID*, exactly in the middle of the length of the hull covered by the floor diagonal (Figure 6.30).

Design Planes and Framing Timbers

Figure 6.20e depicts flat design planes raised at every third frame location abaft amidships. The outline of a frame depicted in a body plan of a drawing represents its shape in a single design plane that has no thickness. When this plane is viewed from the side, it appears as a thin straight line—like looking at the edge of a piece of paper. In Figures 6.20d, e, two equal frame spacing intervals overlap at the midship frame location, and thus two outlines of the midship frame are depicted. Such a doubling of the midship outline is not depicted in any of the historic French drafts presented in this chapter for comparison. In the author's opinion, when these drafts were made, they did not take into consideration on which faces of the framing timbers the shipwright would draw the frame shapes. This was a practical matter that would have been addressed during the actual construction of the vessel. Since this study focuses on the design of *La Belle* as built, the critical relationship between design planes and framing timber faces will be discussed, and these concepts were incorporated into all the reconstruction drawings.

Both the forward and after faces of *La Belle*'s floor timbers and second futtocks create design planes on which the complete frame shapes could be drawn. Although it is almost certain that the curves of the frames were first drawn on these timbers, it is difficult to determine whether this was done on the adjoining or the open faces of these timbers. The notching of the floor timbers suggests that the shapes were drawn on the faces oriented toward the midship frame. *La Belle*'s shipwrights seem to have gone to considerable effort to create a smooth, continuous surface along the open faces of the floor timbers and second futtocks. *La Belle*'s floor timbers have a greater sided dimension than the futtocks. Where they overlap the first futtocks, they are notched just enough to bring the open faces of the second futtocks into alignment with the open faces of the floor timbers while still maintaining greater timber dimensions along the centerline—the dark lines in Figure 6.9.

All of *La Belle*'s surmarks appear on these open faces of the floor timbers and second futtocks that are oriented toward the midship frame (Figures 6.1, 6.3, 6.9). On all these frames except the midship frame, the lower surmarks are located on the floor timbers and the upper surmarks on the second futtocks. Thus in the forward part of the vessel the surmarks are on the after faces of the frame timbers and in the after part of the vessel they are on the forward faces. Since it is the floor timbers and second futtocks that bear surmarks regardless of whether the frame is before or abaft amidships, this change in label orientation is accompanied by a switch in the relative arrangement of the component timbers of each frame. Before amidships the first and third futtocks are set before the floor timbers and second futtocks, and abaft amidships they are set abaft them (Figure 6.9). It should be noted that on the midship frame both surmarks are on the after set of first futtocks, which are superimposed onto the continuous face of the midship floor timber and second futtocks created by notching the forward face of the floor timber. This after set of first futtocks was independently fastened onto the rest of the timbers of the frame that were already secured together with fastenings.

The notches in all the floor timbers are variable in length as well as quality and do not seem to have been cut to strengthen the scarf or to ensure precise timber alignment. In addition, the overall lengths of the first futtocks vary greatly, and thus, there is no consistency from one frame to another as to where their tops and bottoms are located. Therefore, there is no correlation between any features of these scarfs or the lengths of the first futtocks and the locations of the surmarks. There does seem to have been some attempt by the shipwrights to have the arms of the floor timbers extend approximately 1 ft (32.48 cm) beyond the floor timber surmarks. This is the case for all the mold frames except for *VIA*, where this distance is approximately 1/2 ft (16.24 cm), and frames *VIIIIA* and *XIID*, where it is an inch (2.71 cm) longer than a foot (32.48 cm).

La Belle's frames are identified with location labels that follow the same logic as the location labels on the centerline timbers. These location labels appear on all of *La Belle*'s frames and have the same orientation relative to amidships as the surmarks on every third frame. The amidships star is located on the center of the after face of the midship floor timber. All the rest of the floor timbers have the same Roman numeral and letter designations as the corresponding labels on the keel (Figures 6.2b, 6.3). In addition to the centerline labels, the ends of the floor timbers and the lower ends of the second futtocks that butt up against the floor timbers are also labeled (Figures 6.2a, 6.3). These labels give the frame location number together with a letter designating either starboard, *T* for *tribord*, or port, *B* for *bâbord*. The labeling of the port second futtocks can only be inferred since none of these timbers survive. Furthermore, there is no indication with the second futtock labels whether the timber is located before or abaft amidships. The orientation of the label or a physical association with other timbers from the frame must have been deemed sufficient. Overall, there are only a few location labels that are missing or barely discernible. In addition, a few of the labels are oriented upside down or the order of the numbers and letters is reversed.

La Belle's location labels were not intended to identify every framing timber; all the first futtocks and third futtocks are completely devoid of labels. Although these timbers may have been labeled in a less permanent fashion such as with graphite or red ochre, the lack of inscribed labeling indicates a clear distinction between them and the labeled timbers. These unlabeled timbers seem to serve as structural backing for the labeled timbers on which the shape of the frame was drawn.

Beveling

In terms of having the labels and marks visible as aids or guides in the assembly of the hull, the open faces of these timbers would be the only logical choice for their placement. However, the motivation for aligning the open faces of the floor timbers and second futtocks was not to create a nice continuous face for labeling. It is conceivable this was done to create a design plane for drawing the frame shapes, from which the procedure for beveling the timbers would be consistent throughout the length of the vessel.

Bevels are either acute, under bevels, or obtuse, standing bevels, depending on whether they are measured from the after or the forward face of a timber relative to the midship station. Regardless of the shipbuilding tradition, the switch in timber arrangement within a frame relative to amidships reflects a desire to keep the type of beveling for a specific category of framing timbers (e.g., floor timbers, first futtocks) consistent for both forward and after frames (Chapelle 1969:135–136; Pardey 1991:95). Cutting standing bevels necessitates projecting the angle of the bevel beyond the curve, and this requires greater accuracy in the predetermination of the bevel angles. Under beveling is simpler because it entails the removal of wood relative to the curve that is drawn out on a framing timber. Drawing the frame shapes on the open face of the timbers oriented toward amidships would allow for the under beveling of these timbers.

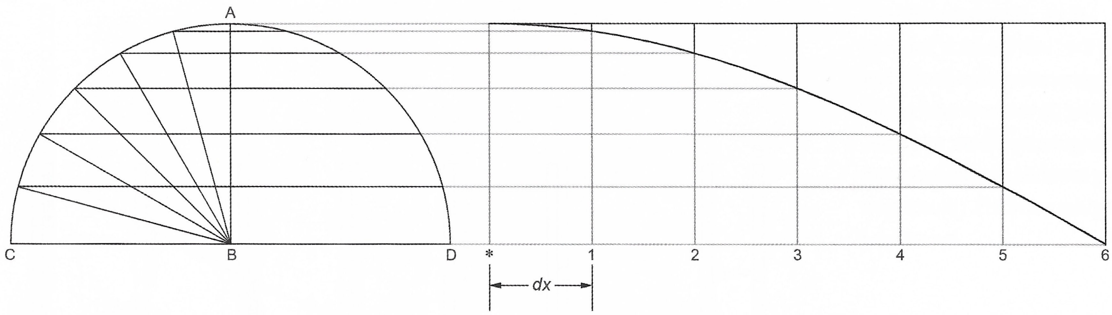
With double framing, the problem with beveling from the open face is that this entails projecting the bevel across two layers of timber. As a result, there is less assurance that the backing timbers will have exactly the correct shape unless the beveling is extremely accurate. For this reason, in some shipbuilding traditions of the seventeenth century and in most by the eighteenth and nineteenth centuries, using the adjoining face for laying out the frames was preferred (Barker 1994:21–22; Murray 1765:165–174; Wilson 1873:145–147). Nonetheless, the characteristics of the beveling of frame *VIIIIA* suggest that, at least in the case of *La Belle*'s surmarked frames, the labeled faces of the floor timbers and second futtocks were used as a drawing plane. While the treenails are centered on the after labeled faces of the floor timber and second futtock of frame *VIIIIA*, they get progressively closer to the outboard edge the further forward they penetrate into the frame timbers. As Figure 6.14 shows, the treenails break out on the outboard surface of the first futtocks quite close to what would be the adjoining face. If the shipwright had drawn the frame curve on the adjoining face and laid out the bevels relative to it, the fastenings would have been more centered on this face.

The interrelationship of framing patterns, beveling, and design planes still needs to be further explored in the case of *La Belle*, as well as in the history of ship construction in general. Therefore, for the study of *La Belle*'s design, frame shapes were reconstructed at both the adjoining and open faces of the floor timbers and second futtocks, but in the final drawings for this chapter, only the sections along the labeled and surmarked faces are depicted.

Diagonal Planes and Framing Timbers

As is shown in Figure 6.20e, at this stage in the design of the hull the frame spacing is already established, but this only provides locations for evenly spaced design planes with no additional data as to the curvature of the hull. It is the diagonal lines *fb'* and *fa* in the body plan (Figures 6.27f, 6.28b) that conceptually define longitudinally oriented inclined planes on which curves can be drawn from the midship station to the ends of the vessel (Figure 6.20f). Although sharing a common point on the midship frame curve, the forward and after components of *La Belle*'s diagonals and the planes they define have different inclinations from the horizontal. These differences in inclination reflect the designer beginning to differentiate the curvature between the forward and after parts of the vessel. The established frame spacing can be used to subdivide these inclined planes into evenly spaced increments as in Figure 6.20g. It is possible at this point to conceive the plotting of offsets for longitudinal curves on these subdividing lines. Of course, *La Belle*'s design was not developed in an isometric drawing therefore the real "secret" to the design process was how the diagonals were subdivided in the two-dimensional body plan.

Shipbuilding documents and treatises from the fifteenth century to the eighteenth century reveal that various geometric and arithmetic methods of generating



6.31. Geometric construction known as the mezzaluna for generating offsets for a curve. (Illustration by author.)

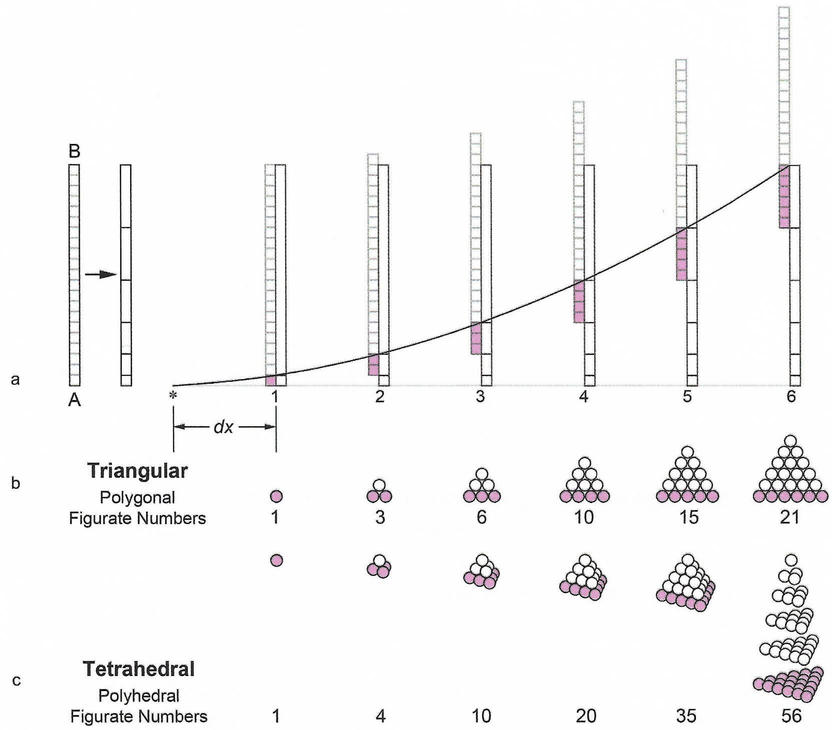
offsets for longitudinal curves played a central role in the quantification of hull curvature. Figure 6.31 illustrates the *mezzaluna*, or half-moon, one of the oldest and best known of these techniques. It first appears in notes on Italian shipbuilding from the fifteenth century (Trombetta [1445]:fol. 45r), and archaeologist Éric Rieth deduced its use in the design of the Culip VI vessel, the remains of which date to the late thirteenth or early fourteenth century and were discovered off the Catalan coast (Rieth 1996:149–164). To create a mezzaluna, a half circle is drawn with a radius, *AB*, equal in length to the final and largest offset (Figure 6.31). The perimeter of each quarter circle is then evenly divided into as many parts as the number of offsets desired. The corresponding points on each quarter circle are then joined with straight lines that are parallel to the baseline *CD* and intersect line *AB*. The distances from the apex, *A*, to each of the points of intersection gives a progression of offsets for a curve. Note that the mezzaluna method is purely a geometric construction with no arithmetic involved in generating the offset distances.

Figure 6.32 and Figure 6.33 illustrate two types of similar arithmetic offset sequences, and Figure 6.32 also depicts a simple mechanical procedure for generating them. Bartolomeo Crescentio presents such a mechanical method of marking offsets on one staff with the aid of another, the Neapolitan "infinite stick" technique, in his 1602 book on shipbuilding, *Nautica Mediterranea* (Bloesch 1983; Crescentio 1602:21–22; Sarsfield 1984).

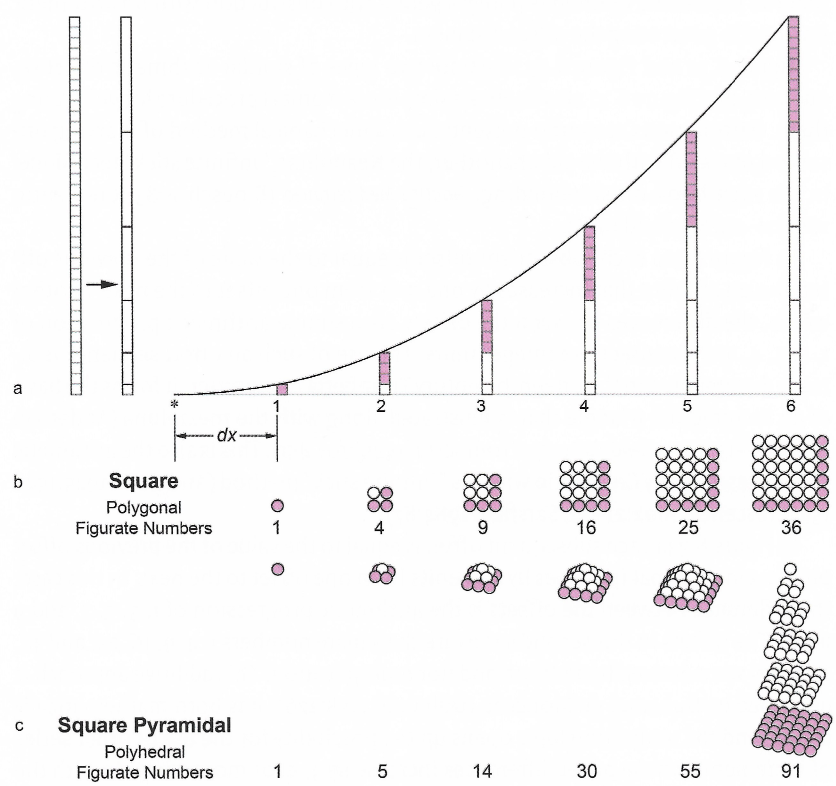
In Figure 6.32a each subsequent offset is equal to the value of the previous offset plus an amount that increases by one unit from one offset to the next. In other words, the differences between the offsets are a simple arithmetic progression of 1, 2, 3, 4, and 5 consecutive integer units. The use of such an offset sequence is already documented in the fifteenth-century Trombetta manuscript; it forms the basis of an incremental triangle that is illustrated along with the mezzaluna (Anderson 1925:153–154; Sarsfield 1984:87; Trombetta [1445]:fol. 45r). This is also the arithmetic series presented by Crescentio with his "infinite stick" method (Anderson 1925:153–154; Crescentio 1602:21–22; Sarsfield 1984:87).

In Figure 6.33a each subsequent offset is equal to the value of the previous offset plus an amount that increases by two units from one offset to the next. In this case, the difference between the offsets is the arithmetic progression of 1, 3, 5, 7, and 9 units. The offsets in this second series are the square numbers 1, 4, 9, 16, 25, and 36, but they were derived by addition and not multiplication. This additive approach is described by Duhamel du Monceau (Duhamel 1758:226); it is both mathematically simple and the underlying logic opens up the possibility for the use of other series of increments whose offset differences increase by 3, 4, or more units. As with the two series in Figure 6.32a and Figure 6.33a each series would yield a slightly different curve (Figure 6.34).

The study of such sequences of numbers (i.e., the numeric values of the individual offsets) dates back at least to the time of Pythagoras (Boyer 1985:59–60). Figure 6.32b and Figure 6.33b illustrate how these numbers, known as figurate numbers, are associated with polygonal geometry. The series in Figure 6.32a is actually a sequence of triangular numbers (Figure 6.32b), and the series in Figure 6.33a is a sequence of square numbers (Figure 6.33b). The amount added to transform one figurate number to the next in the series (the pink circle arrangements) is known as a *gnomon*.

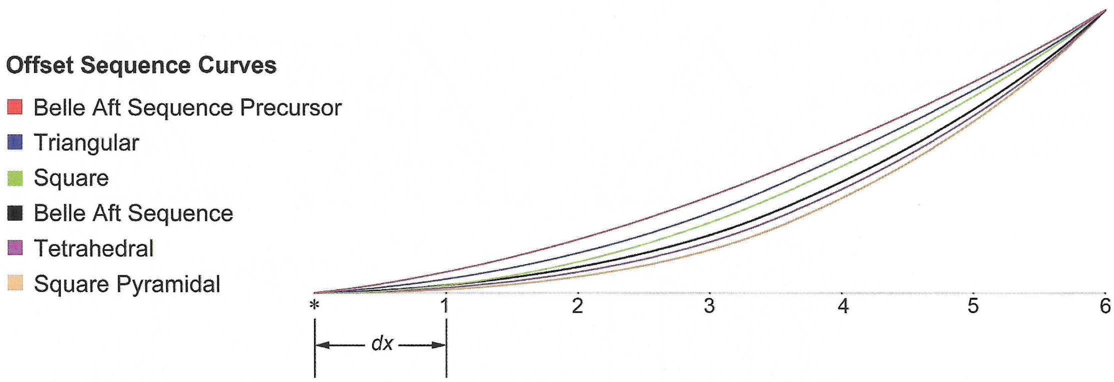


6.32. Generating offsets: (*a*) the "infinite stick" method of generating a series of offset values; (*b*) values produced are triangular numbers; (*c*) generating tetrahedral numbers from triangular numbers. (Illustration by author.)

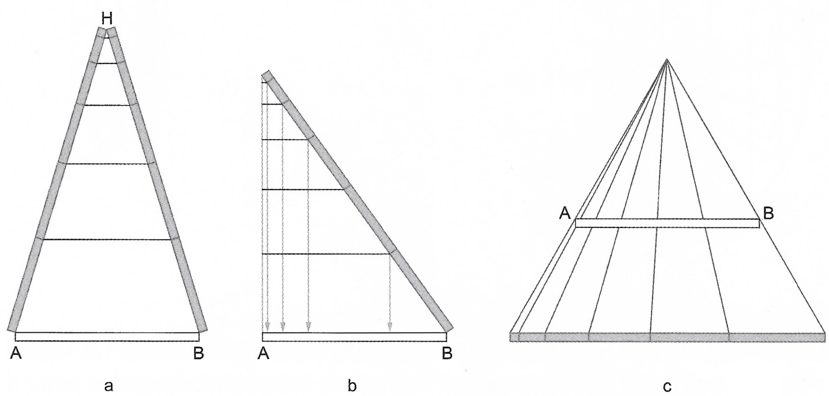


6.33. Generating offsets by addition: (*a*) illustration of addition process; (*b*) resulting series of square numbers; (*c*) generating square pyramidal numbers from square numbers. (Illustration by author.)

It is critical to the discussion of ship design to emphasize that these sequences of numbers or increments only become offsets for curves when they are plotted on parallel lines, known as *ordinates*, at equally spaced intervals (*dx* in Figures 6.31, 6.32a, 6.33a) along a common baseline or axis. The equally spaced subdividing lines on the diagonal plane in Figure 6.20g provide such ordinates for plotting curve offsets for the vessel's design. During actual construction, the equidistant positioning of the design frames themselves achieves the same result in real world, three-dimensional space.



6.34. Comparison of the various curves resulting from polygonal and polyhedral offset sequences and the variations reconstructed for *La Belle*'s aft offsets. (Illustration by author.)



