January 1965

THE PLANIMETER

SOCIETY OF
SMALL CRAFT
DESIGNERS

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Volume 16 THE PLANIMETER Number 1
January 1965

All correspondence should be addressed to the
Executive Secretary, Box 146
Lake Hiawatha, New Jersey

The Balsa Ecuador Lumber Corporation has sent us a sample of balsa wood as used in the Boating Industry along with their technical literature. Interested members may obtain full details from N. G. Boyer, Balsa Ecuador Lumber Corporation, 500 Fifth Avenue, New York 36, N. Y.

George W. Sutton's experience in steel boatbuilding, in which he specializes, has shown him that it is more difficult to build a smooth welded steel boat if it is designed with only simple developable curves. There has to be a certain amount of dish or compound to the shell. Burning and welding of the plate shrink the edges. If the shell is made to conform to a simple curve the extra material will relieve itself in between the frames and longitudinals forming buckles. In providing this note he suggests a column of such hints to appear regularly under a title such as "Proportional Divider". We would like to hear from any member who has such notes available for publication.

Julio Chalbaud of the San Francisco Chapter has returned to his native Venezuela to practice his profession. He has been here for his education having just graduated in Architecture (B.S.) and is also in the process of completing his final Westlawn paper.

The following letter from Donald Hall to Bob Dorris printed in full providing points of interest to members:

November 1

R. S. Dorris Boat Co.
Custom Boatbuilders
1974 Placentia Ave.
Costa Mesa, California

Dear Bob:

In answer to your request for the names of members attending the last SSCD Meeting, they were:

			Rene De Launay
Georges Diry	Willard Tjossem	Romeo Elliot	Seymour Paul
Ken Hankinson	Gus Salmont	Adolph Larson	Donald Hall

Main topics of discussion were:

1. Three vessels recently designed by this office to distinctly differing requirements:
   - (A) 24 foot deep Vee Planing Plywood Stock Cruiser for semi-quantity production
   - (B) 31 foot Trawler Type Long Range Heavy Displacement Yacht for Hong Kong Yard.
   - (C) 20 foot Commercial Workboat for L. A. County.

The above designs were discussed in detail by all members present.

2. Means for improving the public image and technical value of the S. S. C. D.
   - (A) Possibility of using a professional listing in SEA Magazine to inform the public of the organization and goals.
   - (B) Possibility of obtaining a L. A. Boat Show booth to be staffed by members to promote the organization.
   - (C) Contribution of editorials to yachting magazines by members or by chapters on various technical and semi-technical topics.

A committee was appointed to study the problem, examine the aforementioned suggestions, and submit additional recommendations to the Chapter on this subject. Willard Tjossem was appointed Committee Chairman with Gus Salmont and Ken Hankinson appointed to serve on this group.

At your suggestion, an excellent one too, I asked George Diry if he would speak on the problems of designing to the C. C. A. rule. He has agreed to do so at our next meeting at the College on the 21st.

If the organization is to have any value other than that of a rather pleasant social group, there are several things that should be accomplished immediately.

Attendance at meetings must be increased in order to embark upon a program of soliciting qualified speakers.

The membership must be aware of the necessity of notifying chapter officers of their planned attendance at meetings. To this end, meeting notices, requesting an answer, must be mailed to the membership a minimum of two weeks in advance of the meeting date.

The membership, as a group, is saddled with the responsibility of suggesting methods to broaden the scope of chapter activities such as:

- (A) Providing speakers to discuss small craft design with Power Squadron, C. G. Aux., and Yacht Club groups.
- (B) Soliciting the interest of qualified individuals to speak before chapter meetings.
- (C) Broadening the scope of meetings to interest potential qualified members.

Long Beach State College has allowed us the use of their excellent facilities on a continuing basis. It is doubtful whether any other chapter of the organization is as fortunate in this respect. It's now up to the members to actively promote the S. S. C. D. so that this organization will serve as the recognized center of design and production knowledge in the field.

In order that we may have a worthwhile meeting on November 21st, I should like the members to bring forward questions concerning the C. C. A. rule to enliven Mr. Diry's discussion.

In addition, each member is to bring forward a specific suggestion to enable the chapter to move toward the goals outlined previously.

Best regards,

Donald Hall

LOS ANGELES CHAPTER
SOCIETY OF SMALL CRAFT DESIGNERS
Minutes - November 21, 1964

The regular monthly meeting of the S. S. C. D. was called to order by Chapter Chairman Mr. Don Hall, on Saturday, November 21, 1964 at 2:00 P. M. at Long Beach State College.

