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UNDERSTANDING FAIRNESS

By

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Everyone knows that lofting produces a "fair" hull, and most readers of this magazine are familiar with waterlines, stations and buttocks and the lofting process in general. There are any number of articles and even whole books about lofting. These sources discuss the process and details well, but may (probably since it is obvious to the experienced authors) leave the reader wondering about the basic question: What is fairness and why should we be so mindful of it that the elaborate lofting process is required? After all, we don't loft houses - why should we loft boats?

The difference between houses and boats is that boats are curved in arbitrary ways (that is, in other than circles or other definite curves) so that it is not simple to determine the dimensions of enough points on the hull to build it. One way to find out enough information about the shape of the boat is to draw it at a large enough scale so that the dimensions can be measured directly. This is the lofting process: Just redraw the boat so the curves are consistent, smooth and fair. Then you can accurately measure any dimensions full scale.

Note that “full scale” isn’t really required. You only have to loft at a big enough scale to get the dimensions accurately and conveniently. Ships were often lofted at 1/10 scale on glass plates and the templates were enlarged photographically or by machines that followed the curves optically and controlled cutting torches. Most boats can be easily lofted at ¼ scale. The required dimensions could then be enlarged by a home made proportional divider. If the pivot of the divider is four times as far from one end as the other, the big opening will be exactly four times the small opening.

Consistency is required to determine if a collection of fair curves really form a fair surface. Let’s tackle consistency first quickly, just for review: Generally hand lofting is done on a flat surface. We can only see two dimensions at once. In plan view, we can see width (or half-breadth) and length. In profile, we can see height and length and in section, width and height. Occasionally slanted views (diagonals) are used that depict length and dimensions sloping in an athwartships plane. This means that we can measure any dimension in two views. We can measure a breadth in both the section and plan view, for example and both measurements have to be the same. Since the traditional contours are cut at specified locations, the intersections between the contours and the straight lines also give a dimension to the surface, usually in length. Suppose the two foot waterline crosses the three foot buttock in the plan view (so the waterline is a curve and the buttock, a plane seen on edge, is a straight line) six feet aft of the bow. In profile view, that same three foot buttock (which will be a curve in this view) has to cross the two foot waterline six feet aft of the bow as well because they are the same point in both views.

Lofting articles often define this as the principle of correspondence. To put it even more simply, consistency means that all of the views of all the curves define the same surface, not two or three different ones. (It is an old joke that people who buy plans from designers who don’t understand this are getting a bargain – they are getting three boats for the price of one.) This is an obvious requirement, because if a station and a waterline showed different half breadths at the same length and height, there would be no way to know which one was right, and the correct dimension needed for construction would remain unknown.

But why bother to draw three (or more) views? If we can measure any two dimensions and usually imply the third in any single view, why not just use one view, or at most two? Topographic maps adequately depict the earth’s curved surface with only one view, after all. The reason for several views goes back to the issue of fairness. Unless we can see all the contours on the surface as curves, we cannot judge the fairness of the curves and hence the fairness of the surface. If all the curves on a surface, running in different planes, are fair, then the surface itself must be fair. Strictly speaking, modern computer lofting programs can be used judge fairness in a single view. Plot out a very large number of very closely spaced stations and the Moire pattern formed (called a shadow plot) creates a pattern of mottled light and dark in unfair areas. However, the program by definition is actually working in three dimensions anyway, so it isn't really a single view. Also, experienced users of lofting programs actually spend a great deal of effort examining all three views for fairness.

But again, what then is a fair curve?

It helps to cover a bit of background first: If we examine a curve, at any point it has a value. For example, a waterline has a half-breadth at each point along its length. At some other point down the boat length, the waterline will generally have a different half-breadth. The ratio of the change in half-breadth to how far we have moved along the length is the slope between the two points, expressed just as we describe the grade of a road. – the percent of the grade is rise divided by run. A fifty-percent grade rises six inches for every foot of horizontal travel. If the two points are very close together, the slope is termed the "first derivative" at that point.

Since the first derivative is also a value that is determined by where we are along a line, we can plot it as well. It will form another curve, which we can examine in the same way. The slope of points along the first derivative is a derivative of the derivative, or the "second derivative" of the initial curve. Since the second derivative expresses the change of slope, it is related to curvature. In fact, the second derivative is approximately the inverse of the radius of curvature: If the radius is very large, the slope of the curve will change slowly. A straight line has the same slope throughout and thus a zero second derivative (its slope never changes). One over zero is essentially infinity, so a straight line has an infinite radius of curvature (it is an arc of an infinitely large circle). A smooth curve is one where the first derivative is continuous – that is, the slope doesn't change suddenly. This in turn means the curve doesn't have any corners or kinks. A fair curve also has a continuous second derivative – the radius of curvature doesn't change suddenly. One way of illustrating this is to construct perpendiculars close together along the curve (there is actually a special T-square like tool for doing this in traditional shipyard lofts). Two adjacent perpendiculars intersect at the approximate center of curvature of that segment of the curve. If a curve joining these intersections is continuous and smooth, the curve itself is fair.