6.35. Scaling triangles. (Illustration by author.)

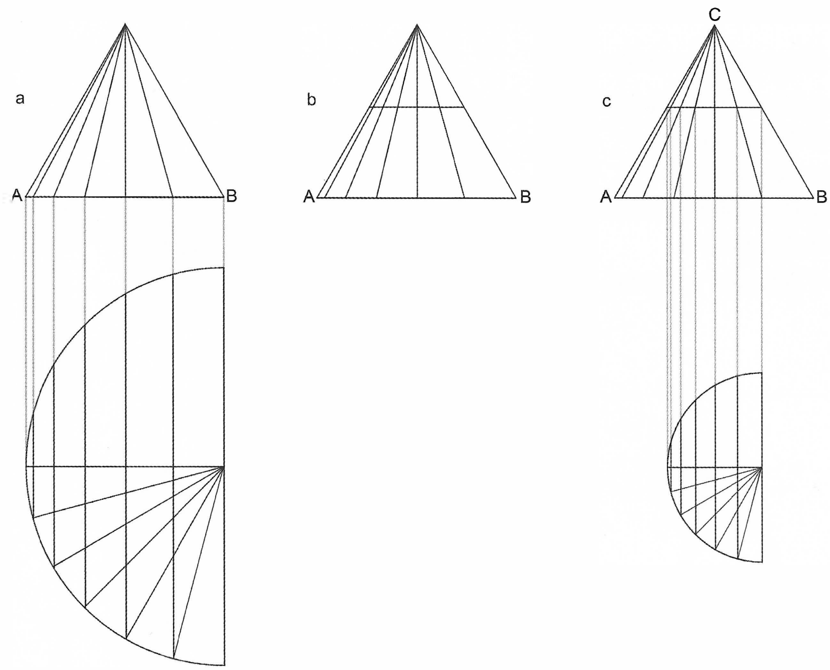
Scaling Triangles

Before discussing how such offsets were incorporated into the design of the ship, it is necessary to address the practical matter of scaling an offset sequence to subdivide any specified length or dimension. With the mezzaluna method the length of the largest offset, *AB*, is the starting point of the procedure; with the arithmetic series the length of the final offset is dependent on the size of the starting base unit. Therefore, for the final distance to correspond to a desired length, *AB* in this case, it has to ultimately be equal to the number of subunits corresponding to the specific arithmetic series being used (21 in the case of Figure 6.32a and 36 for Figure 6.33a). For this reason, Crescentio's first step in creating such a series of offsets is to subdivide a staff equal in length to the desired final offset into the necessary number of subunits. This staff is then used to mark off the offset staff. Unfortunately, in his description of the "infinite stick" method, Crescentio does not state how this is done.

This task could be accomplished by trial and error, stepping off various distances with a pair of dividers until getting the correct number of subdivisions. However, by the time of *La Belle*'s construction in the last quarter of the seventeenth century, various methods and devices had already been developed with which to scale any series of measurements. Figure 6.35 depicts two basic types of scaling triangles that are based on the geometric principle that similar triangles maintain a proportional relationship between the lengths of their corresponding sides. For these examples the scale from Figure 6.33a was used. It is marked with an offset sequence of square numbers and has the same size base unit as the triangular number series in Figure 6.32a. However, any size base unit such as a centimeter, inch, or an arbitrarily chosen distance could have been used to create this starting scale.

In Figure 6.35a two such scales are used to create a triangle with a base that is made equal to the length of the largest offset, *AB* in this case. The lengths between corresponding divisions on the two arms provide proportionally scaled down offsets for dividing the distance *AB* by a sequence of square numbers. The scaling triangle in Figure 6.35b operates essentially on the same principle and clearly shows how the resulting offsets subdivide *AB*. The advantage of the first variation is that there is no need to project any lines. In fact, from the last years of the sixteenth cen-

6.36. A scaling triangle can be used to proportionally enlarge or reduce any type of increment progression. (Illustration by author.)



tury through the mid-nineteenth century, a variety of scaling tools known as sectors were invented based on the concept of having two scaled rulers hinged at point *H* (Figure 6.35a) (Hambly 1988:135). For example, Galileo Galilei describes the sector he developed (1597–1599) in his 1606 pamphlet *Le Operazioni del Compasso Geometrico et Militare* (Boyer 1985:351–352; Hambly 1988:135; Sarsfield 1984:88). While Mungo Murray in his *Treatise on Ship-building and Navigation* (1765) specifically describes the use of the sector (the tool) in ship design (Murray 1765:106–109, 129–130, 146–153, 176–178), the incremental triangle illustrated in the fifteenth-century Trombetta manuscript is such a graphic scaling triangle (Trombetta [1445]:fol. 45r).

Figure 6.35c illustrates a different variation of a scaling triangle that appears in François Coulomb's draft from 1684 (Figure 6.7). As with the other scaling triangles, the two depicted in this draft do not themselves generate the starting offset series. To draw such a triangle, a baseline is divided by offsets for a curve that were already determined in some other way. This set of offsets is referred to as the "mother sequence." In Figure 6.35c the same starting scale is used as in the previous examples. An equilateral triangle is then drawn with the starting scale as the baseline. Rays are then drawn from the apex of the triangle to each of the subdivision points on the baseline. Any line drawn parallel to the baseline, such as *AB* from the previous examples, is subdivided by the rays proportionally to the original mother sequence. Figure 6.36a–c with a mezzaluna mother sequence shows that such triangles can be used to scale any series of increments whether they are originally arithmetically or geometrically generated.

Subdividing the Diagonals

As is shown in the Toulon flute draft (Figure 6.7), using a scaling triangle makes the procedure for subdividing the diagonals in the body plan with a series of offsets amazingly simple. The length of a diagonal is plotted as a horizontal line on the equilateral triangle with its two endpoints on the two outside rays. The increments into which the other rays divide the line are then transferred back onto the diagonal in the body plan. Each of the resulting points on the now subdivided diagonal indicates the point of intersection with a frame. When the process is repeated for all the diagonals, the designer almost "magically" has a series of guide points for drawing each of the predesigned frames. In the Toulon flute draft the lengths of diagonals *AA*, *BB*, *CC* and *BB*, *AA*, *LL* are shown superimposed on two equilateral triangles (Figure 6.7).

In the Toulon flute draft two separate triangles are used to subdivide the diagonals before and abaft amidships. The two triangles are based on different sequences of increments. By using the same type of sequence for all the diagonals to either side of the midship frame, the designer assures that the curves defined by them will have common characteristics and thus define a fair hull shape. The isometric drawings in Figure 6.20h–k illustrate how the process of subdividing a diagonal in the body plan both defines the offsets for a longitudinal curve and also provides a guide point on each of the transverse frame planes through which the curved shape of the frame will be drawn—the circled point in Figure 6.20k.

The true shape of the longitudinal curve defined by the offsets on a diagonal can only be depicted if drawn from a viewpoint perpendicular to the diagonal plane. Such auxiliary views are used in modern ship drawings. However, in the Toulon flute draft, as in the other seventeenth-century drafts, the diagonal curves are shown as they would appear when viewed from above and the sides of the vessel (Figures 6.7, 6.18, 6.19; for *La Belle* see Figure 6.8). In these views, any one diagonal is broken up into its narrowing (y) and rising (z) components (Figure 6.20l). The spacing of the frame design planes provides the equivalent of the x-coordinate for both the narrowing and rising curves. By first identifying the plane of each diagonal in the body plan, the French ship designers were able to define the y (narrowing) and z (rising) coordinates in each frame plane with one set of curve offsets. Formal Cartesian coordinates do not appear in these drafts, nor is ship design presented within the context of coordinate geometry in shipbuilding treatises. However, it must be appreciated in terms of the history of design that shipwrights were using elegant concepts of three-dimensional mathematical curve plotting in order to achieve their very utilitarian goals.

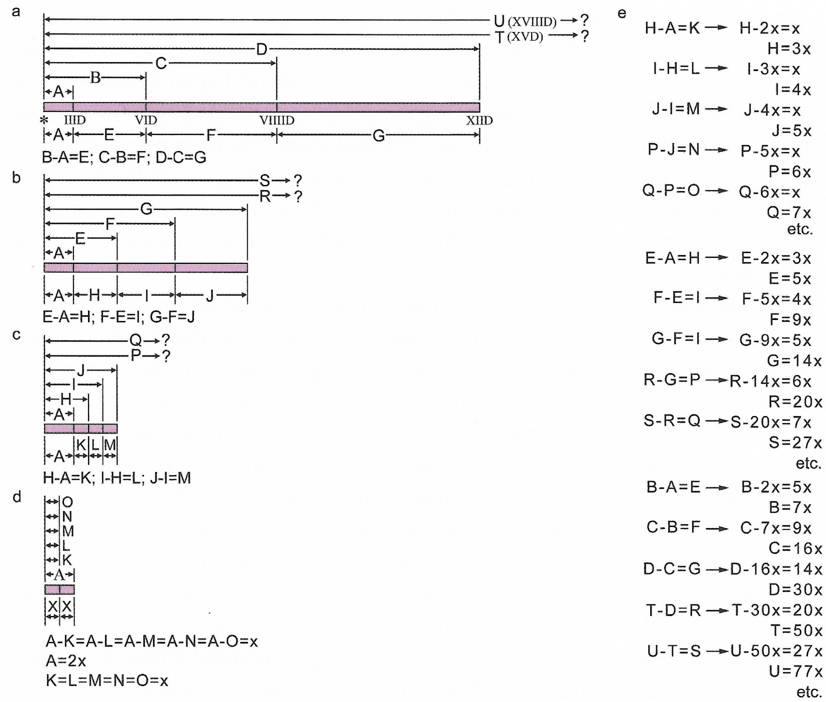
La Belle's *Mother Offset Sequence*

La Belle's archaeological surmark evidence for diagonals subdivided with curve offsets conforms to what is depicted in the Toulon flute draft. However, identifying *La Belle*'s mother sequence and reconstructing its equilateral triangles would greatly strengthen such an association.

The archaeology provides offset lengths from the midship frame to each surmarked frame position along two diagonals both forward and aft. These offset distances are evident in the reconstructed body plan of the superimposed remains of *La Belle*'s surmarked frames (Figure 6.5a, b). These archaeological offset sequences were compared with various different offset sequences known to the author from shipbuilding treatises and from the work of other researchers to "crack the code" of *La Belle*'s mother sequence. Ultimately, the one additional offset value for the frames abaft amidships as well as insights gained from Duhamel du Monceau's treatise helped yield some promising results.

Observe that the curve defined by the offsets along *La Belle*'s after floor diagonal has the same general shape as the curves of polyhedral figurate numbers (Figure 6.34). Polyhedral figurate numbers result from adding successive polygonal numbers. For example, in Figure 6.32c, a sequence of tetrahedral (triangular pyramidal) numbers was generated using the triangular numbers from Figure 6.32b. Knowledge of polyhedral numbers dates back at least to classical antiquity (Boyer 1985:60), and both triangular and tetrahedral numbers appear in Pascal's triangle. French mathematician Blaise Pascal describes the properties of such a number triangle in his 1653 treatise *Traité du triangle arithmétique* (Pascal 1665), but the triangle itself had already been known for at least 600 years and appeared in print for the first time in the West in 1527 (Boyer 1985:327–328, 397–398). Thus by the time of *La Belle*'s construction, knowledge of such number series would have been fairly widespread in mathematical circles, and the evidence from *La Belle* suggests that it may have been known in shipbuilding circles as well.

Since the offsets for such arithmetic curves can be generated by addition, *La Belle*'s archaeological offset distances were subjected to a simple subtractive analysis. This entails geometrically subtracting each offset distance from the previous one and then superimposing these differences on a new line (Figure 6.37). After two rounds



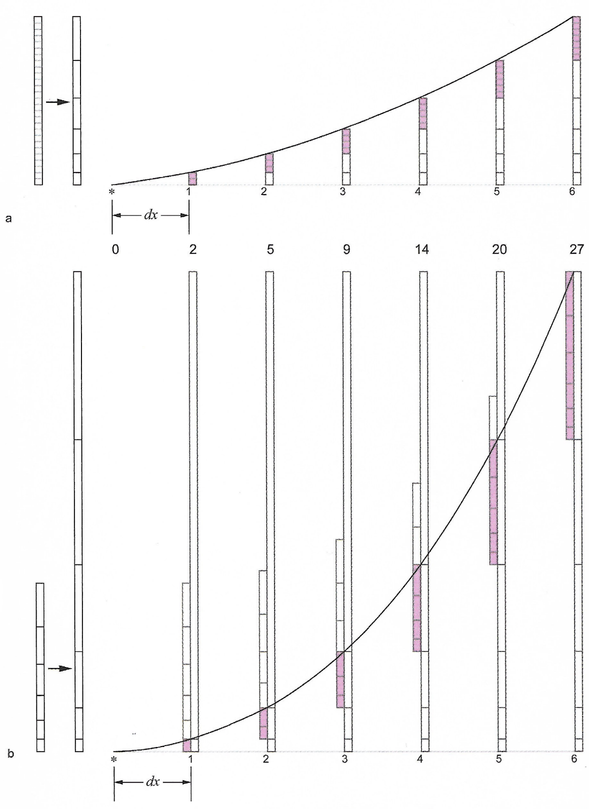
6.37. A simple subtractive method for analyzing offset increments to determine if they are related to "figurate number" offset sequences. (Illustration by author.)

of subtraction (a–b and b–c in Figure 6.37) a terminal sequence is reached in which the first increment is two units (2*x*) and each subsequent increment is one unit (1*x*) (Figure 6.37c, d). Reversing the process by switching back to addition generates the following unit values for *La Belle*'s archaeologically documented offsets: * = 0*x*, *IIID* = 2*x*, *VID* = 7*x*, *VIIIID* = 16*x* and *XIID* = 30*x*. This process also predicts the offset values of 50*x* for *XVD* and 77*x* for *XVIIID* (Figures 6.37e, 6.38a, b). The equilateral scaling triangle in Figure 6.39 was constructed with the resulting mother sequence of 0*x*, 2*x*, 7*x*, 16*x*, 30*x*, 50*x*, 77*x*.

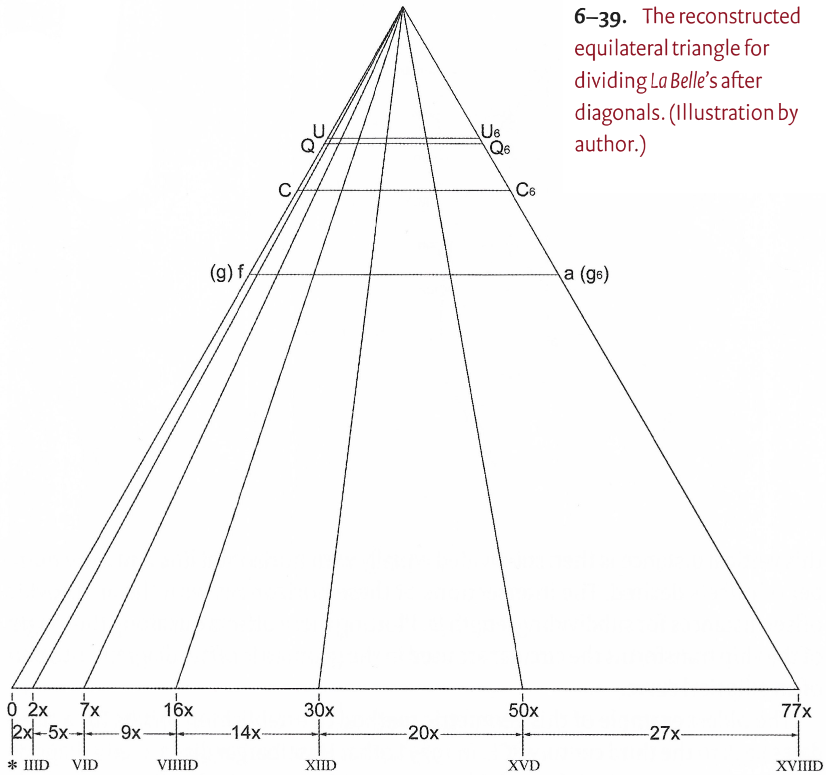
In Figure 6.40a this equilateral triangle is superimposed on the after floor diagonal in the cross-sectional drawing of *La Belle*'s frames. Maintaining the base of the triangle parallel to the diagonal the triangle was shifted until each of the frame sections aligned with the corresponding offset ray. In this orientation the final ray predicted for *XVIIID* corresponds exactly with the upper endpoint of this diagonal (Figures 6.20h, 6.40a). Since the upper endpoint was established prior to the "discovery" of the mother offset sequence, this correspondence supports the validity of the sequence itself.

The mathematical logic of generating this sequence is an expansion on the ideas of figurate numbers—specifically the idea that one sequence (polygonal numbers) can be used to generate another (polyhedral numbers). However, the starting increment in the terminal series above is double the next value, thus it deviates from regular figurate geometry (Figure 6.38). Unfortunately, no discussion has been found of such more complex arithmetic sequences in any shipbuilding treatise. The lack of corroborating documentary evidence does not mean such sequences were not used, but it did motivate continued searches for known historic methods that might yield a similar set of offsets.

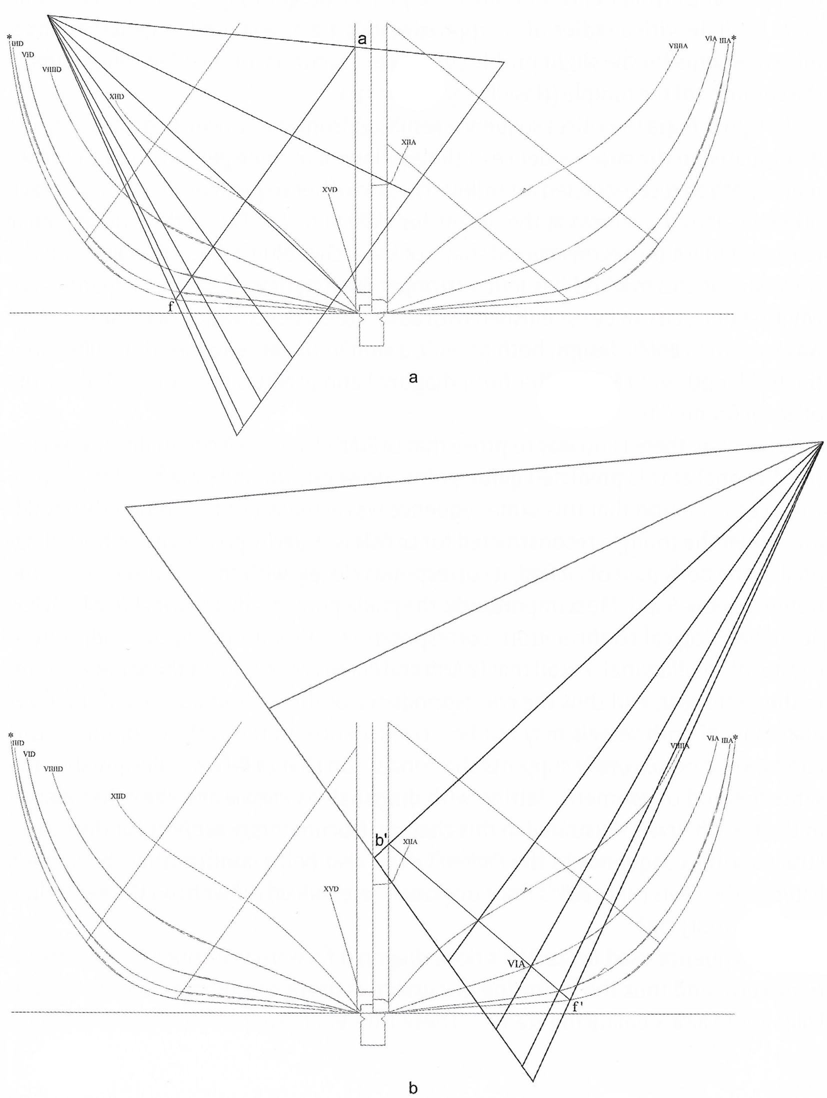
In *Traité du Navire*, published in 1746, Pierre Bouguer presents another geometric method of generating offsets for diagonals known as the method of convexity of arcs (Boudriot 1994:42–43; Bouguer 1746:44–46, Pl. 2, Figures 10–12; Duhamel 1758:xxix, 260). Using this method, an arc of a circle is drawn with a radius that is some multiple of the length of the diagonal. The length of this radius is established at the discretion of the designer (Bouguer 1746:45), and its length reflects how much "fullness" is desired in the final shape of the curve. For *La Belle*'s offsets along the after floor diagonal, a reconstructed radius of 3.5 times the length of the diagonal *fa* was used (Figure 6.41a). A perpendicular is then extended from point *a* to the arc, and



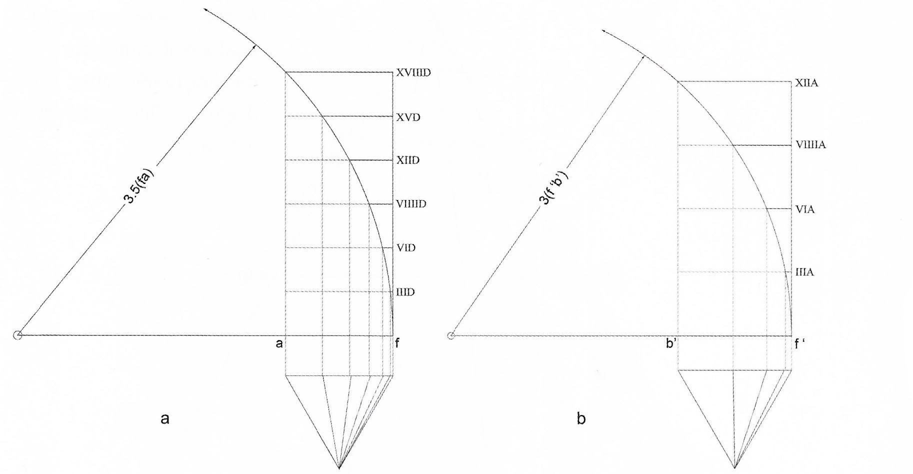
6.38. The values and curves for the two stages (*a*, *b*) of the additive method used to reconstruct *La Belle*'s after diagonal offsets. (Illustration by author.)



6–39. The reconstructed equilateral triangle for dividing *La Belle*'s after diagonals. (Illustration by author.)



6.40. The reconstructed triangle from Figure 6.39 superimposed on the body plan of *La Belle*'s framing remains: *(a)* the floor diagonal abaft and *(b)* before the midship frame. (Illustrations by author.)



6.41. Historically documented French method for generating curve offsets using arcs of circles with radii that are multiples of the lengths of the diagonals. In these figures they are compared to the reconstructed triangles for *La Belle*'s *(a)* after and *(b)* forward diagonals that are based on an arithmetic sequence. (Illustrations by author.)