Member Mr. Georges Diry delivered a very instructive and edifying talk on the C. C. A. Measurement Rule.

Members discussed how to improve the Society and its image to the public.

It was decided future meetings would be on the first Wednesday of the month at 7:30, technical session beginning at 8:00 and adjourning at 9:30 P. M.

The next meeting will be Wednesday, January 6, 1965 at Long Beach State College.

The meeting was adjourned at 4:30 P. M. Members present were: Romeo Elliot, W. I. B. Crealock, Bruce King, Dr. Torres of the College Staff, Robert Dorris, Don Hall, Rene DeLauney and Vern Butts.

Respectfully submitted,

Robert S. Dorris
Secretary

SOCIETY OF SMALL CRAFT DESIGNERS
San Francisco Area Chapter
Minutes - December 5, 1964

The San Francisco Area Chapter met on Saturday, December 5th. Those present were: James Abell, Art Halverson, Ben Ostlund, Bob McMurray (Chapter Chairman), Ernest Murray and Al Vetter.

The meeting was in two parts with the afternoon session being at Ben Ostlund's plant in Oakland where we saw the progress he has been making on his new 25 ft. fiberglass cruiser. The boat will be a production model and will feature a unique concept in hull design for an offshore planing boat - they are presently doing the finishing work on the plug.

Near Ben's place we also looked over a 47 ft. "designed by eye" plywood cruiser.

A trip across town took us to Art Halverson's home for the second phase. Here we had refreshments waiting for us followed by a roast beef dinner and then our regular meeting.

In the course of the meeting we had discussions on the sizing and shrouding of propellers, speed claims of stock boat builders, plastic hinges, and insulating of engine compartments.

We will next meet at the home of Jim Abell on Saturday, March 6th. By that time Jim hopes to have his 20 ft. modified sharpie pretty well completed.

Alexander W. Vetter
Chapter Secretary

LONG ISLAND CHAPTER
OF THE
SOCIETY OF SMALL CRAFT DESIGNERS
Minutes - October 28, 1964

The Long Island Chapter held a meeting on Wednesday evening, October 28th, at the Ho-Wing Restaurant in Little Neck, L. I., N. Y. Following a pleasing Chinese dinner, the meeting was called to order by Chairman Sid Dyer at 8:30 P. M. at which time the Minutes of the previous meeting were read, together with the Treasurer's report. The Minutes and report were accepted as read.

Members Fred Martineck and Vic Harasty lead the informative discussion that followed on ignition systems, past and present.

Chairman Sid Dyer has written an article entitled "Hollow Masts", which is scheduled for printing in "Rudder" in the early part of this year. Mr. Conrad Miller, Editor of Rudder Magazine, has consented to release the article for reprinting in the Planimeter. A copy will be sent in as soon as it is available.

The next meeting was scheduled for March 24th, 1965.

The meeting was adjourned at 10:30 P. M.

Members present: Sid Dyer, Peter Statile, Kenneth Wilcox, Victor Harasty, Fred Martineck and Robert Bohrer.

Respectfully submitted,

Robert A. Bohrer
Secretary-Treasurer

JANUARY MEETING

A most successful meeting of the full Board of Governors was held on January 19th, and every area of the Society's operations and activities was explored in depth with concrete action being taken on logical necessary changes. Complete details will appear in the February Planimeter and should be noted carefully. A few of the basic highlights are noted here:

The three members of the Board will immediately assume specific responsibilities as follows:-

Donald Smith - Executive Organization and Planning
Rogers Winter - Planimeter, Advertising, Editorial
Douglas Gray - Legal, Audit and Acting Exec. Secretary.

The Board looked closely at the possibility of having a permanent Executive Secretary and it is anticipated this detail will be resolved at an early date.

The concept of the Council of the Society has been changed to provide a more logical representation of the membership.

Committees have been established and subject to final confirmation by the members involved are tentatively set up as follows:-

COMMITTEE	CHAIRMAN
Membership	Ullman Kilgore
Revisions	Roland Kenny
Publications	Rogers Winter
Gov't. Liaison	Douglas Gray
SNAME & other Societies	Joseph Koelbel, Jr.
Industry Liaison	Kurt Meyer
Public Relations	Donald Smith
Technical	Robert Broadwell
Legal (Future)	Douglas Gray

(As noted earlier full details will appear in the February Planimeter but any member interested in serving on any of the above committees should contact the appropriate Chairman or any member of the Board.)

