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Designing Plywood Boats: Hard Chines and Developable Panels

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I may be a rare one, but I've always found plywood boats with hard-chine hulls appealing. There are, on the one hand, numerous classic hard-chine designs with well proportioned traditional lines and, on the other hand, designers like Phil Bolger who have gone a long way in showing just how functional hard-chine plywood hull shapes can be. The hard-chine hull form is a fast, inexpensive, and sturdy way to build a boat.

Modern variations of building techniques make the hard-chine hull form even more appealing. Such variations have improved the strength and durability of sheet material joints. The best example of this is 'stitch-and-glue' or 'tack-and-tape' building. For those who may not yet be familiar with this approach, Sam Devlin provides a good primer (*WoodenBoat*, 1992, **106**, 80-89; book expected soon Devlin's Boatbuilding, International Marine). Other technical improvements such as multi-layer lamination of plywood sheet material allow for greater curvature and twist in designs while at the same time enhancing strength and stiffness (see Reul Parker's, The New Cold-Molded Boatbuilding, 1990, International Marine).

The Criticisms of Hard-Chine Hulls. Despite these positive qualities and expanding possibilities for hard-chine designs, critics often deride the hard-chine hull form. Such criticism frequently over-emphasizes the negatives in such features as hydrodynamics, for example by calling attention to the greater surface for a given cross-sectional area but illustrating only the worst case cross-sections. At the same time, positive features of chines (e.g. in lateral resistance) are usually underplayed. However, the most often heard objections to hard-chine hulls is with their 'boxy' aesthetics.

While many very appealing hard-chine designs do exist, one reason that others may be less successful is that to create a new hard chine is a tedious and difficult process. This difficulty results from the geometric awkwardness of designing with flexible sheets. Sheet material will only bend on a single axis, be the material paper or steel (short of torturing it). You can't shape a sheet of paper into a football, but you can make a conical or cylindrical paper cup. Similarly, you can't just lay sheet material over any set of hull lines and have it not buckle or crinkle. There are constraints on the curves over which sheet material will lie smoothly, even very flexible material, and thus there are limits to shapes that can be formed.

Shapes that can be formed from sheet material are technically termed 'developable surfaces.' Theoretically, such surfaces are composed of portions of cylinders or cones, or varied combinations of these two. On the one hand, this constraint is limiting, but on the other, considerable interesting and pleasing curvature can be gotten from variations and combinations of these shapes. The geometric constraint that panels of hard-chine hulls be developable makes designing such hulls at the drafting table time-consuming and difficult. It is just as cumbersome to design hulls by building models, an extensive trial and error process. As often as not, in actuality, hard-chine construction has proceeded in the boatshop without benefit of a drawing of the flattened shape of panels -- instead relying on simple (often cylindrical) panels, on the ability to spring and later trim the panel to a simple frame, on rules of thumb established by years of trial and error, or on patterns taken from similar hulls.

You can observe the emphasis on simple curves by studying the lines drawings of many hard-chined boats. If the cross-sections or stations seen in end-view consist of straight lines throughout a panel, the only shape that can fit that panel will be a portion of a cylinder. Many traditional skiffs, sharpies, and dories take this form. In contrast, if the panel has the shape of a portion of a cone, then some of the station sections will intersect the cone across its axis lines and produce a curved intersection. That is, the hull panel will look curved in cross-section, even though it is formed from a flat sheet. Indeed, if the panel shape is conical, there will be only one station that has a straight line intersect. The others, to some degree, will be curved. Note how this curved intersect shows that even a panel shaped as a portion of a single cone results in a hull form whose lines are more interesting because of having the curved sections.

Getting such curves in station cross-sections of hard-chine hulls is a good example of the way in which more interesting shapes can be formed from plywood. In Figure 1 I've illustrated how the natural curves of panels in a simple, single chine hull can actually generate smooth curves in the both bow and aft sections and transoms of a pram hull. An important point about such hull forms is that, given an accurate pattern of the flat shape of the panels, they are no more difficult to build than a hull with straight cross-sections. Indeed these curves represent the natural curve of the surface of the plywood and will appear virtually automatically if the panels are expanded accurately and fitted tightly at the chine. Try this yourself in a model by cutting out and taping together the panels of the little pram printed as Figure 2. As an aside, you should be suspicious of any 'lines' drawing that has straight but non-parallel station lines in end view. In such instances it is unlikely that the designer has accurately determined the developability or shape of the panels and thus these station frames will not reflect the real shape of the intersection of the panels with frames and bulkheads.