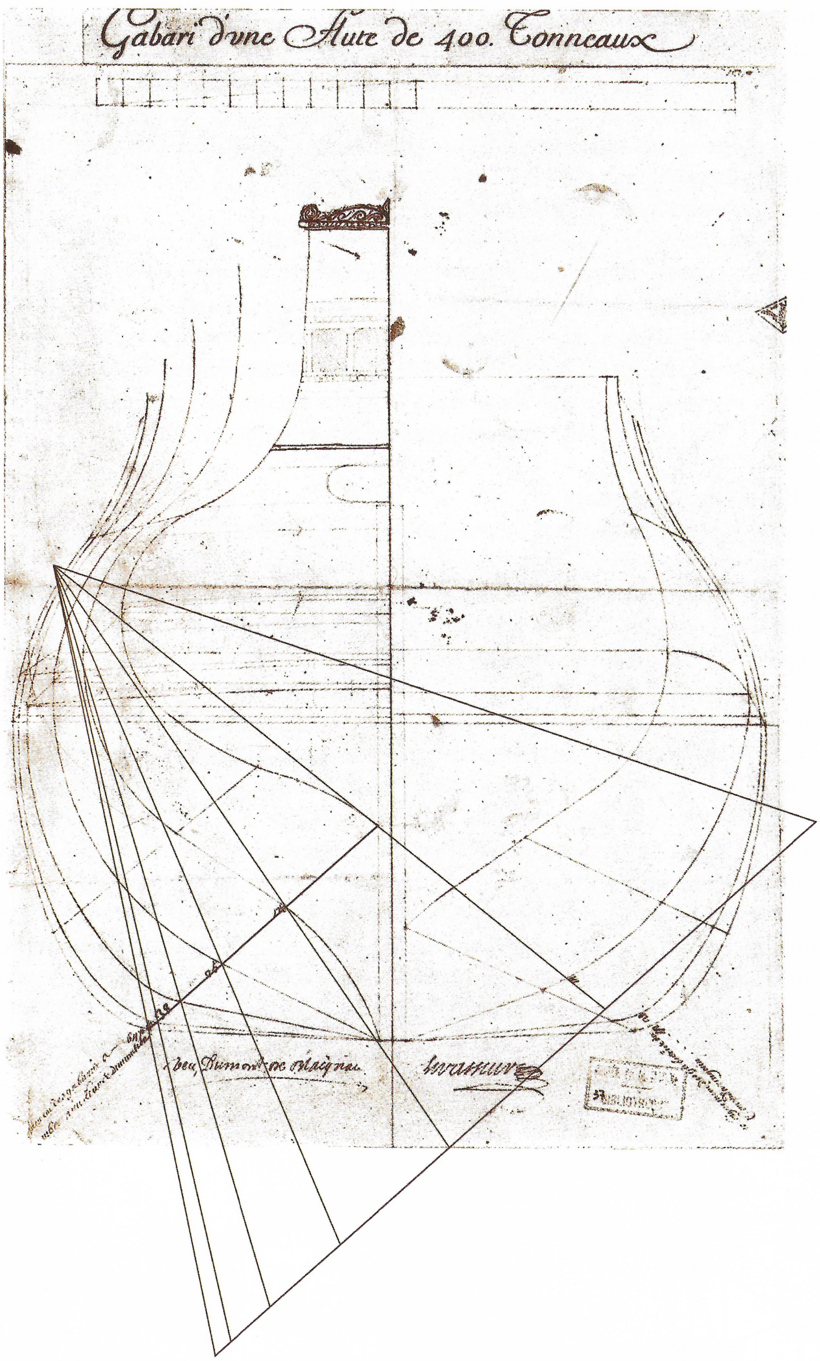
this vertical distance is then subdivided equally with horizontal lines into the number of offsets desired. The intersections of these horizontals with the arc provide offset distances for subdividing length *fa*. Plotting these offsets out along the length of the ship transforms the circular arc used in the geometric offset diagram into part of an elliptical curve.

The oldest example of this geometric method of establishing offsets for a curve dates back to the third century BCE. In 1979 Lothar Haselberger discovered a diagram based on the same principles etched onto one of the unfinished walls of the Temple of Apollo at Didyma in present-day Turkey (Haselberger 1985:130, 131). In this diagram, a circle with a radius of an approximately 3.2 m was used to generate offset measurements for the slight profile curvature, or entasis, of the 18 m long shafts of the columns of the temple (Haselberger 1985:131).

In Figure 6.41a the offset sequence resulting from the convexity of arcs method is compared to the base sequence of the equilateral triangle generated by the arithmetic method reconstructed for *La Belle*. The two offset sequences are similar to each other, deviating the most at the offsets for *VIIIID* and *XIID*. The arithmetic sequence is a better fit for the reconstructed shape of the archaeological hull remains, but the convexity of arcs method has much stronger documentary parallels. Regardless of whether or not it can be established with absolute certainty which of these methods was used in *La Belle*'s design, both provide a similar offset sequence that subdivides the full length of *La Belle*'s after floor diagonal and predicts the same value for the offset at frame *XVD*.

Of course, there is no way to prove that *La Belle*'s frame *XVD* originally intersected the diagonal at this predicted guide point. However, the 1684 draft of *Profond* provides confirmation that this same sequence was actually used in French shipbuilding. When the triangle reconstructed for *La Belle* is superimposed on the floor diagonal in the body plan of *Profond*, it corresponds closely with the intersections of the frames (Figure 6.42). Most importantly, the guide point predicted for *XVD*, which has no archaeological confirmation, corresponds exactly with the upper endpoint of *Profond's* floor diagonal. Recall that *La Belle* and *Profond* were built in the same shipyard in the same year, and thus the correspondence of the after sequences of the floor diagonals of both vessels may not be a coincidence. In the author's opinion, this correspondence strongly supports the conclusion that *La Belle* was designed by the same method of geometric fairing with diagonals as *Profond* and the other vessels in the French drafts illustrated in this chapter. Documentary support for the reconstructed offset sequence in the *Profond's* draft also helps confirm that the heights listed in the devis for *La Belle*'s floor diagonal were indeed offset from the centerline 4 inches (10.83 cm).

The sequence used for *La Belle*'s floor diagonal forward was much more difficult to discern, and thus the following discussion is more speculative. Frames *VIA* and *VIIIID* are *La Belle*'s balancing frames. These timbers have the same width between



6.42. The reconstructed triangle from Figure 6.39 superimposed on the after floor diagonal in the *Profond* draft from 1684 (Figure 6.6). (Illustration by author.)

their floor timber surmarks. Having subdivided the after floor diagonal, *La Belle*'s designer could determine at what point the curve for frame *VIA* would have to intersect with the floor diagonal to have the same width as *VIIIID*. This would give the designer three points along the length of the floor diagonal forward—the two endpoints and the point for *VIA*. These points would then be marked on the edge of a piece of paper—for this discussion represented by line *f′b′* in Figure 6.40b. This line is then positioned on the equilateral triangle at such an angle that these three points fall on the appropriate rays, and the intersections with the intervening rays provide the guide points for frames *IIIA* and *VIIIIA*. The guide points thus obtained correspond exactly with the archaeologically documented intersections of frames *IIIA* and *VIIIIA* with the floor diagonal (Figure 6.40b). The same basic procedure for establishing the offsets for the forward floor diagonal is described by Duhamel du Monceau (Duhamel 1758:246–248). This procedure highlights another aspect of the utility of the equilateral scaling triangle. By adjusting the angle at which the diagonal is placed on the triangle, it is possible to alter the characteristics of the resulting curve while still remaining within the same family of curves defined by the mother sequence.

The convexity of arcs method was experimented with to see if a similar set of offsets could be generated. Using a radius three times the length of the diagonal results in a similar sequence, although in this case with a fairly large deviation at *IIIA* from the arithmetically generated sequence (Figure 6.41b).

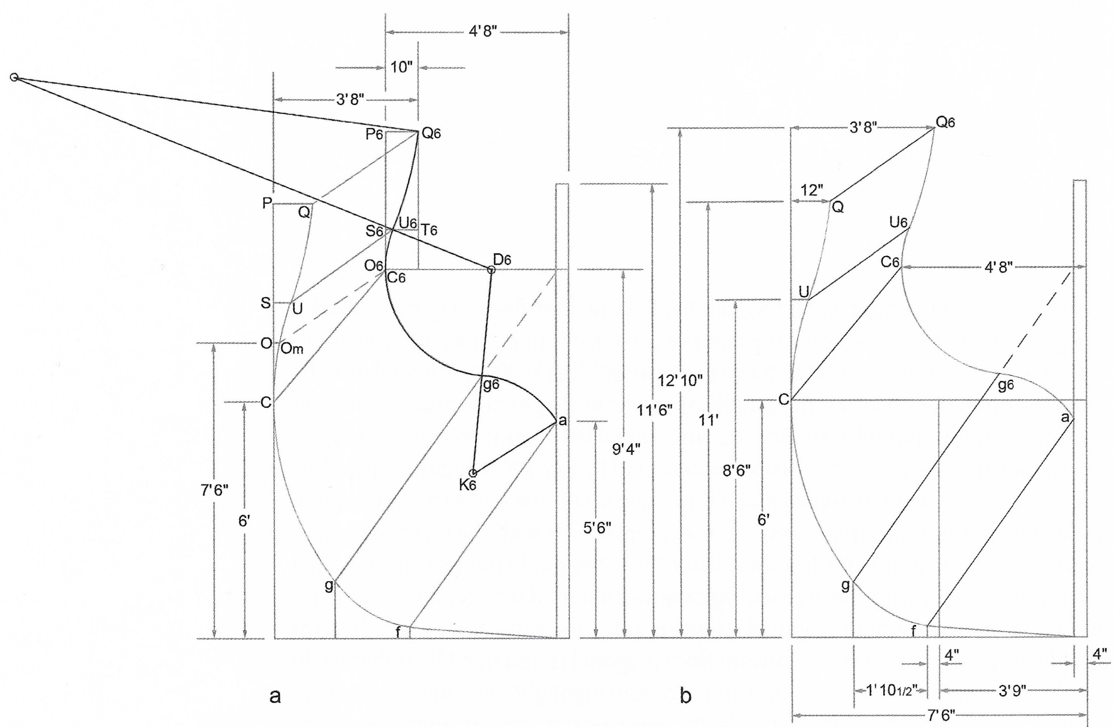
Figure 6.20m–o shows how the offsets established on the forward diagonal in the body plan define the forward part of the longitudinal floor curve; the curvature abaft the midship station was already established with the after floor diagonal offsets. The dark short lines or tick marks projecting from the floor curve in Figure 6.20o correspond to surmarks. The archaeologically documented floor timber surmarks are not only found at these exact locations but are also carved at the same angles of inclination as the diagonal planes in this drawing.

All the After Diagonals

The next step in the design sequence is to establish additional diagonals in the body plan for defining the hull shape above the floor diagonal. The reconstructed design of the hull abaft amidships, in comparison to the hull forward, is much more definitive. Therefore, it will be presented first and in greater detail to illustrate the concepts of the rest of the overall design procedure.

In the stern only the floor diagonal terminates on the centerline timbers. In fact its 5 ft 6 inches (1.79 m) height, as listed in the devis, establishes the height of the top of the deadwood knee and the bottoms of the fashion pieces of the stern (Figures 6.10, 6.20p, 6.28b, 6.30). The endpoints for all the other diagonals are located on the fashion pieces at frame position *XVIIID* (Figure 6.43). For the purposes of design, the fashion pieces are treated as vertical frames, although in the constructed vessel they are actually tilted slightly aft.

The second set of surviving surmarks provides the orientation of the next diagonal above the floor diagonal. Since this diagonal has the same offset values as the floor diagonal, its stern endpoint could be tentatively established. The devis provides several measurements for establishing the endpoints of two more diagonals in the stern. These endpoints also serve as guide points for drawing the shape of



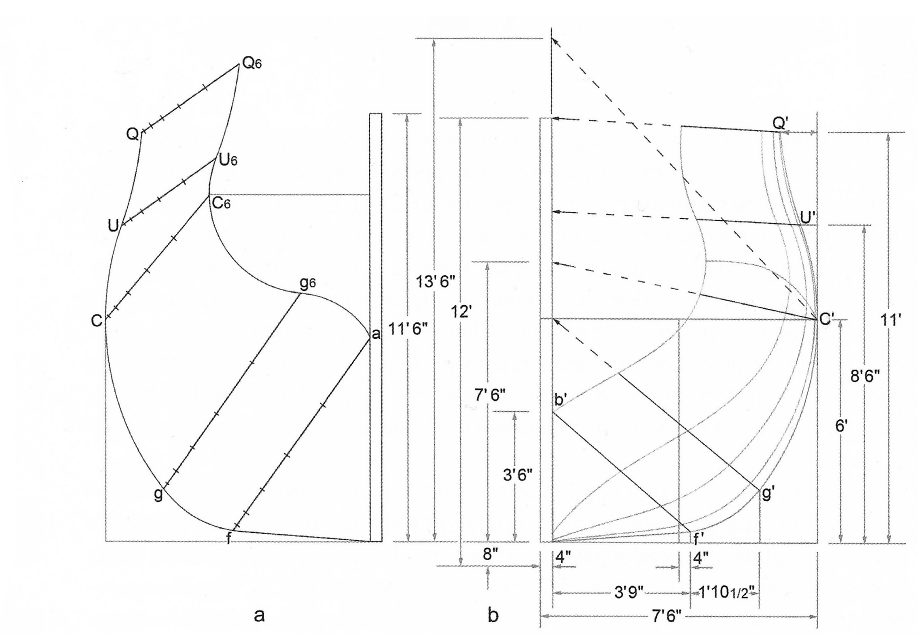
6.43. Reconstruction of the design of the fashion pieces: *(a)* at frame position *XVIIID*; *(b)* this allows for the reconstruction of all of the after diagonals. (Illustrations by author.)

the transom. The 9 ft 4 inches (3.03 m) height of the maximum breadth in the stern listed in the devis corresponds to the height of the transom beam, and the width of the transom beam is listed as 9 ft 4 inches (3.03 m) as well. The only other measurement in the devis relevant to reconstructing the transom is 3 ft 2 inches (1.03 m) given for the tumblehome in the stern. Unfortunately, as in the case of the height for the tumblehome at the midship frame, the devis does not provide a measurement for the total height of the transom. However, by applying the same approach and drawing procedures that were used in reconstructing the lower and upper parts of the midship frame, several variations of the transom were reconstructed. The differences between these transom reconstructions are minor, and the one used for the rest of the design is presented in Figure 6.43a. In this reconstruction, an additional 6 inches (16.24 cm) were added to the tumblehome to adjust for the 15 ft (4.87 m) reconstructed breadth versus the 14 ft (4.55 m) given in the devis. The theoretical reconstruction of *La Belle*'s transom (Figure 6.43a) combined with the midship frame reconstruction allows for the following diagonals to be drawn: floor diagonal *fa*, upper bilge diagonal gg_6, maximum breadth diagonal CC_6, topsides recurve diagonal UU_6, and the main sheer diagonal QQ_6 (Figures 6.20p, 6.43b).

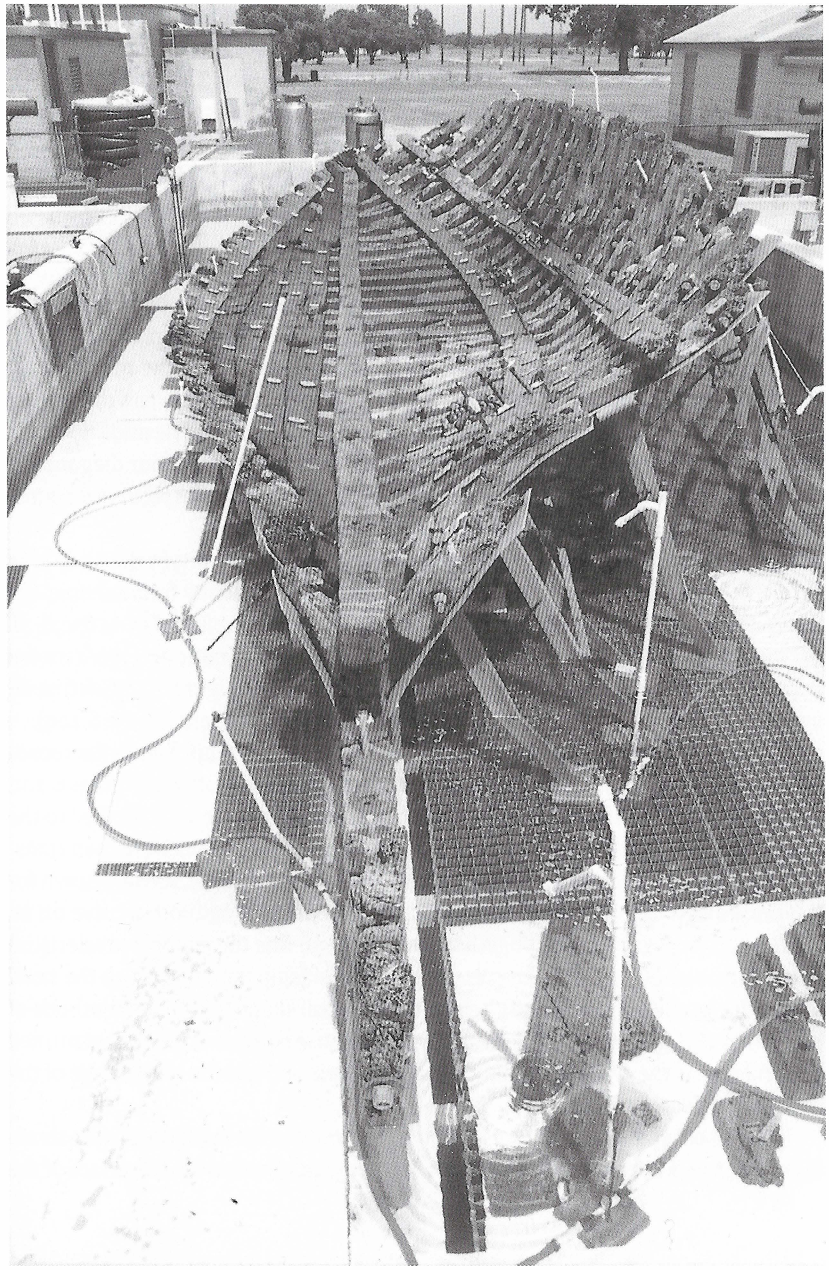
It cannot be overemphasized that these diagonals are straight in the body plan simply because they are drawn as such prior to plotting out any frame shapes between the midship frame and the ends of the vessel. For example, in Figure 6.43b, all of *La Belle*'s after diagonals are drawn with only the midship frame and the transom depicted. Conceptually all these diagonals in the body plan (Figure 6.20p) define diagonal planes from the midship frame to the transom in the stern (Figure 6.20q).

With *La Belle*'s after diagonals defined, their lengths can be applied to the reconstructed equilateral triangle in order to mark them with curve offsets (Figures 6.20r, 6.39). All of *La Belle*'s after diagonals, as in the Toulon flute draft, were applied to the equilateral triangle parallel to the baseline. The offset increments were then transferred onto the diagonals in the body plan (Figures 6.20r, 6.44a). As was shown for the floor diagonal, the offsets of each diagonal define a longitudinal curve on an inclined plane (Figure 6.20s). Together these curves define the major characteristics of the curvature of the side of the vessel abaft the midship frame, in much the same way as the longitudinal ribbands help define the hull shape in ribband methods of construction (Figure 6.15a–c). The difference of course being that *La Belle*'s quantified ribband plan is the central part of the design process and not the initial stage of the construction sequence.

In the sheer plan of the Toulon draft, the longitudinal curves of the diagonals are literally represented as wooden ribbands defining actual curves on the surface of the



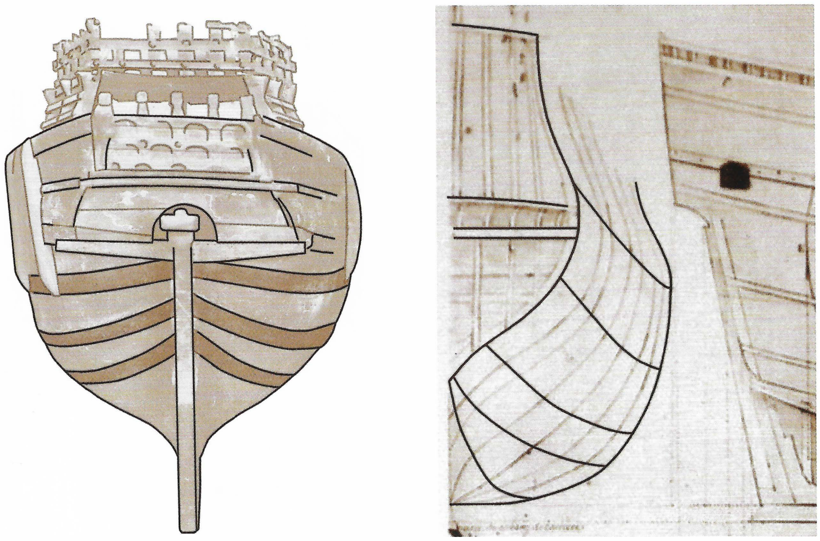
6.44. All of *La Belle*'s reconstructed design diagonals: *(a)* the after diagonals are shown subdivided into increments for the design frame guide points; *(b)* one of the variations of the reconstructed design frames before amidships. (Illustrations by author.)



6.45. View from the stern of *La Belle*'s reassembled hull. The two notched stringers visible on the starboard side basically follow the curves defined by the surmarks. (Photo by author.)

hull (Figure 6.7). In terms of design, this indicates a clear conceptual link between a two-dimensional graphic entity, the diagonal, and a three-dimensional object, the ribband. In *La Belle*'s construction, this interrelationship between lines of design and actual timber curves is also apparent in the hull structure. Two hull strakes as well as two ceiling strakes essentially follow the same curves as *La Belle*'s two bilge diagonals. The two ceiling strakes are stringers, easily distinguishable from the others because they are notched for the frames. There is little doubt that the shipwrights determined the placement of these strakes with reference to the design diagonals (Figure 6.45). In fact, in laying out the bottom ceiling planking, the shipwrights seemed to have just filled the space between the lower stringer and the keelson (Figure 6.45).