Other major details resolved include the Fall Meeting being held in Chicago with a full technical program about which there will be specific information later. It is tentatively planned that the 1966 Fall meeting will be held on the West Coast. The January meeting will continue to be held in New York, but will be a Business, Political and Social Meeting.

A new Roster will be issued as soon as possible but this involves added information and a Personal History form will be forwarded to all members shortly, asking for data that will be included in the Roster - which, incidentally, will have an entirely new format as will following Planimeters.

WATCH FOR YOUR FEBRUARY PLANIMETER WITH COMPLETE DETAILS!

Twenty-two members attended the Annual Dinner also held on the 19th, and after a discussion by Robert Broadwell on the concept of the Technical Committee, the balance of the evening was thrown open to general discussion which continued in a lively vein until midnight.

THE GENERATION OF DEVELOPABLE HULL SURFACES

By Ullmann Kilgore

Abstract.

The geometry of ruled and developable surfaces is analyzed and theorems are proved to isolate universal properties which may be used in the application of a direct procedure for development, eliminating trial-and-error search for rulings. The steps in the development of an example hull are explained in detail.

THE GENERATION OF DEVELOPABLE HULL SURFACES

Contents:

I. INTRODUCTION.
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  4. Fitting Surfaces to Curves.
  5. Cones, Cylinders and Convolute Surfaces.
  6. How to Project a Developable Surface.

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  5. Some Time-saving Tricks.

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I. INTRODUCTION.

The motive for design with developable surfaces is (1) to avoid the expense of plastic deformation of hull plating, or (2) to use sheet materials which cannot be plastically deformed. The aim is, therefore, a saving in construction costs.

The variations in shape of a developable hull are limited to the shapes into which non-plastic panels may be bent. These shapes often do not conform to the lines the designer believes best, so that the savings in construction costs must be weighed against possible loss either in beauty or hull efficiency. The lines finally accepted, if the designer uses the methods of development commonly recommended, will be accepted after a good many hours of trial and error, and after several modifications of his preliminary sketch. The labor of this trial-and-error search for suitable elements, and the difficulty of shaping surfaces for efficiency and good appearance, are the prices paid for the economic benefits. Since these penalties occur in the designer's office, it is no wonder that the profession feels unfriendly towards the task of developing hulls, and that we deprecate them as being boxy in appearance and inefficient in performance.

While the method of design described herein does not eliminate all the objections to developable surfaces, at least the labor of design is lightened and the confusion is eliminated. The designer proceeds directly and methodically, knowing at all times exactly what he is doing, and he reproduces his proposed particulars within close limits of accuracy. No elaborate graphical evolution is needed.

This discussion is divided into two parts, mathematical theory and the application of that theory to design procedure. Some may find it possible to acquire facility in the projection of developable surfaces without digesting basic laws, and such gifted ones may choose to skip the analysis. The mathematical principles involved, however, are simple. Through intimacy with basic laws the designer knows at once what is possible, what is impossible, and what procedure will succeed in any new situation.

II. THEORY OF DEVELOPABLE SURFACES.

1. Some Definitions and Axioms.

To the naval architect, lines and curves both mean the same thing, a buttock line being called a buttock line in every view. For the sake of clarity, in this discussion a line must be considered to be a straight line and will be called a line only in the view where it appears as a straight line. If a locus is not a straight line it is a curve. We call it a curve when it appears as a curve.

Three principles especially useful are that a point and a line, two intersecting lines or two parallel lines determine a plane.

If two lines are parallel, they appear parallel in every view. Intersections or tangencies at a point show as such at the same point in every view.

Repetition of these facts may seem elementary, but these are the principles by which it is possible to render orthographically the points of three-dimensional space on a flat piece of paper. A ruled surface may be projected by projecting its rulings. A developable surface may be projected by projecting the planes that lie tangent to it.

2. The General Nature of Ruled Surfaces.

The embracing definition of a ruled surface is that it is the locus of a family of lines projected according to one or more functional formulae, with one or more parameters. As an example, let a set of lines be generated according to

$$y = tx,$$
$$z = ct. \quad (c \neq 0) \qquad (1)$$

For each value of t a particular locus is determined, having slope t with respect to the X-Z plane, but having distance from the X-Y plane everywhere equal to t. If t varies continuously, the succession of lines so generated determine a surface -- a right helicoid with directrix the Z-axis.