A couple of years ago, Joe Dominic and I, both backyard boatbuilding enthusiasts, wanted to see what we could do with plywood shapes. We believed that much of the objectionable appearance of hard-chined hulls could be reduced by a creative exploration of the shapes that can be formed with flexed panels. I describe here what we found, a process that eventually led us to develop our own hard-chine design computer software.

<u>Computers Make Surface Development Do-Able</u>. Thanks to computers, the equivalent of multi-conic development can now be carried out more easily

and quickly than in the days of manual drafting. Indeed, surface development and hard-chine design capabilities have existed for several years in high quality but expensive boat-design software oriented towards naval architects. Joe and I found ourselves wanting a considerably less expensive way to explore developable surfaces for our own boatbuilding projects. The software we eventually developed we call 'Hard-Chine Boat Design,' or 'BtDzn' (pronounced, boatdesign) for short. [As a personal aside, even though Joe and I have been working together for almost three years and have exchanged hundreds of email letters, countless early versions of our software, and photos of our boatbuilding projects, Joe and I have never met. Joe, who has naval architecture training, works in the marine trade for the Canadian government in Newfoundland. I have a lot of computer experience and to support an aspiring boatbuilding career work as a scientist in North Carolina.]

To provide a feel for how computers do surface development, I will briefly describe one of several computer approaches that can be used to develop panels for hulls. It is the method used in our BtDzn software and is the general approach used by several of the commercial yacht design programs. For a good review of this method see Richard Webster's article in *WoodenBoat* (1987, **79**, 84-89). The method relies on the fact that between the two curves (chines) which define the edges of a developable panel, only a single unique set of straight lines, called 'ruling lines', can be drawn. These lines connect points at which an imaginary flat surface is simultaneously tangent to both lines. For any given point on one curve, there will be only a single plane that is also tangent to the second curve, and thus only a single ruling line. These ruling lines represent the axis along which the panel bends between the curves (these lines might also be viewed as representing small segments of cones in the old multi-conic method). To generate them, one can visualize the motion of a flat board passing along the course of the two curves, stopping every so often to connect the points of each curve that the board is just contacting (i.e. is simultaneously tangent to), Figure 3. Now, if you step back and look at the lines when the ruling process is completed, if a panel is 'developable' the ruling lines will not cross. If the ruling lines do cross, then, in the region of the crossing, the panel requires a complex curve that cannot be formed from sheet material. For a developable panel, the ruling lines established by this procedure represent the surface of the panel. Thus they can be used to establish true cross-sections through the panel and most importantly they can be used to derive the exact unsprung or flattened pattern of the panel by relatively straightforward geometry. This latter process is called panel 'expansion.' The more ruling lines that are used, the more accurate will be the cross-sections and panel expansions. There are even more mathematically sophisticated ways to do surface development, but the geometric approach described above should give you good idea of the kind of thing that must go on to define the surface of a panel.

I should mention that there are short-cuts that can be taken to create flat panel expansions, but these only work well when the panel shape is simple (e.g. cylindrical). When such a short-cut is used, an approximate expansion can be done using the straight edges of the stations/frames. But be careful because the flat panels will be somewhat inaccurate unless a large number of stations is used.

CAD and Boat Design. Besides wanting to make sure we could readily explore developable surfaces, a second matter we confronted in the development of our software was whether to develop a 'stand-alone' program or a program that worked in conjunction with existing graphical software. Professional ship/yacht design systems typically function as independent stand-alone computer programs. These systems are oriented to defining and analyzing hull shapes and offer users only limited drawing/drafting capabilities within the program. Further computer work on a design requires that the hull lines be exported to a separate CAD (Computer Aided Design or Drafting) program via an interchange format. We decided on a different approach with BtDzn. Feeling that there are boatbuilders/designers anxious to work (or learn to work) in the CAD environment, we put our utilities inside one such CAD program, 'EasyCAD' from Evolution Computing. CAD is a highly useful design and drafting environment, from conception of a design to its production. It's one of the things that computers do well. We felt that if BtDzn was a part of CAD it would allow users take advantage of numerous powerful CAD functions and put all their work in a CAD drawing right from the start. Moreover, they would have only one computer program to deal with.