However, it must be kept in mind that *La Belle*'s diagonal design curves are idealized ribband runs. In physical reality, as straight ribbands or planks are bent onto a hull without being forced edgewise, i.e., a normal run, they usually exhibit some curvature when viewed from the ends of the vessel (Figure 6.46a, b). Thus these normal runs exhibit what is known as double curvature. In contrast, in *La Belle*'s design



a b

6.46. Double curvature of plank and ribband runs as documented on a historic model and draft. *(a)* The lowerwale runs are shaded in a stern view of a contemporary fifteenth-century votive model from Mataro in Catalonia, Spain (after Winter 1956:Plate X); the model is now exhibited in the Prince Hendrik Maritime Museum in Rotterdam. *(b)* Longitudinal runs are accentuated in black on a body plan detail from a 1685 draft by François Coulomb (J9e/7375, ©Musée national de la Marine). (Modified by author.)

each of the diagonal curves before and abaft amidships has its curvature confined to a single diagonal plane.

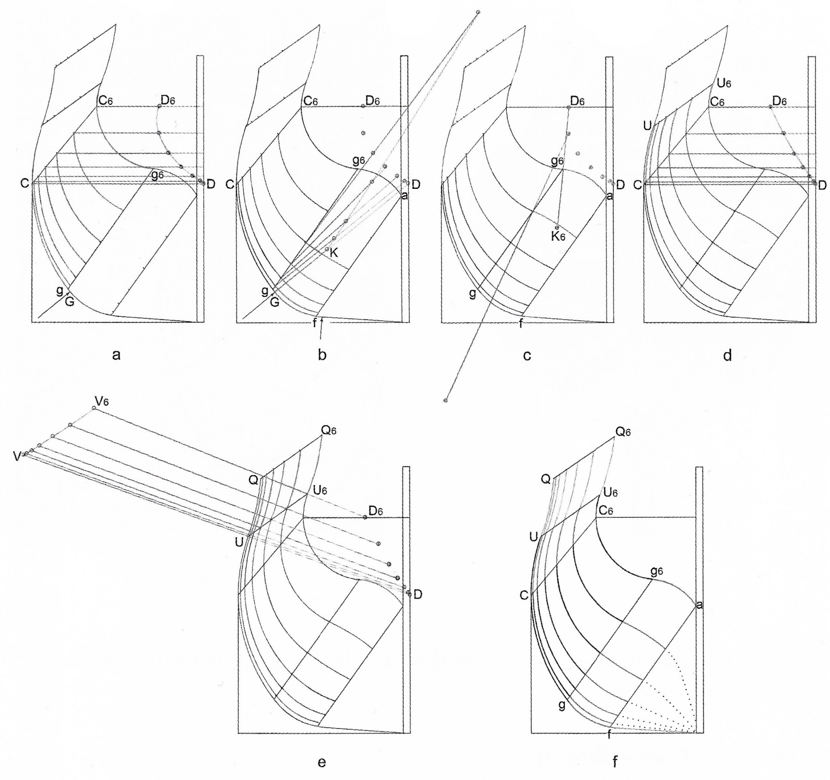
Drawing the Frame Shapes

In shell-first construction, the shell of longitudinally oriented planks provides the information needed for shaping the transversely oriented framing timbers. Similarly, the hull shape defined by *La Belle*'s longitudinal diagonal curves provides guide points for drawing the transverse frame shapes. In *La Belle*'s design system, the offset points for the diagonal curves are plotted at frame positions; therefore, on the conceptual design plane of each frame, each diagonal curve provides a guide point for drawing the frame. In other words, the offset points are the guide points (Figure 6.20t, u).

To completely define the frame shapes, the guide points for each frame must be joined with curves. *La Belle* has only three diagonals for defining the shape of the lower hull, and there is a significant gap of undefined curvature between the maximum breadth diagonal and the upper bilge diagonal. Therefore, *La Belle*'s designers must have had some rules for drawing the transverse curves between the diagonals. These rules would need to limit/restrict the transverse frame geometry in such a way as to assure a smooth transition in curvature from one frame to the next.

At first, due to a general similarity in shape along sections of the surviving frames, it was thought that a single template might have been used to draw the curves between the upper bilge and the maximum breadth diagonals on all the frames (Pevny 1999). However, experimenting with shifting templates based on the shape of the midship section did not give satisfactory results when compared to the shapes of the surmarked frame timbers. In addition, no logical sequence of steps could be reconstructed that would allow the designer to shift the templates in order to get similar results.

The method reconstructed for joining the guide points for the after surmarked frames (Figures 6.20v, 6.47a–f) applies the same drawing principles as were used in the reconstruction of the midship frame. This sequence of steps for drawing the frames, using arcs of varying radii, can easily be duplicated without any reference to the archaeological timber recordings. In Figure 6.47f each category of arcs that combine to form the shapes of the surmarked frames is distinguished by a different shade of gray. Note that the lower breadth and bilge arcs on the midship frame extend slightly below the diagonals. This anomaly is a consequence of the centerline offset that impacted on the positioning of the diagonals on the midship frame. The radii of the tumblehome curves differ so slightly that it would presume a common template could have been used to draw them on the timbers if not already in the body



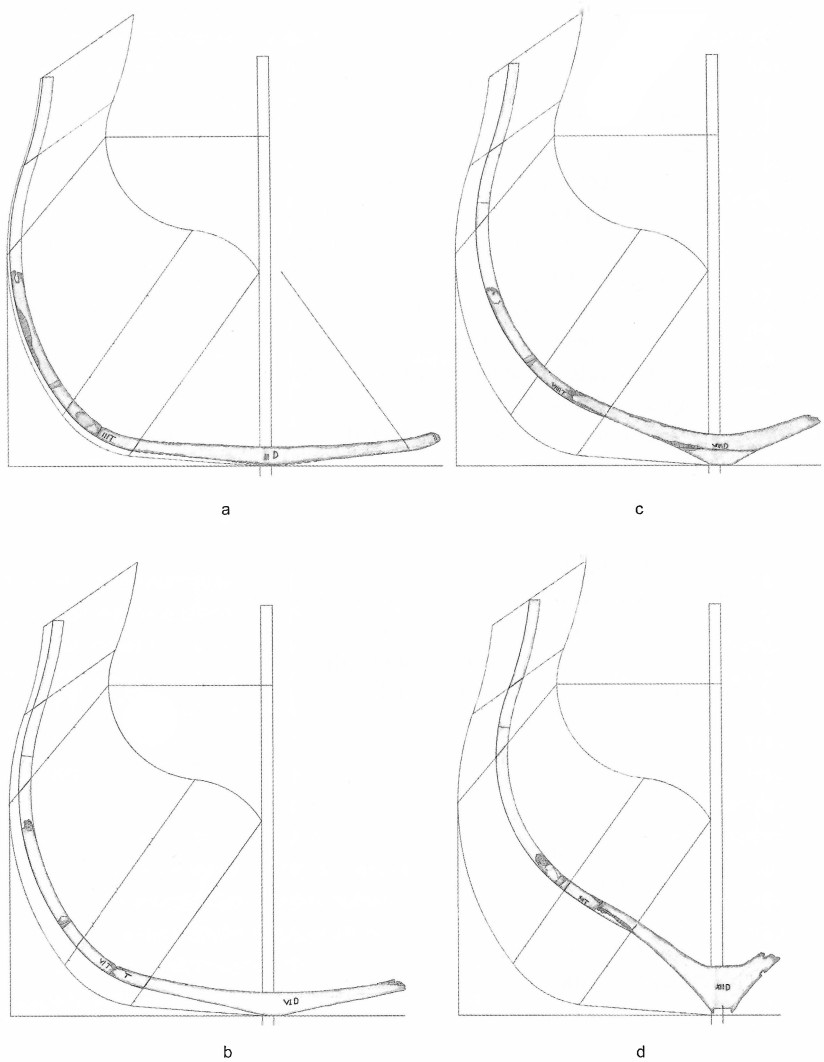
6.47. Reconstructed design procedures for drawing *La Belle*'s after mold frames. See the text for a complete explanation of the drawings. (Illustrations by author.)

plan drawing. The deadrise lines/curves are shown dashed in Figure 6.47f. Since the drawing procedures for these could not be completely systematized, they are not illustrated in the rest of Figure 6.47. Figure 6.20w illustrates how the above design procedures provide the information for defining the shape of frame *VIIIID*. Figure 6.20w also depicts the surmarks as they would appear on the forward faces of the timbers of this frame, and how these marks directly reflect the method used to design the hull.

When the theoretically generated shapes of the after mold frames are superimposed on the recordings of the timber remains, the correspondence is excellent (Figure 6.48a–d). As with the midship frame, in all cases where there is any gap between the two types of curves it is the result of wane disturbing the contour of the frame shape or, in the case of the upper part of floor timber of frame *XIID*, a piece of timber broken off. The figures in this chapter are published at a small scale, but the correspondence of the reconstructed design sections and the archaeological frame shapes is equally close at a large scale. This does not mean that in every detail the reconstructed method of drawing these frames is correct, but it does come close to unraveling what were the basic procedures if not all the nuances. Nonetheless, it cannot be overemphasized that the introduction of additional longitudinal curves decreases the importance of the rules for drawing the transverse curves of the frames; therefore, the reconstruction procedures in Figure 6.47 should not be viewed pedantically.

The Forward Diagonals

As with the diagonals abaft the midship frame, the archaeology provides evidence of floor and upper bilge diagonals before the midship frame along with some of their offset measurements. The rest of the diagonals before the midship station had to be reconstructed on the basis of documentary evidence. In addition to the height of the floor diagonal, *La Belle*'s devis provides only one enigmatic measurement for reconstructing the diagonals before amidships. The devis gives the height of the maximum beam forward as 13 ft 6 inches (438.5 3cm). Plotted in cross section, this results in an endpoint for the maximum beam diagonal well above the height of the stem (Figure 6.44b). This in itself is not unusual, because if the after breadth diagonal were extended upwards, its endpoint would also appear too high. However, this diagonal is cut off in the stern by the transom.



6.48. The theoretical reconstructions of *La Belle*'s after mold frame sections superimposed on the archaeological timber recordings: *(a) IIID*; *(b) VID*; *(c) VIIIID*; *(d) XIID*. (Illustrations by author.)

In both the *Profond* and Toulon flute drafts, all the diagonals forward, other than the floor diagonal, do not extend all the way to the stem (Figures 6.6, 6.7). In both these drafts all the diagonals terminate on the forwardmost design frame. The full lengths of the floor diagonals are defined in these drafts simply because their endpoints are on the centerline timbers at the bottoms of both the forwardmost and aftermost design frames. Since *La Belle*'s floor diagonals also terminate at the bottoms of frames *XIIA* and *XVIIID*, frame *XIIA* is believed to serve as the termination point for all the diagonals forward (Figure 6.44b), just as the transom does for the diagonals aft (Figure 6.44a).

The difficulty with using design diagonals completely to the stem is that, unlike between all the other mold frames, the distance from the forwardmost design frame to the stem continuously increases the higher the diagonal is on the hull. This does not allow the diagonal lengths to simply be applied to the equilateral triangle to be subdivided into increments. By the late 1680s or 1690s this problem seems to have been overcome. For example, in the Cochois frigate draft, the diagonals forward are extended all the way to the stem (Figure 6.18). Unlike in *La Belle*'s design, the Toulon flute draft, and *Profond* draft, the Cochois floor diagonal no longer ends at a design frame position forward. Duhamel du Monceau describes a clever method of adjusting the last increment of the equilateral triangle proportionately to the distance from the forwardmost design frame to the stem at the height of each diagonal (Duhamel 1758:244–245). Since the termination point of *La Belle*'s floor diagonal was used to establish frame position *XIIA* and the forward frame spacing, it is not believed that any such proportional adjustments were applied to *La Belle*'s forward offset sequences.

Three additional diagonals were reconstructed to delineate the probable runs of the curves of *La Belle*'s upperworks for the forward part of the hull. The two almost parallel topside diagonals in Figure 6.44b were reconstructed by first drawing the main sheer line from its height at amidships to the top of the stem. The resulting flat sheer is similar to that of the Cochois frigate in Figure 6.18. The recurve diagonal was set down from the sheer diagonal on the stem the same amount as at the midship frame. A supplementary breadth diagonal for use in design was reconstructed with a height at the center of 7 ft 6 inches (2.44 m) versus the 13 ft 6 inches (4.39 m) listed in the devis. Using these diagonals, several design scenarios were reconstructed for subdividing the forward diagonals and then drawing the forward design frame shapes. The reconstructed frame shapes from one of these scenarios are depicted in light gray in Figure 6.44b. These reconstructed frame shapes correspond well with the archaeological evidence; however, due to their speculative nature and the need for additional research, the methods by which they were generated will not be presented in detail in this chapter. Nonetheless, several definitive observations can be made with regard to the design of the forward part of the hull.

The offset sequences were adjusted individually for each of the diagonals. This was achieved by altering the angles of the diagonals on an equilateral triangle constructed on the basis of the offset sequence of the forward floor diagonal. Since the angles for the upper diagonals on the triangle were extreme, it is possible that separate convexity of arcs drawings or some other method was employed to generate the offset sequences for each diagonal individually.

Before amidships there is proportionally more curvature change in a shorter horizontal and vertical distance than abaft amidships. Therefore, the sides of the hull above the bilge have to be splayed out in order to have a relatively sharp entrance low in the hull and yet maintain deck space higher up. To achieve this result, it is suspected that arcs with a standard radius of 7 ft 6 inches (2.44 m) were used for the bottom sections of the curves above the upper bilge diagonal. The orientations of these standard radius arcs were determined by increments on the upper bilge diagonal and the breadth diagonal. As a result, they progressively tip outward, moving forward from one frame to the next. These standard radius arcs are "cut off" or trimmed by curves with varying radii above and joined to curves with varying radii below.

The trimming breadth curves are tangent to the 7 ft 6 inches (2.44 m) radius arcs and intersect the recurve diagonal at the offset points. As a result, the maximum breadth points of the frames before amidships do not fall on the straight "maximum beam" diagonal. Instead they define a curve such as the one depicted in Figure 6.44b and that can be seen in *Profond* draft (Figure 6.6). The offset points on the maximum beam diagonal fall outside the frame curves due to this filleting procedure. Thus this maximum beam diagonal is viewed as a supplementary design diagonal. It is on this supplementary beam diagonal that the same maximum width as on the transom was plotted to begin the process of defining the shape of frame *XIIA*. This was necessary in order to establish the lengths of the diagonals forward that were then subdivided by offsets.

Lofting

The way the guide points on *La Belle*'s diagonals are joined has repercussions on the procedures that can be used for transferring the resulting frame shapes to the actual timbers during construction. The use of arcs of different radii to draw each of the design frame sections would have made it necessary to draw the resulting body plan at full size for construction. This enlargement of a ship drawing to full size is known as lofting. It is also possible that an accurate design drawing, specifically the body plan, was only developed at full size—at 1:1. Such graphic design at full size may have been an intermediate step before the adoption of scale drawings in French ship construction (Boudriot 1998a:130–131; Rieth 2001:260, 2003b:79–80). However, on the basis of the complexity of the reconstructed design procedures, it is believed that at the very least *La Belle*'s preliminary design was first worked out in a scale drawing.

From the lofted body plan, *La Belle*'s shipwrights would have then fashioned templates for the laying out and cutting of the frames; these templates would be used to transfer the curves onto the actual timbers. This process necessitates that the frame sections drawn in the body plan represent the shapes of the frames in single flat design planes, thus they could be transferred to such planes created on the timbers themselves.

The frame shapes would first be drawn on timbers selected for the floor timbers and second futtocks on what would become their open faces oriented toward the midship frame. Surmarks would then be transferred onto these faces and the location labels carved. The shipwright would have to transfer the surmarks onto the design frames, in a temporary or permanent fashion, because these are the only points at which quantitative information would be available for the change in longitudinal curvature. This information would be essential for laying out the bevels in order to fashion the complete frame.

The conclusion that these timbers were labeled on the ground accounts for the fact that some of the labels are upside down (e.g., *IIIA* in Figure 6.3). The shipwright simply stood on the wrong side of the timber when carving this label. Once the floor timbers and second futtocks were fashioned and placed in their proper alignment, the timbers for the first and third futtocks would be shaped to match and scarfs cut in the floor timbers. The frame pieces would have then been laid out on the ground in their correct alignment and bored for fore and aft fastenings. The resulting holes are more or less perpendicular to the frame surface because the shipwrights bored from above. Thus the overall perpendicularity of the fastenings on the mold frames is a consequence of the design and construction sequence and not a requirement in itself.

The final beveling was likely done on the assembled frames, and the bevels were laid out as underbevels from the surmarked frame faces. This would explain why the fore and aft fastenings tend to be centered on the surmarked faces and exit close to the outboard edges on the opposite side of the frames. This feature is much more pronounced on frames with greater bevel angles, such as *VIIIIA*. It is unclear to what extent, if any, the bevel angles were accounted for in the shaping of the individual frame timbers or in the relative placement of the two layers of framing timbers for each frame. The proposed beveling procedure would explain why frame *VIIIIA* was first assembled with treenails. This would be a prudent precaution if the large bevel angles of this frame were being projected across two layers of timber.

There is no direct evidence indicating whether or not frames *XIIA*, *XVD*, and *XVIIID* had surmarks, since these would have been above the level of preservation. However, the reconstructed design procedure shows that defining the shapes of these frames was as integral to *La Belle*'s design as defining the shapes of the frames with surviving surmarks. Overall the design method determines the shapes of every third frame along the full length of the floor diagonal from and including *XIIA* to *XVIIID* (Figure 6.20x). However, the treenails that were cut through and exposed on the outboard face of frame *VIIIIA* indicate that the shipwrights may have had difficulty determining the beveling of the design frames toward the ends of the vessel. It is possible that the beveling of some of these frames was finished with the aid of actual ribbands. Nonetheless, the overall shapes of these frames were determined during the design stage and once raised they defined the basic shape of the hull.

Mold and Filler Frames

The archaeological evidence indicates that only the shape of every third of *La Belle*'s frames was determined during the design process prior to the start of construction. This is consistent with what is shown in comparative French drafts. For example, in the Toulon flute draft, all the floor timbers are depicted in the sheer view of the bottom of the vessel (Figure 6.7). However, only every third frame before and every fourth frame abaft the midship frame are drawn in the sheer and body plans.

French treatises explain how developing only some of the frames in the design stage relates to the actual construction sequence of the vessel. The frames that are drawn out in the plans are known as mold frames, *couples de gabari(t)* (Duhamel 1758:174; Ollivier 1992a:357). Their shapes were determined prior to the assembly of the ship. They would be raised, whole or in parts, prior to the insertion of the frames in between. Mold frames help define the shape of the hull during construction, and in some discussions in nautical archaeology, such frames are referred to as "active" (Basch 1972:16). The frames inserted between the mold frames are known as filler frames and their shapes were derived from ribbands bent onto and secured to the mold frames (Duhamel 1758:174; Ollivier 1992a:358). These frames provide structural strength but do not contribute to defining the hull shape during construction and can thus be considered "passive."

Laying out frame shapes was a specialized skill that at the time only a limited number of individuals in a shipyard possessed. By first raising only some of the frames, the shipwrights could assure they had the desired hull shape before using the majority of the framing timber designated for the project. Compass timber for curved frame shapes was an expensive commodity that could not be wasted. Ribbands were used not only to secure the mold frames in their proper orientations but also as an aid to judging the smoothness or fairness of the hull curvature. Subsequently forming the frames to match a fair hull shape defined in three dimensions by the ribbands was a relatively straightforward task. By having the main ribbands placed along the curves indicated by the diagonal surmarks, the shipwrights had consistent points of reference for determining frame shapes and positioning the timbers. Cutting the correct bevels for the filler frames would be relatively easy because they could be measured directly from the ribbands. In addition, the fastenings would be inserted once the frame timbers were already beveled and raised in place.

Section II

La Belle's Building Environment

The distinct design characteristics exhibited by *La Belle*'s hull remains are first documented in drafts of much larger vessels that date to the year of its construction, and these characteristics are associated with basic design concepts that were used to build a wide range of French ships for most of the eighteenth century. *La Belle* is a relatively small vessel with a reconstructed length of around 54 ft (17.5 m), a maximum molded width of 15 ft (4.87 m), and a draft of 7 ft (2.3 m). Its small size might suggest it to be too insignificant a vessel to be on the cutting edge of naval architecture. On the contrary, its innovative design system is a product of when and where it was built. *La Belle* was built during a period of French naval expansion that began in the 1660s (Boudriot 1988b, 1998a; Ferreiro 2007:62–80; Lemineur 1992, 1996) in one of the main French naval arsenals of the time, Rochefort, which was only established in 1666 (Boudriot 1985).

During this period of expansion, primarily due to the efforts of Jean-Baptiste Colbert (1619–1683) in his roles as secretary of state of the navy and minister of finances under King Louis XIV, and his son Seignelay (1651–1690), as secretary of state of the navy, more state resources were devoted to the development of French shipbuilding, resulting in the construction of larger ships as well as an increase in the overall size of the navy both in terms of the number of ships and total tonnage. Concurrently, there was an effort to standardize and supervise design and construction. These efforts are reflected in the issue of official royal regulations for ship construction and the creation of new supervisory and inspection positions. Most importantly, there was a growing demand for the documentation of ship design with lists of key dimensions, devis, and also to some extent with drawings.