On the other hand, the family of lines described by the rule

$$z = x\cos t,$$
$$y = x\sin t, \qquad (2)$$

all intersect at the origin of the Cartesian system, and furthermore if attention is focused on a particular value of x while z and y vary with t as a parameter it will be noted that a circle is swept out having center on the X-axis and radius x, and that the locus of all lines defined by (2) -- or of all the circles as the choice may be -- is the cone

$$y^2 + z^2 = x^2.$$

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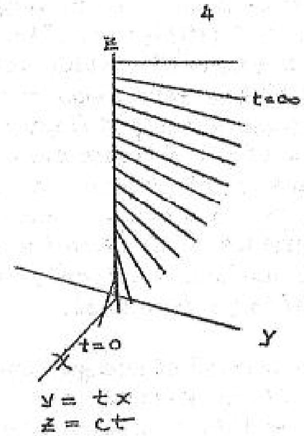
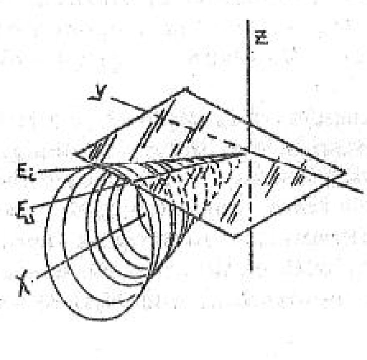


Now it is evident that by formula (1) no two of the lines intersect. Any pair of the family (2) intersect, however, and in such a case they determine a plane. The limiting position of the plane determined by two elements E_i and E_j, as $j \rightarrow i$, is that of a plane tangent to every one of the circles as shown and therefore tangent to the surface along E_i. Evidently



then the surface determined may be brought into isometric correspondence with a plane, while the surface described by (1) cannot.

3. The Special Nature of Developable Surfaces.

Isometric correspondence between two surfaces means that they have common properties by which the mirror image of all dimensions in one surface may be imprinted, or mapped, on the other. It is stated as axiomatic that if a plane may be brought continuously into isometric correspondence with a surface S, then S is developable. Here we say that the plane is applicable to S, and the term, applicability, seems to require no further definition.

The graphical methods of descriptive geometry require that a particular plane be determined by a particular pair of intersecting or parallel lines, but note that in testing a ruled surface for developability it is not necessary to find that every ruling in the surface intersects some other ruling, nor that all rulings be parallel. It is only necessary to find that along every ruling E_i a plane T_i may be laid tangent to S, and to this end it is worth recalling the definition of tangency of a plane to a surface. For reference, call this

> Definition (A): If a plane T and a surface S, intersecting at a point P, have a common normal through P, then T is said to be tangent to S. By extension to other points, if a plane T and a developable surface S have a common line E and also a set of common normals through E, then T is tangent to S. It is evident that the normals to S and T will also be normal to E and to all curves or lines in both S and T which touch E.

The foregoing definitions draw attention away from the question of intersection of intersection or parallelism of elements and direct us to criteria which will be easier to determine. It is held self-evident that if T is found to be tangent to S according to (A) continuously throughout an interval, then within that interval T is certainly applicable to S, which is therefore developable insofar as our interest extends.

4. Fitting Surfaces to Given Curves.

In accordance with the above reasoning, it is commonly stated that a developable surface is the envelope of a one-parameter family of planes, provided the planes are not parallel to each other. The draftsman, however, begins his task with no knowledge of the functions and parameters of the curves at hand. His given data are the pictures of the curves C_1 and C_2, which are known to lie in a surface of some sort, and even known to lie in at least one ruled surface. It yet must be determined whether or not this surface may be developable. Our analysis must begin with the available data, the orthogonal views of C_1 and C_2. The first test must be by the following

> Theorem 1. Two curves, C_1 having arc length $S_1(t)$ and C_2 having arc length $S_2(t)$, may lie in a developable surface through that interval where: (1) a plane T_o tangent to C_1 at an original point P_{10} may be brought into tangency with C_2 at a point P_{20}, and (2) a plane T_i tangent to C_1 at each succeeding point $P_{10+\Delta_i s_1}$ may lie tangent to C_2 at $P_{20+\Delta_i s_2}$.