If you are unfamiliar with CAD, be aware that working in CAD is quite different than working with a computer 'draw' or 'paint' program. The drawings in paint programs are based on the pixels (or dots) of the computer screen. CAD, on the other hand, creates precisely defined geometric objects or entities that are displayed on the screen as accurately as possible at whatever magnification you choose. If you zoom-in closer to an object, say a circle, in a paint program you get an exploded view of pixels jaggedly connected. If you zoom-in on a circle entity in CAD, you get a more accurate and smoother view of a smaller segment of a curve. CAD may be a bit more difficult to use, but it is the system of choice where defining shape and form for construction are concerned. It also generates excellent printed output at any scale (e.g. for models or full-size production).

Joe and I have created a computer program exclusively oriented to exploring hard-chine boat design and to easily determining the shape and developability of panels in a hull. BtDzn will un-spring or 'peel' these panels and project their flat, expanded, pattern. These flat patterns can be plotted to build a model for study or to build the full size hull. In addition, BtDzn provides numerous other functions useful in creating, detailing, and evaluating a boat design and in building a boat, including creating stations, other cross-sections, offset tables, and upright stability hydrostatics.

We're obviously quite enthusiastic about our BtDzn software, but I need to add a note of caution. There's a lot to be said, both good and bad, about computers and creativity. CAD and our BtDzn software will not make you a naval architect any more than a word-processor will make you a writer, or a spreadsheet will make you a financial analyst. Moreover, many forms of software do have the side effect of inducing a certain style or character to the product produced. Nonetheless, we feel that the great benefit of 'computer aid' is to enhance individual creativity. It enhances creativity simply because the software makes possible difficult, tedious, and cumbersome tasks that a user might otherwise not want to undertake -- in this case, hull-panel development and expansion. We hope with BtDzn to have enhanced the tools available to amateurs and small shops to take advantage of such techniques and the compelling strengths and virtues of hard-chine design by helping them easily and quickly explore forms for pleasing, sturdy, and functional hard-chine boats.