The lack of development and knowledge of ship drafting is openly criticized in naval correspondence of the late 1670s, specifically in comparison with progress in civil architecture (Lemineur 1996:56, 220; Rieth 2009:136–137). Regardless of how effective existing methods of hull design were, by the time of *La Belle*'s construction during the height of the Scientific Revolution, older "craft methods" of ship design and construction would have seemed out of step to naval administrators when compared to current developments in science, mathematics, and other fields such as civil architecture. It would still be two centuries before William Froude's mathematical ratios for model testing would make predicting hydrodynamic hull performance a practical reality (Phillips-Birt 1957:12–16), but the need for the development of a science of naval architecture was already emphasized in the late seventeenth century—particularly by Colbert in France (Ferreiro 2007:62–80). Although such developments had limited practical application at the time, they did highlight the need for graphic depictions of hull shapes in order to standardize construction and carry out mathematical analysis.

Surviving French ship drafts as well as *La Belle*'s archaeological evidence testify that in this dynamic environment, concrete progress was made in graphic ship design in the last two decades of the seventeenth century. Jean-Claude Lemineur, in *Les Vaisseaux du Roi Soleil*, suggests an intriguing possibility that an architect from Paris may have been responsible for some of these innovations in graphic ship design (Lemineur 1996:57). Arnoul, intendant of the Toulon arsenal, writes in a letter dated November 17, 1679, that a young architect and master carpenter from Paris named Chaumont has worked for two years drawing vessels, and the sons of the Toulon shipwrights Coulomb and Chapelle have already been working under him for a year (Arnoul 1679; Lemineur 1996:56–57, 220–221; Rieth 2009:136–137). The 1684 Toulon flute draft (Figure 6.7) that presents the basic concepts of design with diagonals is signed by [François] Coulomb (son) (Coulomb 1684)—one of the two sons of shipwrights referred to in this letter.

The 1684 body plan of *Profond* (Figure 6.6), the other early example of design with diagonals, relates to flutes built in Rochefort by Henri Mallet, the senior master shipwright (Boudriot 1998b:58; MnM 1684a:PH 178893). Researcher Jean Boudriot concludes that it was probably one of the junior shipwrights, like Henri's son Pierre Mallet, or Pierre Masson, the son of his brother, or Jean Guichard, who executed this draft (Boudriot 1998b:58), and *La Belle*'s devis actually bears the signatures of Henri Mallet and these three shipwrights (Levasseur 1684). The evidence seems to suggest that in the late 1670s and early 1680s, knowledge of this new graphic design method of geometric fairing with diagonals spread among the next generation of shipwrights working in the leading French naval shipyards. Quite fortuitously for the study of the history of naval architecture, *La Belle* provides unique archaeological evidence of the practical application of these recently developed design techniques.

What specific ideas or skills civil architects contributed to the development of French ship drafts is unknown. As Lemineur (1996:57) writes, the architect Chaumont is forgotten by history. Unfortunately, this also applies to the ship drawings made by him in the course of at least two years in Toulon (1677–1679). His work is mentioned in Arnoul's letter, but no such drafts have yet been discovered. It is known that by this time the principles of orthographic projection, enabling the depiction of multiple cross-referenced views of a structure, were well established in art and civil architecture (Booker 1963; Lefèvre 2004). However, terrestrial structures of the time did not incorporate the complex curvature that characterizes the shapes of ship hulls. The following discussion will explore whether *La Belle*'s design method was a completely new invention or an expansion on preexisting concepts in ship design and civil architecture.

Ship Kit

The use of an innovative design method for *La Belle*'s construction may be partially explained by the fact that it was built from timbers originally being prepared for a kit—a *barque* in bundles. Soon after *La Belle*'s excavation, professional archivist Bernard Allaire examined records of correspondence between the Rochefort arsenal and the crown in search of additional materials relating to La Salle's expedition—including any dealing with the construction, outfitting, and manning of *La Belle* (Allaire 1999; Bruseth and Turner 2005:73).

Based on his discoveries, Allaire definitively concluded that *La Belle* was built in 1684 from a barque in bundles (*en fagot*) that was being prepared at Rochefort for La Salle's expedition (Allaire 1999:4–7). A list of materials accorded to La Salle by the king dated March 23, 1684, includes as item 22 a 40- to 50-ton barque rigged or in bunches (*en botte*) with its rigging (Louis XIV 1877a:380; the original document has not been relocated). "En botte" refers to a vessel in pieces with presumably its timbers arranged in bunches for storage or transport ("*bâtiment en botte*, a frame in pieces numbered for putting together," under "botte" in Boyer and Salmon 1802). Soon after the preparation of this kit was undertaken, it must have become apparent that there was insufficient room on the designated vessel, *Le Joly*, to load such a kit along with the rest of the cargo. From two surviving copies of a letter with the crown's response, dated April 17, 1684, it is known that the arsenal informed the king in early April of this dilemma and suggested the use of a larger vessel, the flute *Le Dromadaire* (Louis XIV 1684b; Arnoul 1684). The Crown rejected the idea of using *Le Dromadaire* and suggested that instead of the barque en fagot (in bundles) to provide La Salle with a *traversier* (a colonial dispatch vessel) or a good barque (Allaire 1999:5). This small vessel would make the voyage to the New World loaded with some of the cargo that would not fit in *Le Joly*.

There is little doubt that both contemporaneous references, to a barque . . . en botte in one and to a barque en fagot in the other document, are alluding to the same kit ship ("Frame of a boat in pieces, *chaloupe en botte ou en fagot*," under "frame" in Boyer and Salmon 1802). A marginal note on the arsenal's copy of the king's response next to the paragraph referring to the barque en fagot directly states that construction of the said barque must continue and that it is already well advanced (Arnoul 1684). Furthermore, as Allaire points out, the arsenal had no choice but to complete this new vessel for La Salle because no similar vessels were available at Rochefort at the time (Allaire 1999:5). A dispatch from January 16, 1684, informs us that of the four *corvettes* (a vessel type like *La Belle*) at Rochefort, only two were able to be used, and they were committed to duty elsewhere (Allaire 1999). In fact, the marginal note mentioned above states that work on the vessel should continue for this (La Salle's) use or that of the port [Rochefort] that is in need [of it] (Arnoul 1684). The subsequent completion/assembly and outfitting of the kit ship conforms well with *La Belle*'s official building period from May to June 1684, as given at the top of its devis (Levasseur 1684).

Preparing timbers for such a kit necessitates being able to define their shapes prior to the final assembly of the vessel. Since the surviving correspondence makes it clear that this kit was not based on timbers from an older vessel, the preparation of such a kit would have provided an ideal opportunity for applying a newly developed graphic method of ship design. Thus *La Belle*, having been built from a kit, in no way masks the study of its design method. Quite the contrary, if this accounts for the clear location labels and design marks, it is quite fortuitous, and it may be the reason *La Belle* serves so well as an exemplar of design.

La Belle's timbers provide evidence of a onetime assembly sequence in which the shapes of its filler frames were determined during construction; thus it is possible that the original kit only included the essential mold frame timbers. Including only these essential timbers would make sense for practically transporting a kit ship somewhere distant for future assembly. Additional timbers to finish the hull could be acquired at the place of assembly while avoiding the major difficulties of defining the hull shape. Bernard Allaire located a document from April 5, 1680, that mentions shipping over only the frames for *barques longues* in bundles (en fagot) and acquiring the planking timber in the West Indies (Allaire 2001b; Bruseth and Turner 2005:73).

It is also possible that the preparation of such a kit involved the preliminary raising of the frames, *montage à blanc*, with the use of temporary fasteners, *clous à demi enfoncé*. René Burlet and José-Paul Verne (1997:64–68) discuss the documentary evidence for such procedures in an article on the prefabrication of three frigates and a galley in 1678 to 1679 at four French naval dockyards, including Rochefort, and the mass building of 15 galleys at Rochefort between 1689 and 1690. Based on the available sources, it is not possible to determine how much of the barque kit was prepared before the shipwrights shifted to the permanent construction of *La Belle*. The extensive labeling on *La Belle*'s mold and filler frames may indicate that their primary shapes were defined in a trial run of the frame assembly.

Discrepancies with the Devis

If *La Belle*'s final construction was based on a kit, then certainly some if not all of the timbers of the surmarked frames were prepared beforehand. Therefore, if the devis

(Figure 6.17) represents an original list of design measurements, then some of the discrepancies with the archaeological evidence must be accounted for by changes made at the time of the kit was prepared. For example, the 15 ft (4.87 m) versus 14 ft (4.55 m) maximum beam and the 7.5 (2.44 m) versus 9 ft 4 inches (3.03 m) floor measurements would have been established when cutting timbers for the kit. From dendrochronological analysis it is known that the main keel timber was cut from a tree felled in 1683 (Carrell 2003:296). This dating of the keel timber provides additional evidence that *La Belle* was built no earlier than 1683. Thus when *La Belle*'s spine timbers were shaped, most likely in the spring of 1684, the rake measurements were laid out differently than the common usage of the terminology in the devis would suggest.

Glenn Grieco, from his experience building two research models of *La Belle* based on the archaeological remains, concluded that some of the measurements in the devis could represent dimensions taken off the completed vessel (Grieco 2003:50–56). For example, he proposes that the 51 ft (16.57 m) in the devis is the length between the rabbets taken at the height of the deck, and the 14 ft beam (4.55 m) was measured between the internal faces of the bulwark planking. These measurements were then mistakenly listed as design dimensions in the devis.

Glenn Grieco's interpretation basically corresponds with the shape and structure reconstructed for *La Belle*'s hull as built in Section I of this chapter (Figures 6.21, 6.27, 6.29). However, the ratios of the measurements in the devis are consistent with those for design measurements. The 4 ft 6 inch (1.46 m) stem rake is one-tenth the 45 ft (14.62 m) keel length. The 1 ft 6 inch (48.73 cm) sternpost rake is one-third the stem rake. The design keel length plus these two rakes does equal the length of 51 ft (16.57 m) listed in the devis. Similarly, the 9 ft 4 inch (3.03 m) floor width given in the devis is two-thirds the listed 14 ft (4.55 m) maximum breadth. If 14 ft (4.55 m) represents the internal width between the bulwarks, then not only was it listed in the devis using incorrect terminology, but also the related floor measurement was subsequently derived using an incorrect ratio.

At the beginning of the devis, it is clearly written that *La Belle* was built in May and June of 1684. Yet for some unknown reason, shipwrights and administrators signed this document on December 15 of that year even though it did not account for any changes to or discrepancies with the dimensions of the kit or the completed vessel. In this case, *La Belle*'s small size may have meant that assuring its devis accuracy was relatively unimportant, and mistakes could have been easily ignored or overlooked.

Rebuilt Ship with Reused Timbers?

Since *La Belle* is an important example of developments in French ship design and construction in the last decades of the seventeenth century, any ambiguity as to the temporal or geographic provenance of its design must be thoroughly addressed. Preliminary dendrochronological analysis, based on 26 samples from various timber types from *La Belle*, indicates that most of the sampled timbers were felled at least 20 years and some a century or more prior *La Belle*'s construction (Bruseth and Turner 2005:79–80; Carrell 2003:295–297).

Toni Carrell, who was in charge of hull analysis for the *La Belle* Shipwreck Project (Carrell 2003:iv), has proposed a completely different interpretation of *La Belle*'s design and construction than is presented in this chapter (see Chapter 5 of this volume; Carrell 2003). Carrell concluded that these dendrochronological dates are consistent with an extensively rebuilt ship that was designed using "older" methods. In order to avoid misrepresentation, the following are some of Carrell's conclusions in her own words.

* "[T]he ship that they eventually called *La Belle* was nearly complete and was not, in fact, the boat in pieces. . . Thus, they substituted *La Belle*, a ship nearing completion in the yard and originally projected for the Intendant, for the still to be completed little barque en fagot that was first requested." (Carrell 2003:73)
* "The surprising results of the dendrochronological analysis . . . and detailed examination of individual timbers introduced the potential for reuse of many of its components." (Carrell 2003:108)

* “The differences in the fastening patterns, the results of the dendrochronological dating, and the varying sided dimensions of the timbers all point to a ship that was not a built-from-scratch or “new” ship made to order for the expedition. Rather, it may have been a ship so extensively rebuilt that it was considered a new ship in the French system.” (Carrell 2003:216)
* “From a technical standpoint, the French practice of assembling frames with bolts meant that when breaking a ship apart the frames held their shape. In a rebuild, no matter how extensive even to the point of shifting frames into a completely different ship, their shape was not altered, nor would they require disassembly and reassembly, only some dubbing and slight adjusting to fit. That would account for the differences in the sided dimensions of the forward timbers.” (Carrell 2003:218)
* “[A] ship with an existing older method of hull design . . . is more likely to be easily blended with new timbers in a ship that is being extensively rebuilt.” (Carrell 2003:220)
* “In *La Belle* . . . the ribbands, and by direct association the surmarks, do not control the shape of the hull because they are not located at the touch of arcs. Rather, they serve as construction aids.” (Carrell 2003:360)
* “In *La Belle*, when combined with the information from the study of its fastening patterns and the physical dimensions of the frames, it clearly indicated the reuse of complete frame sets. Further, if *La Belle* was a completely new ship, rather than a ship incorporating used timbers, then nearly all of the samples should have dated to the few years just prior to its construction.” (Carrell 2003:407–408)

In fact, some of the same evidence used by Carrell strongly supports the opposite conclusion—that *La Belle*’s design and construction features are consistent with an innovative design system applied to the construction of a new vessel in 1684, regardless of the felling dates of its component timbers. The design and construction features supporting this conclusion are so distinct that even without any of the historical documents specifically relating to *La Belle*’s construction, it would have been possible to conclude that *La Belle* was a French vessel built no earlier than about 1680.

The presence and preservation of the surmarks on *La Belle*’s timbers is a unique gift for ship reconstruction work. The diagonals defined by these surmarks in a body plan (Figure 6.5a, b) are not indicative of supplementary marks simply used as aids in the assembly of the hull. Fairing and construction ribbands that are not associated with design exhibit double curvature on the hull—meaning they are not straight when viewed in cross section (Figure 6.46). Therefore, surmarks do not line up on oblique straight lines by chance; they represent primary control points that were used in the design of the hull. Such multiple diagonals associate *La Belle*’s construction with a design system that only appears for the first time in the historical record in the 1680s. Shipwrights rebuilding an old vessel with an already defined shape would have no need to insert such surmarks. Furthermore, the floor surmarks play a critical role in terms of the fundamental layout of *La Belle*’s shape and structure (Figure 6.30):

* The last frame positions *XIIA* forward and the fashion pieces at *XVIIID* aft are located at the ends of the floor diagonal defined by these surmarks.
* The midship section is located at two-fifths to three-fifths along the length of the floor diagonal.
* The mainmast is located in the middle of the overall length of the floor diagonal.
* The deadwood both forward and aft begins at exactly half the distance from the ends of the floor diagonal to the midship frame and this is an integral part of the layout of *La Belle*’s centerline timbers. The fact that the positioning of the deadwoods is directly related to the lower diagonal indicates that the overall layout of *La Belle*’s structure cannot be separated from the surmarks.
* Where the deadwoods begin is also the location of two of *La Belle*’s surmarked mold frames—its balancing frames. The positioning of these frames,

combined with the fact that the last mold frames are at the ends of the floor diagonal, indicates that the positioning of all the mold frames and thus all of *La Belle*'s frames is inextricably tied to the surmarks. In turn, the surmarks and the diagonals they define are indicative of construction in the 1680s.

The framing bolt pattern definitely proves that every third of *La Belle*'s frames was erected prior to the filler frames in between (Figures 6.11, 6.12). There are no anomalies to this framing pattern, in terms of the number of fastenings or their angles, which cannot be explained within the context of a single design and construction procedure. Furthermore, there are no unused fore and aft fastener holes going completely through any of the framing timbers. Taken out the context of a discussion of mold versus filler frames, the double set of fore and aft fastenings on *VIIIIA* and the extra scarf fastenings on just some of the frames could be mistakenly interpreted as evidence of reuse of old timbers, repair, or rebuilding. *La Belle*'s mold and filler frame pattern along the whole length of the hull conforms well to what is known of design methods using diagonals from seventeenth-century French drafts as well as eighteenth-century French shipbuilding treatises. Shipwrights replacing framing timbers or frame sets on an older vessel would have absolutely no reason for maintaining or re-creating such a mold and filler fastening pattern—it would be impractical and unnecessary.

As with its surmark characteristics, *La Belle*'s partial double framing arrangement (Figure 6.1) is not documented in French shipbuilding prior to the period of *La Belle*'s construction. *La Belle*'s two sets of lower surmarks are located on the floor timbers and second futtocks of every third frame. In the earlier stepped framing arrangement, the second futtocks (top timbers) are located higher up on the frames with gaps between the bottoms of the second futtocks and the heads of the floor timbers (Figure 6.4b). It is hard to conceive that shipwrights rebuilding an older vessel, even one with stepped framing and relatively small gaps (Colbert 1670), would shift the second futtocks down till they joined the heads of the floor timbers. First, on *La Belle* their shapes would not fit in these lowered positions. Therefore, such a change to partial double framing would at minimum entail cutting new second futtocks for all the frames. Second, such work would leave plenty of evidence of having been done; yet there is absolutely no evidence for such alterations on *La Belle*'s timber remains. Third, shipwrights doing such work would have no reason to maintain *La Belle*'s documented mold and filler frame fastening pattern.

At first glance, *La Belle*'s framing timbers do appear to have a large number of extra treenail holes on their outboard faces that cannot be accounted for by the regular fastening pattern for the planking: two crisscrossed nails and two treenails per frame with extra bolts and nails at the scarfs. What is especially peculiar is that these extra treenail holes often occur in batches. The explanation for these holes is not timber reuse or vessel repair. They are a direct result of the prolific use in French shipbuilding of iron bolts versus treenails for fastening together the frames (Ollivier 1992a:65–67).

Documentary evidence indicates that the French attached all or at least multiple strakes of the internal ceiling and external hull planking with nails prior to further securing them with treenails (Ollivier 1992a:52). As a result, the shipwright boring holes for the treenails could not see the locations of the fore and aft framing bolts. With surprising frequency, sometimes multiple times in one location, *La Belle*'s shipwrights had to abandon and plug auger holes after encountering a fore and aft bolt or sometimes even the tip of a nail driven from the opposite side.

There are unused shallow auger holes and nail holes on the lateral surfaces of the framing timbers as well as extra nail holes on the outboard faces. Similarly, on the sides of the keel there are some nail holes that were filled with wooden plugs. Such extra "minor" fastenings and holes are not unusual in the construction of a vessel, and they are likely related to the squaring and shaping of timbers and/or the fastening on of temporary supports during construction such as ribbands, chocks, braces, and cross-spalls.

There are no anomalous centerline fastenings in the keel, the floor timbers, or the keelson that would indicate that any of these timbers were independently replaced during a repair or rebuilding prior to 1684. The after section of the keel is one of four timbers that have 1683 as the proposed felling date (Carrell 2003:219, 295–297). Since this is one of the main timbers of the keel, it can be safely concluded that this timber is fundamental to the construction of the vessel. It is possible to replace the keel in an older vessel; however, if this part of *La Belle*'s keel was a replacement timber on an older hull, the shipwrights would not have needed to carve frame numbers on its port side (Figure 6.8). Furthermore, this after part of the keel is scarfed to the forefoot, and *IIIA* is carved across the seam of the scarf. This suggests that both pieces were scarfed together at the time this label was carved. Thus the labeling of the complete keel and the assembly of the centerline timbers was almost certainly a onetime event that occurred no earlier than in 1683.

All the labels on the frames are sequential forward and aft along the entire vessel. Each and every label is in its correct location and on the appropriate timber conforming to the overall labeling logic. All the framing labels correspond to the labels on the keel, and there are no anomalies. This strongly supports the conclusion that all of *La Belle*'s frames were placed in their location on the keel for the first time in 1684. If any of the labeled framing pieces or complete frames were replaced individually prior to 1684, there would be no reason for the shipwrights to label or relabel them. The extensive and consistent labeling on *La Belle* only makes sense—serves a purpose—in the context of a onetime construction event or the preparation of timbers for a kit ship for future assembly. It is difficult to imagine, as Carrell proposes (Carrell 2003:216–221, 407–408), that "a ship with an existing older method of design" was so extensively rebuilt in 1684 that complete frame sets from other older vessels were incorporated and all the components were relabeled and marked with surmarks. It must be kept in mind that a vessel of *La Belle*'s small size was unlikely to garner such attention within the context of the French naval establishment.

Replacing worn-out planking is fairly straightforward, but replacing parts of the framing situated under ceiling planking and stringers is a massive undertaking. Such work would leave extensive and unambiguous evidence—for example, differences in fastening patterns, differences in frame layout, old fastening holes, damage edges, areas of where rot was cut out, or repair pieces. Quite the contrary, when first seeing *La Belle*'s framing timbers, it was striking how crisp the edges were and how little wear and tear the timbers displayed. *La Belle*'s remains in no way gave the impression of being assembled from components of older ships.

Even if one still presumed such extensive rebuilding work was done in 1684, it would not explain the scattering of sampled felling dates throughout the first half of the seventeenth century and earlier. All but five of the sampled timbers have felling dates earlier than 1666, the date of the establishment of the naval dockyard at Rochefort. Even disregarding the samples with felling dates from the sixteenth century and the two samples with fifteenth-century felling dates, the other samples have felling dates in each decade of the seventeenth century between 1613 and 1683. Since none of the sampled timber felling dates group nicely before an "original" building date, the dendrochronological dates themselves do not provide a reason for shifting the known building date of *La Belle*.