Proof: The tangency of planes $T_{i,j}$ to C_1 and C_2 is continuous, determining a continuous series of points $P_{1i,j..}$ and $P_{2i,j..}$ through which may be drawn rulings $E_{i,j}$. The locus of the family of lines E is therefore a continuous surface, S.

Now every ruling E in S also lies in a plane T, and since S is a continuous surface it may contain a curve C_j lying in the normal plane to T and E_i and intersecting E_i at Q. At this point the direction of the normal to C_j is simultaneously the direction of the normal to S and to every line in T_i. By definition (A), T_i is therefore tangent to S. Evidently some plane may be tangent to S along every ruling, so that every dimension in S may be mapped unaltered on a single plane. Therefore S is developable.

Figure 1 demonstrates the principle expressed in Theorem 1.

The immediate observation is that the location in the above manner of planes tangent to C_1 and C_2, if such planes exist, will be a painful business. If one of the given curves is a plane curve, say C_1, and if the tangents to C_2 have such direction that they intersect the plane of C_1 within the bounds of the drawing board, it is not difficult to find pairs of tangents which define tangent planes. Except to a limited extent, this condition does not occur. A direct method must therefore be devised. Full demonstration of such a method will follow, but first it is necessary to examine the basis which makes it possible:

Theorem 2. If two or more curves in a developable surface S are determined by the intersection of S with two or more parallel planes, none of which contains any ruling of S, the tangents to all such plane curves at their respective intersections with any particular ruling of S are parallel.

(For Figure 1, See Page 11)

Proof: Let parallel planes R_1 and $R_2 \ldots R_n$ intersect S, a developable surface, in the allowable manner. If S is continuous, it may have a tangent plane T_i along any ruling E_i, and every curve C_j in S which has a point on E_i has a tangent line which lies in T_i. Now the plane curves $C_1, C_2 \ldots C_n$, cut in S by planes $R_1 \ldots R_n$, have such tangents, called $L_{1i, j..}$, $L_{2i, j..}$.

L_{1i} and L_{2i} both lie in T_i, but they also lie respectively in R_1 and R_2. They therefore are identical with the lines of intersection of a plane T_i with two parallel planes and consequently must appear parallel in all views.

5. Cones, Cylinders and Convolute Surfaces.

Up to this point no attention has been paid to the properties of special developable surfaces for the reason that in the investigation of their general nature the exact description is of no importance. The draftsman will not make his work easier by harboring preconceptions of the special nature of the surface to be generated. Whether or not a surface is "a series of tangent cones or cylinders" is practically a meaningless question, but the assumption that the surface is of such-and-such a nature has been the cause of the failures proceeding from the methods of generation commonly used. Although it has been proved that any developable surface is either a cone, a cylinder or a convolute surface, it does not follow that given curves can be made to fit some particular genus plucked out of the air. There are instances, however, when surfaces of special nature may be employed to advantage.

The method of generation of cones, cylinders and convolutes from their directrices result in the properties by which each is known. In none of them is any certain kind of directrix required, although there are some restrictions. For instance, the directrix must have a tangent at every point over a suitable interval.

The cone is generated by a line bound at a fixed point, the apex, and moved along the directrix. The cylinder is generated by a line which maintains a fixed direction while following the directrix. The convolute is generated by the tangents to a three-dimensional curve. In practical drafting it is seldom necessary to know anything of the original directrices of these surfaces, but only to have available some curve known to lie in the surface and a knowledge of the directions of its rulings.

Cylindrical surfaces are especially easy to construct, since all that is required is the one known curve which may be used as a directrix, and one direction, so that the projection is accomplished by drawing parallel lines in three different views, which are not necessarily orthogonal.