We have to understand why we seek fairness to understand what this means. There are three main reasons for fairness: Aesthetics, hydrodynamics and constructability. The aesthetic issue is based mainly on tradition; we are used to seeing fair hulls and judge a boat's suitability this way. However, this tradition exists because fairness is a practical issue.

Fairness is important for hydrodynamics because water particles flow over the hull surface and their motion is governed by the derivatives of the curves on the hull surface. We can also examine other quantities in terms of derivatives, notably motion. If we plot position versus time for a moving object, the slope, or first derivative, is the rate of change of position against time. This of course is speed and the first derivative of speed, which is the second derivative of position, is acceleration. If we track a water particle around a hard corner, the particle has to suddenly change direction. This means that the particle has to acquire velocity in a new direction instantly, i.e. it has to accelerate at an infinite rate, which is impossible. Instead, the particle separates from the hull surface and forms a swirl, which increases resistance. If there is a sudden change in curvature, without a corner, such as a straight line tangent to a circle, a similar loss occurs: The sudden change in curvature is a jump in the second derivative of the curve. This means that a sudden change in the second derivative of position, acceleration, is required. This in turn means that there has to be a sudden application of a force. In a fluid, this requires a sudden change in pressure, which is impossible as well (at least without supersonic speeds or underwater explosions). Again, the water separates into a swirl, which increases resistance. This situation is not unique to water flow: "Railroad curves" are special French curves used in laying out railroad track. They consist of a circular arc, a straight section and a section connecting them which gradually increases the curvature to the desired radius. If straight track is directly connected to a circle, the side forces generated by the sudden change will cause the train to derail.

The most important reason for fairness is constructibility. Hand lofting is done by placing battens along a series of points and adjusting them until the batten passes through all of them. This is a very practical test because all hulls, except perhaps ferrocement ones, are made of some kind of elastic beams lying on the surface. The batten is simply a model elastic beam. By forcing points on the surface to lie on the batten we are verifying that we will be able to put a plank, plate, sheet of plywood, sheet of C-Flex, piece of foam core or whatever on the surface when we build it (or the tooling). We will also install the hull material by connecting it to the frames or station molds at a series of points along the beam. An understanding of how the planking will be bent on the real boat thus helps us to handle the battens when we loft. This in turn will assure us that the real test of fairness is met – we can build it easily.

If we apply forces at points along a beam a bending moment is created in the beam between each point. The beam will then bend to a radius proportional to the moment. The larger the moment, the tighter the radius (that is, the more the beam will curve) and the more force on the points. The moment in the beam is the distance between the forces times the force – it is a torque, just like a torque wrench. Just past one point, the moment in the beam is the distance to the next point times the load at the next point. The distance obviously changes directly with itself – i.e., each inch you move toward the next point, you get an inch closer to the next point. This means the moment changes linearly. Since we are just putting forces on each point, we can't take any torque at a point. This is why the radius of curvature can't jump. In order to do so, there would have to be a point torque, which is generally very difficult to produce on the real boat – it requires very large forces in opposite directions very close together. There are, of course, exceptions to this. In a metal boat, it is common to have a radiussed stem. The waterlines meeting the stem often do not fair into the stem (though they are smooth), but this is because the stem plate is usually a separately formed piece and there is no moment across the joint.

This tells us that when we loft, we have to look at the position and magnitude of the forces put on a batten, since we will have to duplicate them full size on the hull. For this reason, I dislike using nails to hold a batten. They can sustain a great deal of force without warning you. Weights will slide if they are forced. (A good test is to stomp the floor next to a weight. If it skids, it probably was too heavily loaded.) I like coffee cans or cut down bleach bottles filled with concrete or a mixture of left over catalyzed resin and sand. A bent nail or welding rod makes a good pointer, but I prefer not to place the pointer on the batten. Friction with the floor can create a local moment, and you will not know whether the weight is pulling or pushing (and you usually end up cracking a batten). Instead, push the pointer against the side of the batten – then at least the batten can lift away from an unnecessary restraint.