Why some of the sampled timbers have such early felling dates and why the felling dates are scattered over so many decades are legitimate questions. The dendrochronological study also revealed that almost all the sampled timbers came from the greater Rochefort/Charente region (Bruseth and Turner 2005:80; Carrell 2003:254), and it is suspected the answer to the mystery of the timber dates lies in understanding the buildup of timber stockpiles at the Rochefort arsenal from the time of its establishment in 1666. The Rochefort dockyard built and maintained large ships, and this consumed great quantities of timber. It would seem the timber stockpiles of the dockyard could have been "scavenged" for timbers suitable for building the relatively small *La Belle*, and this could account for the diversity of its sampled timber dates. However, this is mere speculation, and this aspect of *La Belle*'s construction is in need of further research. Whether or not some of *La Belle*'s individual timbers were carefully selected from dismantled ship timbers or were timbers previously used for purposes other than shipbuilding, the evidence for the design and construction of a new vessel at the time of *La Belle*'s official building date of 1684 is extensive and unequivocal.

La Belle's Design Method: Invention or Expansion?

Although *La Belle*'s design system using diagonals was innovative for the 1680s, was it a completely new invention or an expansion on existing ship design concepts? Seven other vessel remains have been discovered with surmarks and/or numbers carved on their frames. All but one of these "marked" vessels predates *La Belle*:

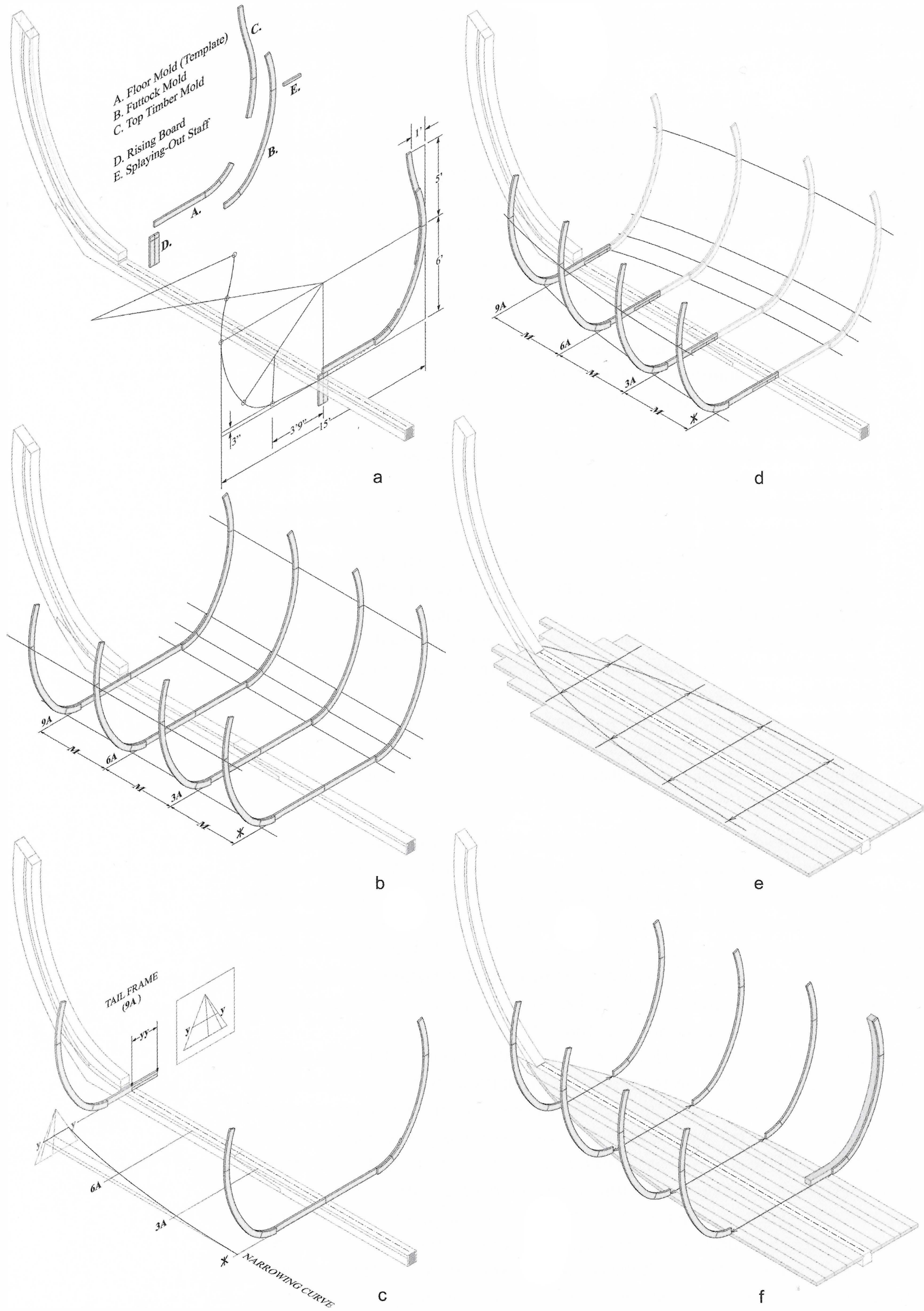
* The Culip VI vessel from the late thirteenth to early fourteenth century discovered off the coast of Catalonia, Spain (Rieth 1996:149–164; Rieth and Pujol 1998).
* The Sorres X vessel from the second half of the fourteenth century discovered off the coast of Catalonia, Spain (Raurich et al. 1992).
* The Ria de Aveiro A vessel from the mid-fifteenth century discovered off the coast of Portugal (Alves et al. 2001a).
* The Cais do Sodré vessel from the late fifteenth/early sixteenth century discovered in Lisbon, Portugal (Rodrigues et al. 2001).
* A Basque whaling ship (probably *San Juan*) from the mid-sixteenth century discovered in Red Bay, Labrador, Canada. There are no location labels found on this vessel, and the marks on the frames have a distinctly different "arrow" shape (Grenier 2001:277; Loewen 1998b:217) compared with those on the rest of the surmarked wrecks. Researcher Brad Loewen has also proposed that a "distinctively 'Atlantic' method of whole-moulding" was used in its design (Loewen 2001:243). Despite these and other differences, for now this vessel should be mentioned among these "marked" wrecks.
* *Nossa Senhora dos Mártires* from the early seventeenth century discovered near Lisbon, Portugal (Castro 2005:105–179).
* The chayka-type vessel from 1738 discovered on the Dnipro River in Ukraine (Kobaliya and Nef'odov 2005).

Analysis of surviving features on these vessels indicates that they are all associated with a nongraphic system of hull design, in contrast to *La Belle*'s design system, in which the graphic development of the body plan is a central element. This older nongraphic method in its national and temporal variations is referred to in various ways: the ancient method, the *partisone* system or method, Mediterranean molding, the method of the *maître-gabarit*, *la tablette et le trébuchet*, Mediterranean whole molding, and whole molding (Alertz 1995; Barker 2003; Bellabarba 1993; Bloesch 1983; Castro 2005; Rieth 1996; 2003a; Sarsfield 1985, 1991).

Our understanding of the basic concepts of Mediterranean molding is a result of more than a century of effort by many scholars primarily working with documentary materials from the fifteenth to the eighteenth centuries and some ethnographic parallels (Rieth 1996). However, Éric Rieth's investigation of the remains of the late thirteenth- to early fourteenth-century Culip VI vessel definitively showed that the system itself predates the earliest documentary evidence from fifteenth-century Italian manuscripts (Rieth 1996:149–164). Furthermore, investigation of the remains of the ninth-century Bozburun (Harpster 2009) and the eleventh-century Serçe Limani (Steffy 2004) vessels discovered off the coast of Turkey indicates that the origins of some of the design concepts of Mediterranean molding, with regard to frame-first construction, may date back to the Middle Byzantine era (see discussion in Rieth 2009:132–134).

Mediterranean Molding

The series of isometric drawings in Figure 6.49 illustrates what are considered the basic concepts underlying the definition of the hull shape of a vessel in the fully developed version of Mediterranean molding design. All of these drawings are modeled on *La Belle*'s general shape and curvature characteristics from the midship frame forward. They were developed to compare the principles of the Mediterranean mold-



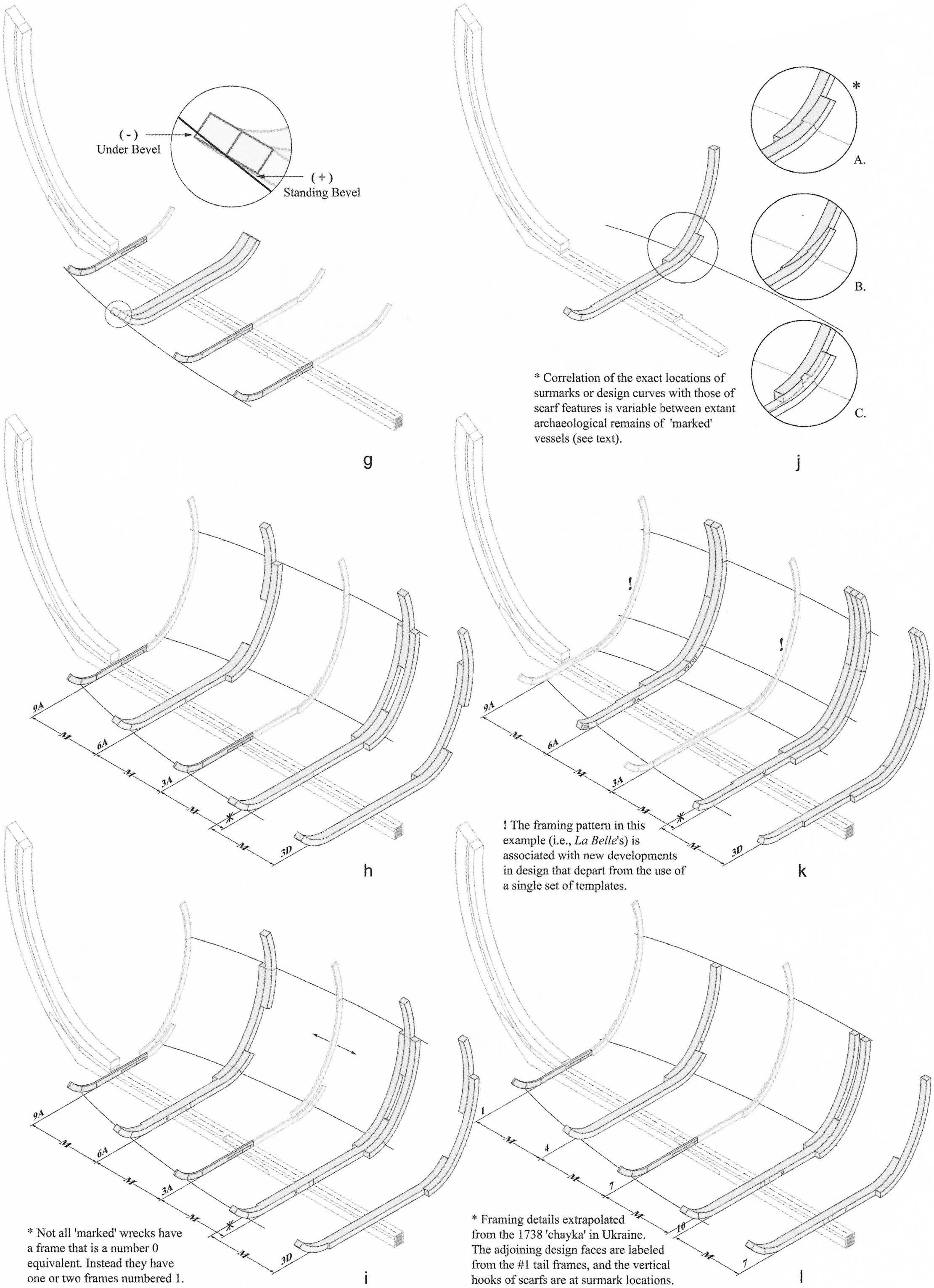
6.49. Isometric drawings illustrating the concepts underlying Mediterranean molding, a nongraphic design system of geometric fairing. See the text for a complete explanation of the drawings. (Illustrations by author.)

ing method, as delineated in seventeenth- and eighteenth-century French sources, with those of *La Belle*'s design method; they do not adhere to the exact proportions or measurements of any specific Mediterranean molding tradition.

Templates

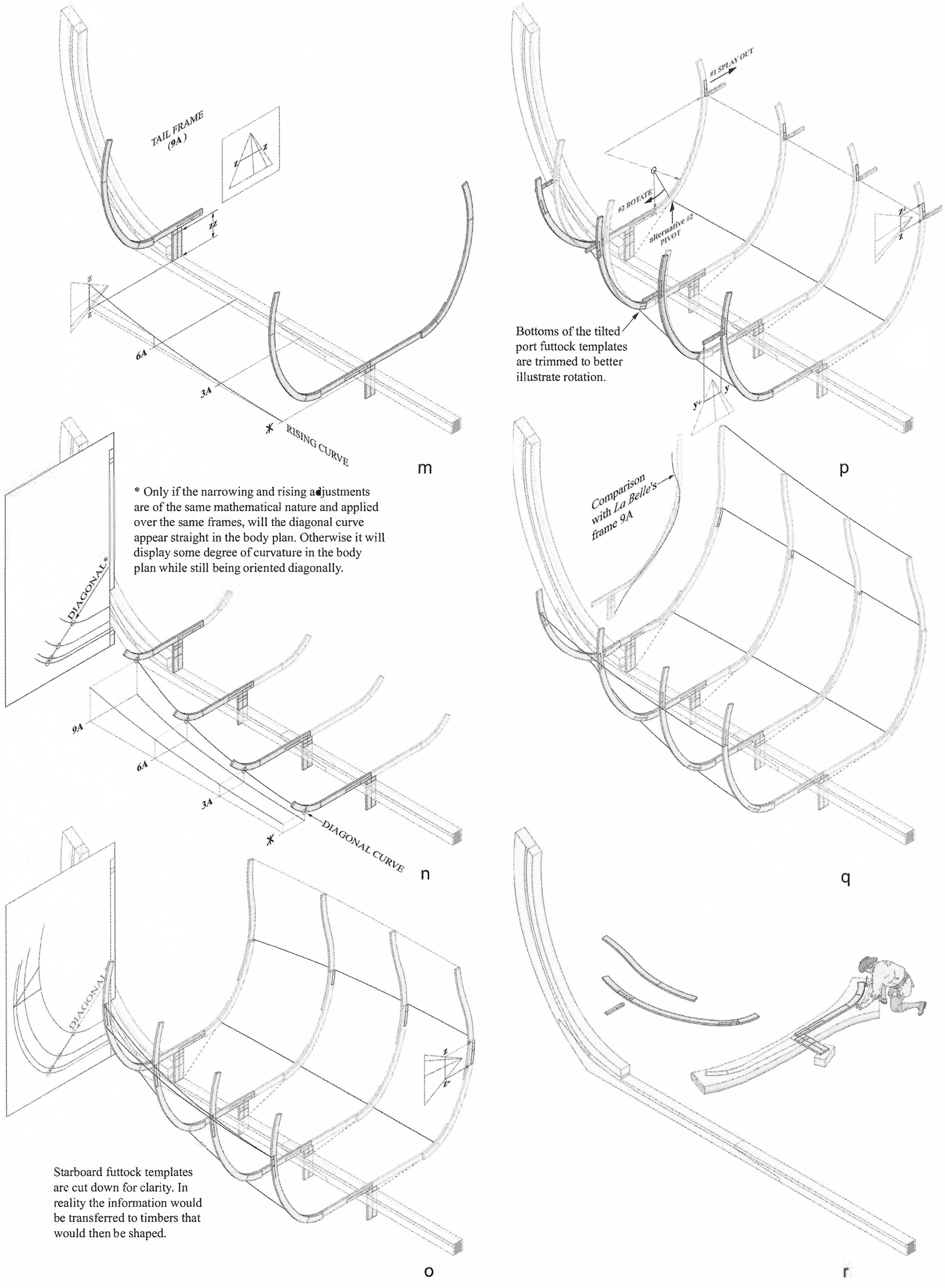
It is also important to keep in mind that this series of drawings does not illustrate an actual design sequence, since with Mediterranean molding there is no develop-

6.49. *(continued)*



ment of the hull shape in a drawing. In Mediterranean molding the frame shapes are drawn directly on the timbers using a single set of full-size templates based on the shape of the midship frame (Figure 6.49a, r). Most commonly, there would be one template used to draw out the floor timbers and another for drawing out the futtocks (Figure 6.49a). The two templates would be overlapped to define the area of the bilge much like the overlapping of floor timbers and futtocks in a stepped framing system. Templates for the uppermost parts of the frames, such as top tim-

6.49. *(continued)*



ber molds, are occasionally depicted (Figure 6.4a) but are not generally discussed in manuscripts.

The component templates for a frame have surmarks centered in the middle of their overlaps. Such surmarks transferred onto the timbers would provide reference points for the assembly of the complete frame in its proper shape (Figure 6.4b). On all the "marked" vessels other than *La Belle*, there is only one surmark on the bilge. This is consistent with all the documentary descriptions of Mediterranean molding. Thus *La Belle* having surmarks both on the upper and lower parts of the bilge curve already distinguishes its design from Mediterranean molding.

In Mediterranean molding the drawing of the frame shapes begins by placing the templates on the framing timbers after the centerline timbers are shaped (Figure 6.49r). Once the templates are actually ready to be placed on the timbers, they have already been marked with several scales subdivided into increments. Without this additional data marked on them, the midship templates cannot be used to design a "boat-like" shape. Even when duplicated and evenly distributed along the keel at frame stations, at best, the result is only a "barge-like" shape. Figure 6.49b illustrates that straight lines would define the longitudinal relationship between such templates.

The use of templates gives the impression that in Mediterranean molding the transverse sections play the primary role in the design of the hull shape. However, to be useful, these templates must be marked in a way that indicates how much they need to be shifted, relative to a common centerline and baseline, to progressively alter the transverse shape from one frame to the next. In other words, it is necessary to quantify how much the shape of each frame narrows and rises in such a way that will result in smooth longitudinal curvature. It is the series of increments marked on the templates that hold the "secret" to how hull curvature is defined within the Mediterranean molding system of design. Understanding the design concepts behind these increments and the development of their use is itself the "secret" or key to our understanding the evolution of the quantification of curvature in Western ship design.

Tail Frames

Defining the parameters for the change in hull curvature at specific frame positions before and abaft the midship frame, at the tail frames, is a fundamental element in Mediterranean molding. Since in traditional Mediterranean molding the frame shapes for only a limited percentage of the hull length are predetermined, design marks and sequential location labels appear only on the frames between and including the tail frames. Archaeologically some or all of the predetermined frames in these hulls are also distinguished from the frames at the ends of the hull by having more elaborate scarfs that are secured better between the floor timbers and first futtocks. This feature of a given number of central frames with distinguishing scarfs can itself be considered at least indirect evidence for the use of Mediterranean molding.

It is important to note that the scarf type (e.g., hook versus dovetail) and the percentage of the predetermined frames with such scarfs seem to be broad but still vague indicators of regional and temporal variations of geometric molding (Loewen 1998a; 2001; Oertling 2001; 2004; Rieth 1998a). For example, the presence of dovetail scarfs on preassembled frames is a characteristic prominent in, if not exclusive to, a fifteenth- and sixteenth-century Atlantic vessel type of an "Iberian-Mediterranean subtradition" (Oertling 2001; 2004).

How near to the endposts the tail frames were located when using the Mediterranean molding method seems to have varied greatly between shipbuilding traditions, vessel types, and even individual shipyards and shipwrights. However, there are no archaeological or documentary examples of tail frames being located over the deadwoods, if such timbers are present. On the 1738 Ukraine vessel, which has identifiable tail frames fairly near the ends of the vessel, the deadwoods begin at the tail frames (Kobaliya and Nef'odov 2005). This feature is also present in illustrations from the 1670 *Album de Colbert*, which depicts the construction of a large French vessel based on Mediterranean molding principles. Based on this evidence, for the Mediterranean molding drawings, *La Belle*'s forward deadwood was trimmed to start at frame *VIIIIA* (Figure 6.49).

On the actual *La Belle*, surmarked frames *VIIIIA* and *XIID* are situated over the deadwoods (Figures 6.1, 6.30), and the floor diagonal is defined all the way to the endposts where the final design frames are located. Therefore, tail frames are not mentioned in *La Belle*'s devis or any other devis accompanying French drafts that depict design with diagonals. This difference in terminology is also evident in the devis of the 1684 *Profond* (AR 1684; Boudriot 2000:41) that follows that of *La Belle* in the French naval records. Referencing the surviving body plan of *Profond* (Figure 6.6), Jean Boudriot and Jean-Claude Lemineur, in their 2000 book on *La Belle*, insightfully concluded that *La Belle* was probably designed using the French system of graphic design with diagonals (Boudriot 2000). They came to this conclusion without even having knowledge of the surmark evidence.

Thus far there is no archaeological evidence for the use of a mold and filler frame approach between the tail frames in Mediterranean molding, although there is documentary evidence for the use of this approach in some shipbuilding traditions, particularly for galley construction (Alertz 1995:146; 2009:263; Bondioli 2003). For clarity of presentation, only every third frame position is depicted in the conceptual drawings of Mediterranean molding in Figure 6.49.