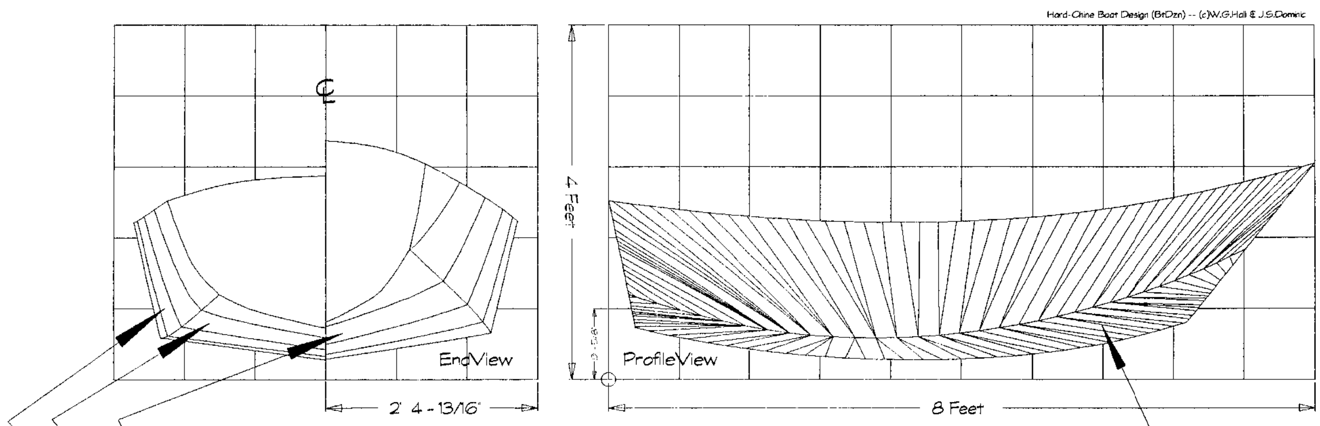
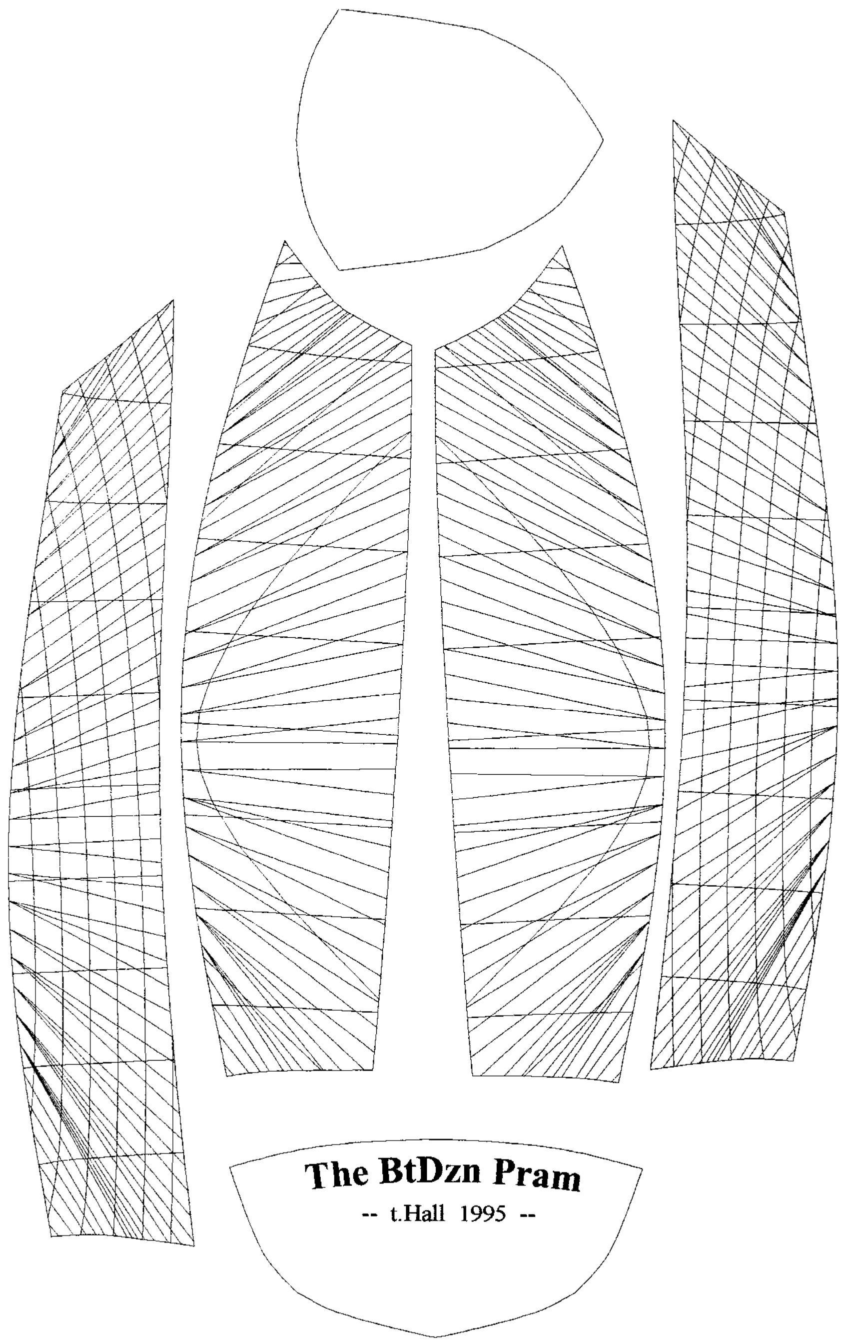


Figure 1. End View and Profile View of a small pram. 'Ruling lines' describe surface of the panels of the hull in Profile. Station cross-sections in End View show how the intersectons of the flexec panels with most stations and the transoms are curved.