You also do not want to place weights any closer together than the frame spacing and the further apart, the better. It is also unwise to have adjacent weights pushing in opposite directions, as this implies the curvature is changing sign. Though this may fit the mathematical definition of fair, there is probably unnecessary curvature. The curve should be as simple as possible – which implies a judgment call. Always remember that you are testing the curve for constructibility. The technique of getting your eye in line with the curve, close to the floor and looking down it is called for here. Walking down the batten and lifting each weight in turn is a good test too. No single weight movement should change the shape of the curve. This means that the energy, and hence the force required to ultimately fasten down the plank, is minimum. Finally, though many sources advocate this, avoid placing weights beyond the ends of the hull as much as possible. If the batten is restrained outside the hull, the plank still has moment when it passes the last connection. It is very difficult to apply moment at a fastener or even a weld, so that the curve on the real boat will be different than that produced on the loft floor. This may not be important, but there is no point in intentionally distorting the curve.

Though full scale lofting rarely uses French curves, improper use of one during design is common. French curves are mainly for tracing lines produced by battens to ink them or making them dark, not for originating a curve. The curve on a French curve is fair, but a curve produced by tracing part of a French curve, then shifting it and tracing the rest almost certainly isn't – the radius of curvature is different on the two portions and shifting the curve produces a jump in curvature. There are also a number of devices that are used for making plots, especially pieces of lead enclosed in plastic. These also do not necessarily produce fair curves. One professor of naval architecture was famous for discovering students using these devices in the drafting room and throwing them (the devices, that is, not the students) out the window. If you want to use some kind of device, test it and make sure it always matches a batten. One family of devices uses a stack of battens and various means of connecting them. These devices sometimes work, but they can produce a continuous means of support, which may be hard to duplicate in the real ship. A similar point worth repeating for both design and full scale lofting is that tangency is smoothness, not fairness. It is common to see a straight line or gentle curve suddenly transform into a circular arc. This is not fair and may be difficult to build full size unless it is at an actual seam on the hull.

Computer programs for lofting are very helpful, but since fairness is at least partly a judgment call, they don't relieve us the duty to understand and ensure fairness – they only handle the busywork and spare us from getting down on our knees. These programs simply substitute mathematical battens and weights for real ones. Battens are also called "splines", and most programs use either an "interpolating cubic spline" or a "cubic B-spline" algorithm. The exact differences between them are not important for this discussion, but both are essentially models of an elastic beam. "Cubic" means that they have point forces, just like a real batten. Since the splines behave just like real battens, you must use them the same way. Most programs allow zooming in on a portion of the curve to examine it in detail for lumps. Most allow stretching a curve in one axis or another. This is basically the same as looking at it with your eye close to the floor. Most programs allow deleting or temporarily turning off a point. This is exactly the same as lifting off a weight. The one tool that software provides that you can't get on the floor are curvature plots: Most programs display a second derivative or a curvature plot. This is often in the form of "porcupines". Curvature is plotted as a line outward from the curve. A longer line represents a tighter radius of curvature. To use this feature, you make sure that the porcupines change smoothly and in the fashion you want, based on your knowledge of how the curvature of the surface affects the construction process. In general, most curves on the hull will begin at one end of the hull with no curvature, increase to a maximum, then decrease, ending with no curvature. They may change sign, but you should be mindful of this and ensure this is what is intended – they are S-shaped turns on the hull. Such reversing curves are not as common as ones that just decrease to zero. Often curves that do not lie perpendicular to the hull plating, such as low waterlines or outboard buttocks, will have two peaks in the porcupines, one at either end. This is OK for these curves as they are somewhat distorted by the extreme angles made when the cut the hull, but it should be viewed with suspicion for curves that are in a plane perpendicular to the hull. Several increases and decreases in the curvature down the length of the curve almost always represent unnecessary curvature.

We don't have this sort of tool available to use on the real lofting floor, but since the side forces on the weights are proportional to the moment in the batten, this is a direct measure of curvature, and every bit as good as a porcupine plot. Be sensitive to the forces on the weights, both their magnitude and direction, and you can get the best curvature in the batten. Very large forces requiring several closely spaced weights are a symptom of a problem. So are weights on alternating sides - this implies several increases and decreases in curvature. It is worth a few hours of just playing with a batten and some weights when you start learning to loft. Place the weights, look at the curve, lift them, intentionally try to make a curve that causes them to skid, intentionally place weights on alternating sides and so on.

A fair hull is simply one that we can build easily, at least in terms of bending the material it is made of into shape. By using either a real or mathematical batten to model the planking while we keep in mind the ultimate requirement to plank the hull, we can produce an attractive, hydrodynamically efficient, and buildable hull.

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