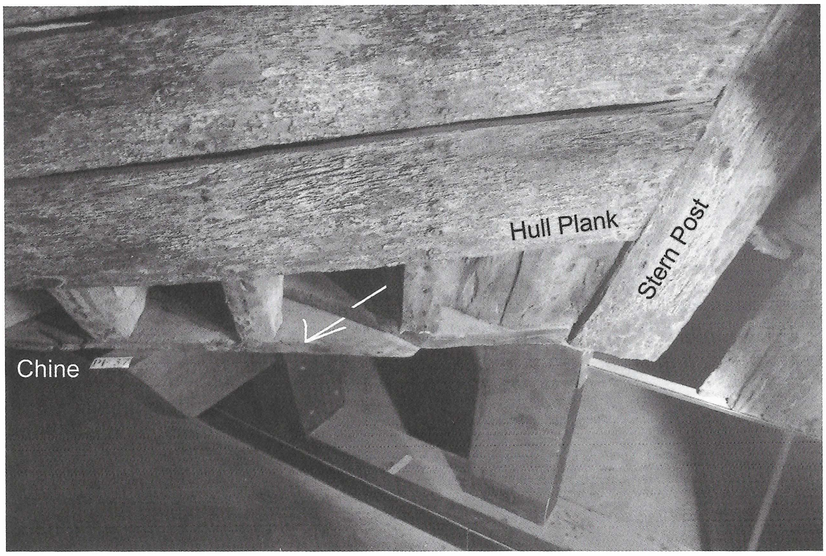
Narrowing

In Figure 6.49c the forwardmost template was moved inward—narrowed—by the amount *yy*. Without some method of defining the intervening longitudinal curvature, no additional templates can be raised between the midship frame and this tail frame. In Mediterranean molding the longitudinal curvature is defined by the arithmetic or geometric methods of generating offsets for a curve, such as the mezzaluna, that were discussed in Section I of this chapter. For this example, a scaling triangle was constructed using *La Belle*'s forward "mother sequence" to derive the narrowing offsets. When these offsets for a curve are marked on the floor template, they provide guide points for shifting the template inward at specified frame positions, and only when these offsets are correlated with evenly spaced frame positions do they define fair longitudinal curves (Figure 6.49c, d).

The templates are marked with the narrowing offsets relative to the centerline of the vessel. This allows for the practical shifting of the template, specifically during construction when the template is placed directly on the timber without any external points of reference. In fact, on the vessels associated with Mediterranean molding, surmarks on the floor timbers are usually accompanied by vertical lines marking the edges of the keel and/or centerline. In addition to aiding in positioning the frames on the keel, these marks would have been used to align the template when it was flipped on a piece of squared compass timber to trace out the opposite arm of the floor timber (Figure 6.49r).

A hypothetical curve drawn through the narrowing offset marks on the templates would not actually lie on the curved surface of the hull. However, above the flat of the floor the shifting of the templates defines identical narrowing curves along any consistent point on those templates (Figure 6.49d). Figure 6.49e, f illustrate the concept that all the change in hull curvature in Figure 6.49d could actually be defined by lower bilge or chine curves drawn on a flat horizontal surface. This is due to the fact that all the longitudinal curves depicted in Figure 6.49d are identical and all the templates have the same shape above the flat of the floor. Although the restrictions or rules placed on the transverse geometry, e.g., using one set of templates, are important, it is the definition of longitudinal curvature that actually quantifies the change in hull curvature along the length of the vessel. In other words, although in Mediterranean molding templates are utilized to enable frame-first construction, Mediterranean molding does not simply equate with frame-based design.

In a completely flat-bottomed vessel, these chine curves could be drawn on a platform of planks. Once the bottom planking was cut to shape, identical futtock timbers could be secured along the chine. In essence the chine curve is extruded upward following the transverse contour defined by these identical futtock timbers. While working with archaeologist Peter Fix on a conservation assessment of the flat-bottomed gunboat *Philadelphia* (1776), housed in the Smithsonian National Museum of American History, several "V" marks and offset lines very similar to those depicted in Figure 6.49e were discovered scribed on a section of exposed bottom planking along the chine (Figure 6.50) (Pevny 2010). These "V" marks are very similar to surmarks in terms of the underlying design concept, and yet they are located on the longitudinal hull planks and not on transversely oriented frames. This example underscores the importance of differentiating between design concepts and their manifestation in the construction sequence.



6.50. The lower stern of the flat-bottomed gunboat *Philadelphia* (1776) housed in the Smithsonian National Museum of American History. An arrow formed by a "V" mark at the end of a transverse line scribed into the bottom planking is accentuated in white. (Photo by author.)

Framing Patterns and Templates

Templates are made from thin planks, while actual framing timbers have substantial sided dimensions. Therefore an unbeveled framing timber will only fit the curvature defined by a template along one of its vertical faces. Which face conforms to the hull curvature depends on whether the timber is positioned before or abaft the conceptual design plane at the frame station (Figure 6.49g).

As is shown in Figure 6.49g, from amidships forward, an underbevel has to be cut for any timber before the design plane and a standing bevel for any timber abaft the design plane. When laying out for underbevels there is always the assurance of excess wood that can be cut away to make the outboard face conform to the hull curvature. In Figure 49h, i, k, all floor timbers are positioned for underbeveling relative to the frame station. Figure 6.49h, i depict variations of a stepped framing arrangement, and Figure 6.49k shows the same partial double framing arrangement as on *La Belle*.

In Figure 6.49h the first futtock at frame station *VIA* is placed on the side of the floor timber oriented toward amidships, its after face. Thus the adjoining faces of the floor timber and first futtock align with the frame station line at the theoretical design plane defined by the templates. There is no documented example of such a relative placement of first futtocks to floor timbers that has been associated with traditional Mediterranean molding. There is some evidence that such a relative placement of floor timbers and first futtocks was used in English shipbuilding. An early seventeenth-century shipbuilding manuscript copied by Newton directly addresses the issue of creating in-line design planes (Barker 1994). As understood by the author, it describes the relative placement of first futtocks to floor timbers shown in Figure 6.49h. Furthermore, this is the relative arrangement of floor timbers to futtocks that is common within the complete double framing of the eighteenth and nineteenth centuries in European and American shipbuilding (Murray 1765:173–174; McKay 1839:48). In this framing arrangement floor timbers are underbeveled, but the first futtocks have to be laid out with standing bevels.

All the archaeological examples of "marked" vessel remains have the relative placement of first futtocks to floor timbers that is depicted in Figure 6.49i,l. Before amidships the first futtocks are placed before the floor timbers, and abaft amidships they are placed abaft the floor timbers. It would seem a foregone conclusion that in vessels with stepped framing the adjoining face would have to be the design face since it is the only continuous plane. With the first futtocks placed on the side of the floor timber distant from midship frame, it is indeed reasonable to conclude that their shapes must have been drawn out on the adjoining face and underbeveled.

In order for the design faces of the first futtocks to be in line with the design faces of the floor timbers, the floor timbers would have to be laid out with standing bevels relative to the adjoining face (Figure 6.49l). However, on all the "marked" vessels except the 1738 chayka-type vessel, the design marks and, in general, the frame numbers appear on the open face of the floor timbers oriented toward the midship frame. Similarly, the early seventeenth-century depiction of a midship frame by João Baptista Lavanha ([1608]:fol. 71r) shows surmarks on the open faces of the floor and second futtocks (Figure 6.4b).

Visible surmarks on the open faces of the floor timbers may have been useful during construction. They allow for symmetry to be easily checked during frame raising and would guide the positioning of ribbands. Such ribbands would have been used to hold the design frames in proper alignment as well as to define the shape of the hull to aid in shaping and fitting of additional timbers. Visibility is certainly the reason why *La Belle*'s shipwrights carved surmarks on the after faces of the after first futtocks of the midship frame versus the after design faces of the floor timbers and second futtocks, which are completely concealed at the bilge (Figure 6.1).

Since the open faces of the floor timbers would be the logical place for surmarks in terms of visibility, the presence of design marks on the open face cannot be simply used to identify it as the design face. However, the issue of visibility does not explain why on "marked" vessels centerline marks and almost all location labels also appear on the open faces of the floor timbers. Along the centerline both the forward and after faces of the floor timbers are equally visible. It would seem logical, although it cannot be presumed, for the shipwright to have carved these design marks and numbers on the face of the floor timber on which its shape was originally drawn. Furthermore, as in the case of *La Belle*, transferring surmarks onto the design faces of the timbers of the predetermined frames would be essential for laying out the bevels. At these points the shipwright could determine the amount of change in curvature to the opposite side of the timber and draw the back curve with the aid of the same template.

Although it could still be argued that for frame raising it would have been useful to have all the design marks and labels on one face, in some cases could the open faces of the floor timbers simply have been the design faces? In Figure 6.49i the floor timber design faces are the open faces oriented toward the midship frame. With this framing timber placement and arrangement, the design faces of the floor timber and first futtocks do not lie in the same plane. This would not necessarily pose a problem in actual construction. One of the features of Mediterranean molding is that all the frame shapes are derived from the same transverse shape. Therefore, as long as the surmarks of the first futtocks are positioned along the curves defined by the surmarks of the floor timbers, the separation of the design planes by a single sided dimension would have a minimal impact on the overall fairness of the hull shape. This is particularly true if the tail frames are set fairly far from the ends of the vessel; the bevel angles on all the design frames would be relatively small. One of the benefits of this framing arrangement, in terms of ease of construction, would be the underbeveling of all the frame components. Underbeveling itself would give the shipwrights a margin of flexibility in fairing out the frames. However, it would still be critical to assure that the overlaps of the floors and first futtocks aligned properly at the surmarks. The frame drawing in Lavanha's treatise (Figure 6.4b) depicts lines on the inboard faces of the frames that were certainly used to transfer the surmark locations from the design face of the floor timber across to the opposite face. Unfortunately, the direction of transfer is not specified along with the mechanism of transfer.

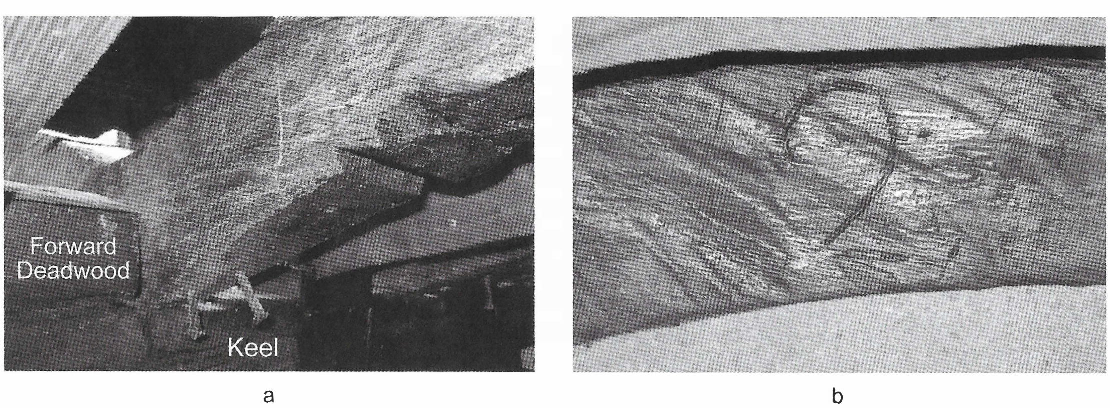
Once the surmark alignment was assured, it would have been imperative to secure and maintain each floor timber and its two futtocks in this orientation when being raised into position as an integral unit or during sequential assembly on the keel. It seems this was accomplished by the use of the hook or dovetail scarfs that distinguish some or all the design frames in the Mediterranean molding method. Combined with their fastenings, such scarfs would keep the floor timbers and first futtocks from slipping out of alignment. Almost certainly during actual construction temporary beams (cross-spalls) and braces would have also been used to help maintain the shapes and positions of the design frames. It seems that on at least some "Iberian/Atlantic" archaeological hull remains, preassembled frames with dovetail scarfs may represent only the central portion of the frames with predetermined design (see Loewen 1998a).

Thus far no consistent correlation has been established between any supplementary marks or scarf features on the adjoining faces of design frames and surmark locations on the open faces of the floor timbers (Figure 6.49j) (in relation to dovetail mortices, see Barker 2001:221). If the adjoining faces of the floor timbers were widely used as design faces, one would expect such a correlation to be prominent. On some of the "marked" vessel remains this lack of correlation may be a clear indication that the adjoining faces of the floor timbers were not used for laying out the frame shapes. On others the issue of such a correlation has not been sufficiently explored, and future research may indeed reveal the use of the adjoining faces for design on some of these vessels.

The "marked" vessel found in Ukraine (Kobaliya and Nef'odov 2005) provides an example of the use of the adjoining faces for design along with the Mediterranean molding method (schematically depicted in Figure 6.49l). In both 2008 and 2009, the author was fortunate to have the opportunity to examine briefly one of several 1738 vessels found along the banks of the Khortytsia Island on the Dnipro River in Ukraine.

On this vessel there are no surmarks on the open faces of the floor timbers oriented toward amidships. However, the hooks of the floor timber to futtock scarfs on the design frames are almost certainly placed at the equivalent of surmark locations. First, these scarfs are present only on the frames between the deadwoods, and their hooks are cut perfectly vertical on each frame. Second and most significantly, the hooks define symmetrical port and starboard longitudinal curves. This second feature of these scarfs is consistent with the geometric principles governing Mediterranean molding design. Bolstering the conclusion that the hooks themselves are at surmark locations on the design faces is the fact that all other design marks and labels are on the adjoining faces of the floor timbers and first futtocks (Figure 6.51a). They are visible because this vessel has stepped framing and these marks and labels are located beyond the areas of timber overlap. Unlike in all other archaeological examples, the location labels use Arabic versus Roman numerals and the numbering runs from the two tail frames toward amidships (Kobaliya and Nef'odov 2005:39). All the floor timbers of these numbered design frames also have vertical marks at both the centerline and the edges of the keel, and like the numbers, these marks are located on the faces of the floor timbers oriented away from amidships. Although the hull was mostly articulated when first examined, one of the loose first futtocks had the frame number "2" carved on what corresponded to its adjoining face when in position (Figure 6.51b). Other than on *La Belle*, this is the only example that the author knows of a labeled futtock timber.

La Belle retains the same relative placement of first futtocks to floor timbers as is typical of Mediterranean molding. Yet on *La Belle* this stepped framing arrangement was transformed to a partial double framing arrangement, with the second futtocks



6.51. Numbers carved into a vessel dating to 1738 discovered along the banks of Khortytsa Island on the Dnipro River in Ukraine: *(a)* floor; *(b)* futtock. This vessel is presently housed in the conservation facilities of the museum of the National Preserve Khortytsa. (Photos by Maria Pevny.)

butting up to the ends of the floor timbers and the third futtocks to the heads of the first futtocks. *La Belle* has its location labels and surmarks located on the open faces oriented toward amidships on both its floor timbers and second futtocks. In the case of *La Belle*, all the frames bear location labels, thus these labels do not distinguish the design frames. Similarly, all of *La Belle*'s frames have similar scarfs between the floor timbers and first futtocks. It is the presence of surmarks and the differing angles of the fore and aft fastenings that primarily distinguish the design frames.

A partial double framing arrangement such as *La Belle*'s could have been introduced for purely structural reasons, but this new framing arrangement is also integral to the use of a new design system on *La Belle*. As was discussed in Section I, the design with diagonals necessitates a continuous design face, and there is strong evidence that *La Belle*'s mold frames were laid out on and underbeveled from the surmarked open faces of the floor timbers and second futtocks. The shapes of the component timbers in this partial double framing arrangement no longer parallel the shapes of the overlapping design templates used with Mediterranean molding (Figure 6.49k). Therefore, there is no correlation between any scarf features and the surmark locations, and the surmarks were not necessarily used to assure the proper alignment of the two layers of timbers that compose each individual frame. The first and third futtocks simply serve as backing timbers to maintain the shape-defining floor timbers and second futtocks in their proper alignment.

Rising of the Templates

The interrelationship between framing patterns and design faces is illustrated with drawings that only depict the narrowing of the hull. This made creating the drawings far simpler, but in reality all known applications of Mediterranean molding define both narrowing and rising adjustments of the floor at the tail frames.

In Figure 6.49m the tail frame is elevated the distance *zz* above the keel. Note that the small additional distance between *zz* and the floor template is the deadrise at the midship frame as shown in Figure 6.49a. As with the narrowing of the hull, this total rising distance had to be subdivided into offsets for a curve that determined how much the template has to be elevated at each design frame station. These offsets are marked on a separate rising board that is used in conjunction with the templates (Figure 6.49a, m–r).

Diagonals in Mediterranean Molding

As with the narrowing scale, a curve drawn through the rising offsets at the centerline would not define an actual curve on the hull. It is for the practical reason of being able to adjust the master template on the timbers that the narrowing and rising increments for the lower hull were applied relative to the centerline. In fact, the narrowing and rising shifts in Mediterranean molding can be conceived as diagonal shifts at anchor points such as the bilge surmarks. Interpreted this way, the narrowing and rising curves defined by the two sets of offsets combine into a single longitudinal run on the hull (Figure 6.49n). Although a bilge curve running along the surmarks would only become apparent once the frames were raised, the author believes, its quantification is a foundational concept of the Mediterranean molding design method.

Only when the same types of offset sequences for both the narrowing and rising curves are applied over the same number of frames does the combined bilge curve appear as a perfectly straight oblique line when viewed from the ends of the vessel or projected onto a transverse plane as in Figure 6.49n, o. In these examples, the result is a diagonal because *La Belle*'s offset sequence was used for both the narrowing and rising. Similarly, the same series of narrowing and rising shifts at the top of the futtocks combine to define a diagonal that has the same slope and offset spacing as the floor diagonal (the uppermost diagonal in Figure 6.49o). In this figure identical futtock templates were raised on the port side. Their bilge curves overlap those of the floor templates with the surmarks perfectly aligned.

Since with the nongraphic Mediterranean molding method there is no body plan in which to first plot straight oblique lines (diagonals), the combinations of rising and narrowing curves more often than not result in an oblique run with a slight degree of curvature. This is because different types of sequences were sometimes used for the narrowing and rising offsets and/or rising was not applied starting from the midship frame. Nonetheless, the general orientation of these runs could still be characterized as diagonal when viewed from the ends of the vessel.

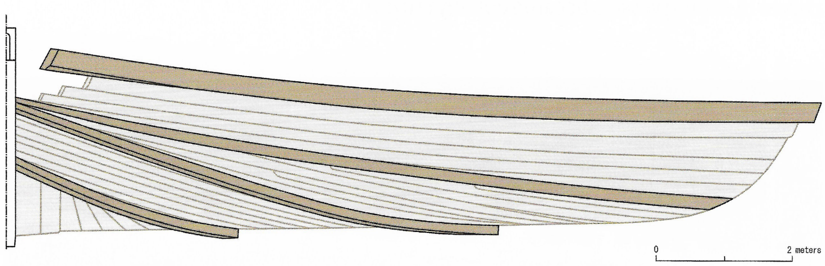
Defining Longitudinal Runs: A Broad Perspective

It is important to note that such diagonal runs are a general characteristic of planking patterns in shipbuilding—in both shell-first and frame-first construction. On most vessels, when planks are bent to conform to the hull shape, they run diagonally when viewed from the ends of the vessel (Figures 6.46a, 6.52). This is a consistent and predictable behavior, particularly for planks that are straight before being fitted to the hull and which are bent on without excessive edge-set—their natural or normal runs (Chapelle 1969:376–377; Pardey 1991:193–196). It is the author's opinion that this makes such runs at distinct or "key" points of shape transition ideal for regularizing or regulating hull curvature during construction.

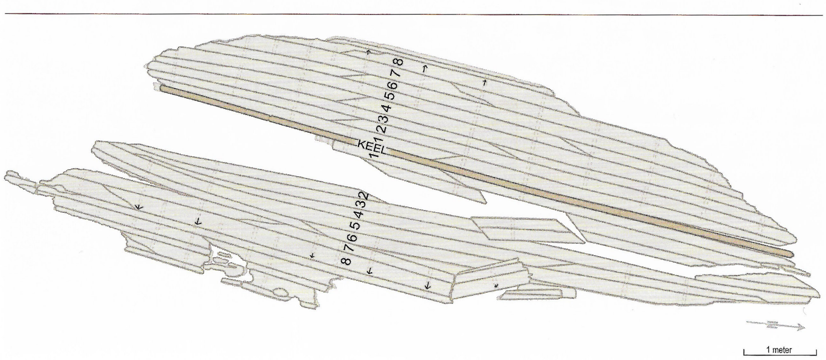
Intriguingly, on the remains of a vessel built shell-first, the Jules Verne 7 from the end of the sixth century BCE discovered in Marseille, the planks of the eighth runs (strakes) on both the port and starboard sides have shipwrights' marks on their inboard faces (Pomey 1998:63–64, 2009:57–59) (Figure 6.53). The asymmetry of the first seven strakes on the port and starboard sides of this vessel is regularized with these eighth strakes. Patrice Pomey refers to these as the "adjustment strakes" (Pomey 2009:59). Pointing to the upper edges of these strakes are regularly spaced "arrow" marks corresponding to frame positions (Figure 6.53). In this vessel framing timbers were added only after parts of the hull shape were defined by the edge-joined shell of planks, thus the "arrow" marks on these longitudinal runs were made prior to the insertion of the framing. The next strakes above the "marked" adjustment strakes are thicker planks known as wales; these wales clearly define the lower "sectors" of planking on both sides of the vessel.

Such distinct "sectors" of planking are also evident in an end-on view of the planking of the second Nemi ship from the middle of the first century AD that was discovered in Lake Nemi, Italy (Figure 6.52). On this vessel the "sectors" of planking in the lower hull are also bounded by wales. An end-on view allows us to visualize these "sectors" from a modern perspective, but researcher Marco Bonino has proposed that the formal definition of the longitudinal geometry of some of these runs constituted part of the design of the hull (Bonino 1989; Pomey 2009:60).

Centuries separate these two examples, and many more intervene before the



6.52. "Sectors" of planking accentuated in a drawing of the second Nemi ship from the mid-first century AD. (After Ucelli 1950:Plate VIII; also see Bonino 1989:50). (Modified by author.)



6.53. "Arrow" marks and planking seams accentuated on a site plan of the Jules Verne 7 vessel from the end of the sixth century BCE (Modified by author based on original site plan by M. Rival and after Pomey 1998:63.)