Figure 2. Making a model is one of the most helpful things you can do in evaluating the form of a hull. We rarely see a real hull exactly in profile view or exactly in end view. Being able to freely rotate the model shape in your hand and study it will provide a considerably richer appreciation of a hull's appearance from the angles you are likely to normally view it from. Building a hard-chine model is easy to do using the flat expansions of the hull panels. The following is one suggestion for building a quick initial model to inspect. If you'd like a stiffer model, or want to save your copy of 'Messing about ...', you can Xerox this page onto another sheet -- use card stock for the stiffer model. You might also use 'double-sticky-tape' to fully adhere a thin-paper copy to card stock. First, cut the model out. You'll find that the panels are amazingly accurate, so make an effort to 'split' the outline as you are cutting in order to have them fit together precisely. Then, tape the panels together with small strips of scotch tape. Pre-cut a bunch of these before you start by cutting across the width of the tape to make strips that are 1/8" - 1/4" wide. Start the assembly at the keel with the two panels on either side of the centerline. Use the Ruling lines to keep the panels lined up exactly and work from amidships forward and aft. Hold the panels closely together as you tape them. After finishing the lower panels, attach the sheer panel on each side using a similar taping technique. Yes, this is just like you'd build the real thing. You'll be surprised at the degree to which the hull shape emerges in this process. This easy generation of shape occurs because the chine curves fully define the form of the hull and the panel shapes establish the chine curves. Note that this exercise will illustrate to you why molds are not required when building with the 'stitch-and-glue' technique. Along with the junction of the panel curves themselves, a single cross-section, piece of deck, or thwart is usually sufficient to fully establish the shape for inspection.



The BtDzn Pram
-- t.Hall 1995 --

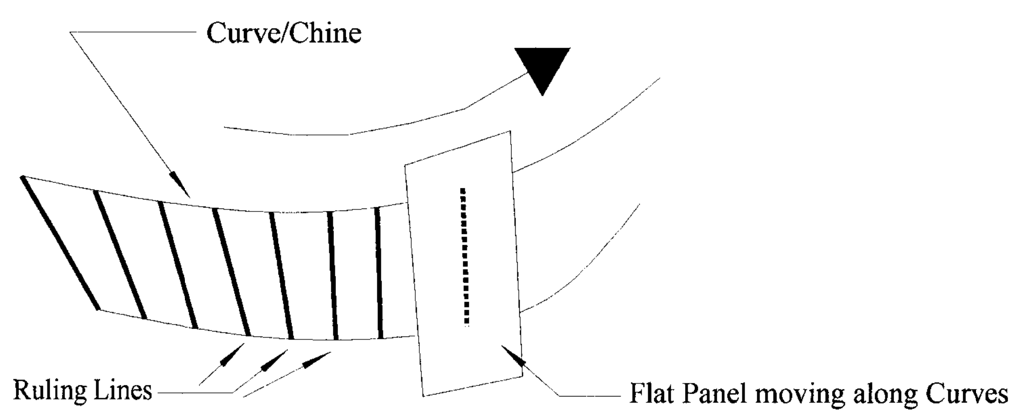


Figure 3. Illustration of the 'tangent-plane' technique to define the surface between two curves by establishing 'ruling lines' between points where a flat panel is simultaneously tangent to each curve.

[SIDEBAR]

CURVES, FAIRNESS and SPLINES

In computer drafting, curves are defined as geometric entities by 'spline functions.' Splines are mathematical formulae or procedures representing a curve. There are many types of splines which serve many different purposes. Some types of splines provide good approximations to what a boatbuilder means by a 'fair' curve. The cubic b-spline is one example. Nonetheless, the use of mathematical splines in a boat design situation is sometimes misunderstood because a spline can be employed in several ways. A cubic b-spline with, for example, just a few control nodes is 'fair' by definition and will appear fair when plotted at any scale (assuming a high enough screen or printer resolution). A cubic b-spline used to create a curve that 'interpolates' between numerous control points (e.g. drawing a curve between 10 points on existing stations) yields a curve that is locally fair (i.e. when you inspect a small segment) but which may have bumps or bulges when viewed in its entirety. These bumps and lack of fairness happen for the same reason that even a curve created with a fairing batten may not be fair if it is restricted at too many positions by lofting pins or ducks. In a CAD program or a surface-development program such as BtDzn, where cubic b-splines are used to define curves, hull lines will be fair and no special techniques are required to make them fair, as long as the spline is appropriately controlled.