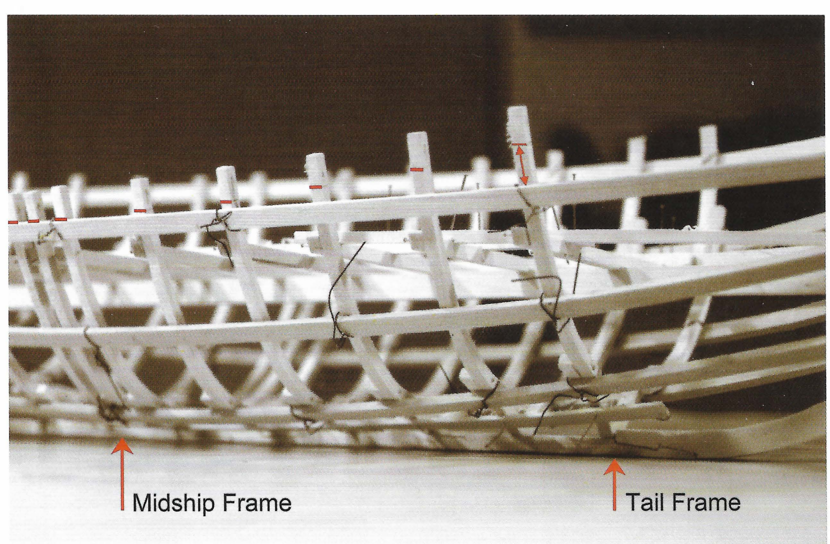
earliest evidence for the use of the Mediterranean molding design method in conjunction with frame-first construction; this does not allow us to draw any direct "evolutionary" connections. However, these examples, together with the above presentation of Mediterranean molding, underscore the existence of universal features in the geometry of planked hulls that would have been evident to shipwrights undertaking a transition from shell-first to frame-first construction—whenever and to whatever degree. The author believes that ultimately the practice of regulating hull curvature along designated strake runs, whether normal runs or not, led to the quantification of idealized plank or ribband runs in geometric methods of hull design (for related views, see Barker 1988:544–547; Beltrame and Bondioli 2006; Boudriot 1994:50–51; Sarsfield 1988:70–72, 1991:141–144). It is proposed that to be able to quantify such runs, they were broken up into their narrowing and rising components. This enabled offsets to be generated for practical use in ship construction: for example, in marking templates for frame-first construction.

Upper Narrowing and Rising

To gain independent control over the curvature higher up in the hull, in more advanced versions of Mediterranean molding, additional offsets were introduced to allow the curves of the upper hull to narrow and rise differently than those in the lower hull.

In Figure 6.49o, an additional set of offsets reduces the slope of the rising curve at the breadth surmark. Analyzed graphically, this upper rising adjustment reduces the slope of the diagonal in the body plan. On the starboard side of the vessel in this drawing, the futtock templates were cut down along the adjusted upper rising curve. This was done to show how the top timber templates could then be slipped in with their surmarks aligning with the adjusted upper surmarks on the futtock templates.

Such a reduction in slope of the diagonal runs in the upper hull is clearly visible in a stern view of the fifteenth-century votive model from Mataro in Catalonia, Spain (Figure 6.46a) (Winter 1956). Figure 6.54 is a photograph of a research model the author built while studying the use of Mediterranean molding in fifteenth-century Venetian ship construction. It depicts how a ribband run "normal" in the upper hull (at the *bocha*) significantly flattens the slope of the longitudinal curve defined by the lower narrowing and rising adjustments (Figure 6.54). In the construction of galleys, for which the exact height of the oarsmen is vital, the quantification of such additional adjustments would have been critical and appears in the historical records by the late fifteenth century (Bellabarba 1993:284–286; Lane 1934:29–31). Similarly, as the layout and functionality of gun decks gained in importance over the course of the sixteenth and seventeenth centuries, quantitative control over the upper design curves in sailing vessels became equally critical.



6.54. A research model under construction depicting the difference between the normal run of a batten on the upper parts of the futtocks and the upward shift of surmarks as a result of the lower rising. (Model and photo by author.)

The shape of the midship section impacts the relative amounts of narrowing and rising required to have fine curves low in the hull while retaining fullness in the upper hull. The rising of a midship section with a narrow floor actually results in a significantly greater narrowing of the curves along horizontal lines in the lower hull than in the upper hull. In our example the need for substantial narrowing of the floor results in excessive narrowing at deck level. The additional offset scale applied at the breadth in Figure 6.49p controls the splaying out of the upper futtocks and reduces the amount of narrowing in the upper hull. In Figure 6.49p the port futtock templates were rotated at the bilge as they were simultaneously tilted out. In Mediterranean molding the surmark on the bilge served as either the anchor point for pivoting or a reference point for rotating the futtock in order to separately control the narrowing of the hull at the top of the futtock mold. Thus the scales that appear at the bilge on the futtock templates in Figure 6.49q were not derived directly. They were marked off as the futtocks were tilted and rotated (Figure 6.49p). It is the offsets on a separate splaying out staff (upper narrowing) that directly quantify the adjustment to the narrowing of the hull. Note that in Figure 6.49p, q a new set of upper rising offsets was used to reset the rising of the breadth curve.

As the final step, the frame outlines generated by adjusting the positions of the templates are joined to the keel. For simplicity, in these examples straight lines were drawn tangent to the bilge curves (Figure 6.49o–q), although treatise evidence indicates that reverse curves were commonly drawn by flipping one of the two templates and using it as a pattern.

Conclusion

It is important to reemphasize that the Mediterranean molding design method does not rely on two-dimensional versions of the conceptual drawings in Figure 6.49. Mediterranean molding is a nongraphic system of design, and the actual definition of the frame shapes begins when the shipwright lays the template on a piece of framing timber (Figure 6.49r). What these isometric drawings hopefully convey is that the quantification of "key" runs on a hull is the fundamental concept behind the increments of offsets marked on the templates used in Mediterranean molding.

In fact, in Mediterranean molding the shape of the hull beyond the tail frames was defined during construction using actual ribbands that were extended from the design frames to the ends of the vessel. The frames at the ends of the hull would be cut to match the hull shape defined by these ribbands. This process simply represents a physical extension of the same concept that was used for the design frames. In a Portuguese treatise by João Baptista Lavanha [1608] and an anonymous French treatise on galleys from 1691, supplementary methods are presented for predetermining the shapes of the frames beyond the tail frames (Lavanha [1608]:163–167; Marine Royale 1691:19–32). Both these treatises describe methods of defining the shapes of the ends of the hull with graphic versions of ribbands depicted as narrowing and/or rising curves in the breadth and sheer plans of a drawing. These treatises do not contain a transverse view of the ribbands as do the French drafts discussed in this chapter; however, these ribbands are conceptually presented as graphic extensions of the design between the tail frames.

Even in the most elaborate versions of Mediterranean molding the change in hull curvature is only defined along two longitudinal curves on each side of the vessel. The lower narrowing and rising offsets quantify change along the bilge curves, and the upper narrowing and rising offsets adjust the change along the breadth curves. The standardization of transverse shapes above, below, and in between these controlling curves allow for the complete hull shape to be defined between the tail frames. This concept of using mathematically defined longitudinal curves to provide guide points for drawing or positioning transverse shapes with restricted geometry is the essence of the geometric fairing method (Rabl 1941:28, 38). Using this approach, shipwrights for centuries were able to duplicate effectively the basic hull shapes of vessels they deemed successful and make quantifiable changes to generate new hull designs. Indeed, Mediterranean molding was probably the dominant method used in French naval shipyards through the end of the seventeenth century (Rieth 2001).

Although it is possible to develop quite complex curvature using Mediterranean molding design, this method has an inherent limitation. Since it is a nongraphic system, all the sets of offsets that define the change in hull curvature have to literally be marked on the templates themselves. This dependency on one set of templates to both mark the positions of the curvature control points on the timbers and define the curves between these points makes it difficult to add additional longitudinal controlling curves to the system. This increasingly becomes a problem in the ends of the vessel, where the change in curvature becomes more pronounced and such additional control is desirable. Therefore, the predetermination of frame shapes with Mediterranean molding is limited to the portion of the hull between the tail frames.

The added ability to adjust the upper narrowing and rising enables the tail frames to be placed nearer the ends, since it allows for greater flexibility in narrowing and rising the bilge curve. Nonetheless, one of the big shortcomings of Mediterranean molding is the fact that only one set of narrowing and rising increments controls the definition of the longitudinal curvature along the bilge of the hull. As can be seen in the drawing of *La Belle*'s frames, as in the French drafts presented in Section I of the chapter, moving away from amidships the curvature between the two lower diagonals progressively flattens and ultimately changes from convex to concave (Figures 6.5, 6.6, 6.7, 6.18, 6.19, 6.47). The use of two sets of bilge surmarks as points of control does not appear in any documented methods of Mediterranean molding, and thus control of this area of transition is severely limited.

It is important to note that in French drafts using the "geometric fairing with diagonals" method, the curves between the lowest two diagonals are not single arcs. The procedures by which the control points on the diagonals were joined with transverse curves in these drafts are unknown, and this aspect of the design process is not clarified in later descriptions of this design method. In the reconstruction of *La Belle*'s design, single arcs with radii changing from one frame to the next were used to draw the curves between the diagonal guide points (Figure 6.47), but this remains the most tentative part of the reconstructed design sequence. This ambiguity arises from the fact that the introduction of additional longitudinal control curves reduces the importance of the restrictions or rules imposed on the transverse geometry. The rules or restrictions for drawing the transverse shapes is a necessity with only a limited number of guide points, but this is only a secondary aspect to the evolution of geometric methods in Western ship design. The fundamental concept in these design methods is the quantification of longitudinal curvature.

French shipwrights were able to expand on this basic concept of Mediterranean molding by merging it with the principles of orthographic projection. In the process of developing a graphic design method, the French shipwrights limited the curvature of longitudinal runs to flat design planes both before and abaft amidships. Therefore, in this "new" French design method, the normal runs of planks or ribbands, exhibiting double curvature, were transformed into design diagonals that are always straight in the body plan. These diagonals would be drawn first in the body plan without the use of any transverse templates. Curve offsets could then be directly plotted on these diagonals, thus making it possible to draw the shapes of all the design frames in one cross-sectional view—the body plan. However, in the sheer and breadth plans, the curves defined by these diagonals were still separated into their narrowing and rising components in order to show how these diagonal curves would actually appear on the hull in plan and profile.

This transition to graphic design was thus dependent on both the knowledge of the existing methods of quantifying curvature in ship design and advances in orthographic drawing methods in terrestrial art, architecture, and engineering. It is an intriguing possibility that this is exactly the mixing of ideas that occurred when terrestrial architects were brought to Toulon to teach the next generation of shipwrights drafting methods. Unfortunately, from the surviving historical evidence it is only known that this interaction occurred and not specifically what drawing methods were developed or how quickly or widely they were adapted. For example, the same François Coulomb, who drew the 1684 flute draft illustrating the method of geometric fairing with diagonals (Figure 6.7), wrote a description of the Mediterranean molding method of design in 1683 (Lemineur 2007; Rieth 1998b). This manuscript presumably was meant to represent the current method of ship design since it was based on his lessons at the school for naval cadets in Toulon, where he had been the head instructor since 1681. Although François Coulomb presents an innovative method of extending the design of the floor timbers to the ends of the hull, the basic method he describes is traditional Mediterranean molding (Rieth 1998b).

Although such evidence indicates that this was a period of experimentation and transition in design, *La Belle*'s archaeological remains clearly show that the new method of graphic design with diagonals was already effectively being used for the everyday construction of vessels by 1684. *La Belle*'s example also concretely shows that this shift to graphic design allowed for both the predetermination of a larger percentage of the hull shape and greater flexibility in drawing the frame shapes.

Because the diagonals are drawn and the guide points are defined without the use of any transverse templates in this design method, it is in theory possible to insert as many diagonals as desired. With only one additional bilge diagonal added, it is still necessary to have some geometrical rules for joining the widely spaced guide points. With the introduction of more diagonals and thus with more guide points, such restrictions became increasingly unnecessary. Duhamel du Monceau (1758:241) states that an experienced designer can join these points freehand, while a novice may have to resort to bending small ribbands or splines as an aid. Since bending splines does not involve any regular geometry or quantification, this is a major step toward freedom of design. In addition, Duhamel du Monceau (1758:233) states that the diagonals themselves can be oriented at various angles to the baseline of the equilateral triangle. Changing the angle of these lines relative to the baseline allows for the altering of the nature of the curve of the diagonal along its length, while still retaining a similarity of curvature with the other diagonals. The choice of these angles is completely at the designer's discretion without any additional rules or restrictions. Mungo Murray, who wrote a treatise on shipbuilding that includes a translation of Duhamel du Monceau's work, writes in frustration on the inability to formalize this method: "but as the artists leave us so much undetermined as to the angles that each diagonal is to make . . . when they are applied to the triangle, it will be very difficult to apply this method to practice" (Duhamel 1764:32; Murray 1765).

By the beginning of the nineteenth century this trend toward overcoming the restrictions inherent to geometric fairing methods results in a great conceptual leap—the almost complete abandonment of geometric fairing. The modern drawing of a hull adopted at about this time, the lines drawing, is conceptually the graphic equivalent of carving a model of the hull shape in wood. Unlike in geometric fairing, in which measurements are generated in order to draw fair curves, in this graphic version of optical fairing, measurements for construction are taken from curves that have been drawn without any mathematical rules or restrictions. Thus the lines drawing offers complete freedom to define any shape desired.

With the development of the lines drawing method of hull design there was the realization that the use of geometric fairing methods does not have any inherent connection with the performance of a hull shape. What they did offer through the centuries of their use was a method of standardizing and replicating hull shapes that were empirically determined to be desirable. It is important to keep in mind that the development of these geometric design methods predates the discovery and practical application of most scientific methods of reliably predicting hull performance (Ferreiro 2007; Phillips-Birt 1957:1–17). In addition, by predetermining frame shapes, these methods made it possible to build using a frame-first construction sequence that is both practical and economical.

This does not mean that the development of design methods that enabled the predetermination of frame shapes for a frame-first construction sequence were a complete conceptual shift from the design principles involved in shell-first construction. Analyzed from the perspective presented in this chapter, the design methods used to allow for frame-first construction do not equate with frame-first design. Quite the contrary, it is the quantification of longitudinal curves, versus transverse curves, that has an equal if not a dominant role in designing the overall hull shape.

The author believes that the idea of quantifying runs of planks at key points of curvature change on a hull formed the conceptual basis for the development of predetermination in Western ship design. As a result, when looking for evidence for the evolution of predetermination in ship design, it is as important to look for clues to the quantification of longitudinal curves in terms of planking patterns, design marks, longitudinal alignment of framing scarfs, etc., as it is to find clues of "active" framing elements that were erected prior to the planking.

Note

1. For this chapter Mr. Pevny had the opportunity to address some points of Toni Carrell's interpretation as presented in her dissertation (Carrell 2003). Carrell was given the opportunity to read Pevny's chapter and revise her contribution for this publication, which she did. Though Pevnywas also permitted to read Carrell's revision, he chose to let his chapter stand as is. Readers are invited to study both contributions and to make their own decisions on the two interpretations of the design of *La Belle*'s hull.

REVIEW COMMENTARY (added to this pdf):

The two chapters addressing design

The editors of the book added the above note at the end of Pevny's Chapter 6. Toni Carrell's Chapter 5 titled "Hull analysis" is a partial summary of her 2003 dissertation for the University of St. Andrews; the dissertation is available at: https://research-repository.st-andrews.ac.uk/handle/10023/2798.

In a 2018 review of the book for the *International Journal of Maritime History* (30(1): 153-157)—with regard to the overlapping material in these two chapters—Fred Hocker concludes the following:

"Pevny... presents a clear and sound case for his interpretation, which does not require any tortured gymnastics in interpreting the historical evidence or ignoring the significance of the markings on the frames. In fact, his interpretation rationally explains the meaning of all of the archaeological evidence in a coherent construction context. To him, *La Belle* is an early example of a new method of scientific design known to have been in use in the yard where the ship was built in the 1680s; it is by far the more convincing argument" (Hocker 2018: 157).

In addition, as part of a 2010 open peer review of Pevny's chapter for the Texas Historical Commission, Hocker wrote:

"This is a very impressive piece of geometric and archaeological detective work, which shows careful attention to the fine details of the archaeological evidence. It is very much relevant to the overall question of the development of hull design, and the author's conclusion about the relationship between pre-mathematical shell-based building methods and the quantification of longitudinal curvature is extremely important. I believe that this will be a significant chapter in the book."

Furthermore, in his review of the book Hocker notes that: "The editors [in the conclusion] take the trouble to address some of the problems in the main text, even largely contradicting the conclusions of Chapter 5 [Carrell's chapter]" (Hocker 2018: 155). The following are several excerpts from the concluding Chapter 40 by editors James E. Bruseth, Bradford M. Jones, Amy A. Borgens and Eric D. Ray, which support and reference the interpretations presented by Pevny in Chapter 6:

"Surmarks are associated with both the Mediterranean tradition and orthographic approach; however, the quantity and placement of the marks, in addition to other evidence, are more suggestive of the latter (Chapter 6 [Pevny's])." (Bruseth et al. 2017: 807)

"The surmarked frames not only provide clues to the design method but additional evidence that *La Belle* may have originally been constructed as a *barque en bottes* (in bundles), meaning that it was fabricated as a series of dismantled components that could be transported as a "kit" and later reassembled (Chapter 6 [Pevny's])." (Bruseth et al. 2017: 807)

"The proposal [Carrell's] that the ship timbers are reused contrasts with the physical evidence that suggests *La Belle* was newly constructed in 1684 (Chapter 6 [Pevny's]). The view that *La Belle* was a new ship was reinforced for the senior author of this chapter after spending 12 months during 2014 to 2015 reassembling the hull as part of an exhibit a the Bullock Texas State History Museum in Austin." (Bruseth et al. 2017: 808)

The lack of a lines drawing etc.

In his review of the overall book Fred Hocker does express his disappointment that "there is no actual presentation of the hull remains, no proper hull report which describes and illustrates the surviving parts of the hull in detail. There are three chapters which address the construction of the ship (Chapters 5, 6, and 9, by Carrell, Pevny, and Grieco, respectively), but none of the authors offers a detailed description of the hull remains as a base for the analysis..." (Hocker 2018: 156).

Hocker continues that “there is no final lines drawing (other than Grieco's simplified version for the model), no comprehensive longitudinal section, cross sections, or plan of the remains, in short no proper set of drawings that will allow the reader to see the construction of the hull and no comprehensive set of scantlings. For the reconstructed hull, there is no calculation of displacement, internal capacity, or the form coefficients that would allow us to compare La Belle to other hulls. Such things are, by now, more or less standard components of archaeological hull reconstructions. Why are they missing?" (Hocker 2017: 156)

It is surprising that Hocker does not attribute these shortcomings directly to Toni Carrell and the editors. Carrell’s chapter is titled "Hull Analysis" and is the leading chapter for the hull section in the book. The very specific topics of the chapters by Pevny and Grieco are evident from the titles—"Capturing the Curve: Underlying Concepts in the Design of the Hull" and "Modeling the Vessel"—as well as the content of each of the chapters. The chapters by Pevny and Grieco provide the reader with numerous and detailed figures that clearly and comprehensively illustrate the topics under discussion. In the 2010 peer review of Pevny's chapter for the Texas Historical Commission, Hocker himself wrote that "the heavy use of illustrations is essential to getting the complex ideas of this chapter across to a non-specialist audience, and **I can only think of one that really needs to be added**, an illustration of the arithmetical regression method Pevny proposes for generating the changes in curvature [subsequently added]. **The illustrations themselves are very clear and well drawn**."

However, in relation to Carrell’s chapter, Hocker's question of "Why are they missing?" is very legitimate. The shortcomings become even more puzzling when one considers that Carrell included in her dissertation many additional and pertinent drawings by Pevny (can be viewed at https://research-repository.st-andrews.ac.uk/handle/10023/2798), most of which she chose to omit from her book chapter along with any related discussions.

The originals for all of the following figures were reconstructed and drawn by Pevny at a scale of 1:10; they were used by Carrell in her 2002 final report for the Texas Historical Commission and in her 2003 dissertation (the dissertation page numbers are listed below):

pg.102 Unattributed body plan with reconstructed diagonals (every third central frame plus the end frames).
pg.116 Isometric drawing of keel timber remains.
pg. 119 Profile view of stem assembly remains.
pg. 124 Isometric view of keel and stem assembly remains.
pg. 128 Longitudinal section of centerline assembly remains with fastenings (keel, stem, stern post, floors and keelson).
pg. 132 Plan and profile views of all framing remains and centerline timbers.
pg. 143 Isometric drawing of the centerline timber assembly and every third frame.
pg. 146 Plan and profile views of the ceiling planking remains.
pg. 339 Unattributed cross section of master frame subsequently adapted by Donald Keith for arc analysis.
pg. 342 Unattributed cross sections of all forward frames subsequently adapted by Donald Keith for arc analysis.
pg. 345 Unattributed cross sections of all aft frames subsequently adapted by Donald Keith for arc analysis.
pg. 355 Cross section of master frame with ceiling planking.
pg. 357 Unattributed body plan with reconstructed diagonals.
pg. 363 **Lines plan of the hull remains** in reconstructed "as-built" orientation [unfortunately poorly reproduced].
pg. 375 Unattributed cross section of master frame subsequently adapted by Donald Keith for arc analysis.

No doubt, Pevny would have utilized these and more of his drawings if he had been tasked to present *La Belle*’s remains in a chapter titled "Hull Analysis”.

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Abbreviations

ADCM—Archives Départementales de la Charente-Maritime
AN—Archives Nationales de France
AR—Archives du Port de Rochefort
MnM—Musée national de la Marine, Paris
SHMR—Service Historique de la Marine, Rochefort

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