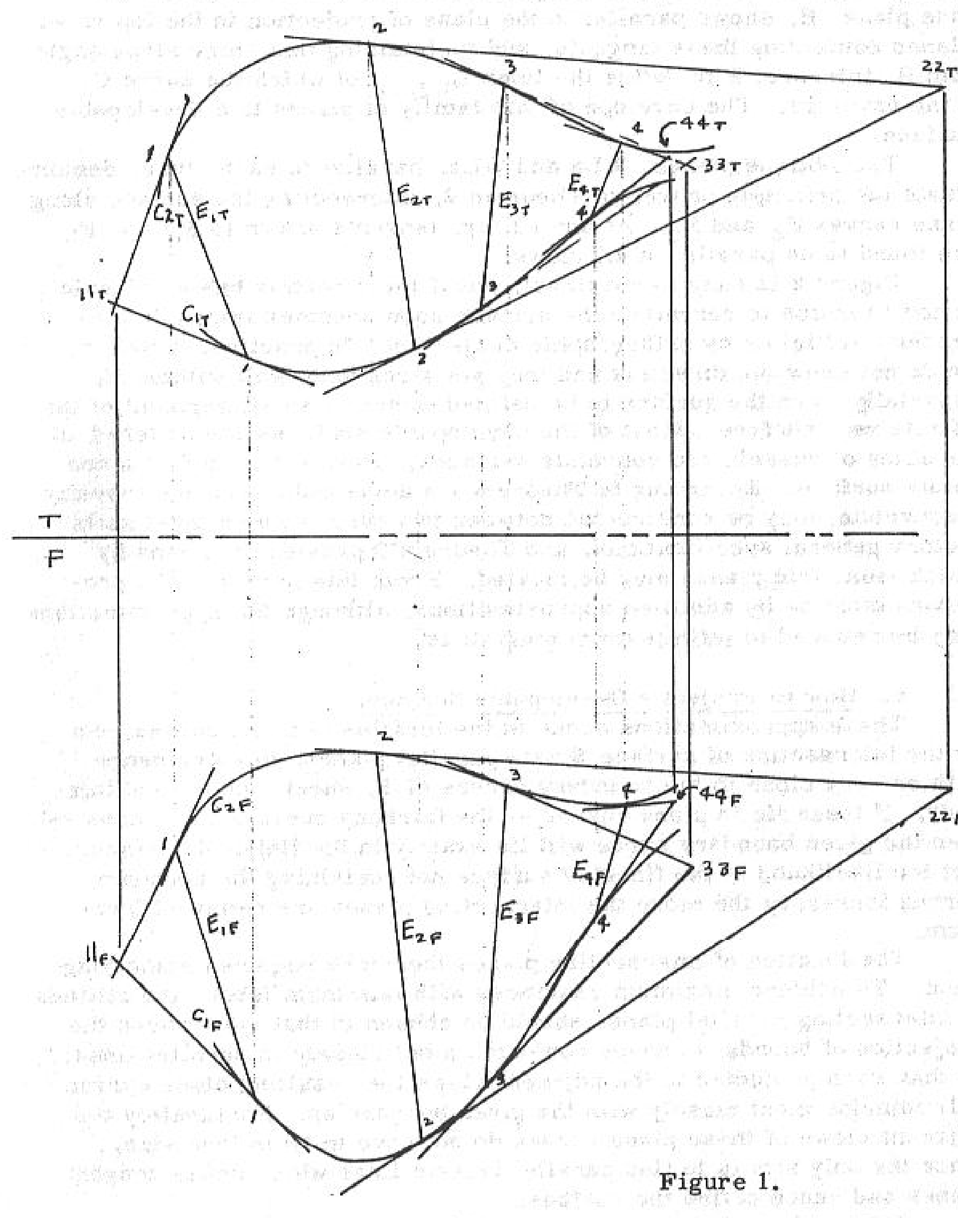

2
3
22_T
44_T
4
33_T
1
C_{2T}
E_{1T}
E_{2T}
E_{3T}
E_{4T}
11_T
C_{1T}
T
F
44_F
22_F
C_{2F}
E_{4F}
33_F
E_{1F}
E_{2F}
E_{3F}
11_F
C_{1F}

Figure 1.

Construction of the cone requires both a curve known to lie in the surface and an apex whose location if not known must be found. This feat is seldom easy, and it becomes somewhat more difficult when the surface is in fact not conical as assumed and therefore has no apex.

If the construction of the convolute surface had to proceed from the directrix, the job would be even more difficult than that of the cone or the cylinder. Figure 2 is a demonstration of a simple convolute having a directrix, D, whose tangents maintain a fixed angle with a base plane, B, shown parallel to the plane of projection in the top view. Planes containing these tangents, and maintaining this same slope angle with B, intersect B to define the lines $L_{i, j \ldots}$ of which the curve C_1 is the envelope. The envelope of this family of planes is a developable surface.

Two oblique planes, WLa and WLb, parallel to each other, demonstrate the principle proved in Theorem 2, intersecting the surface along plane curves F_a and F_b. At any ruling, tangents drawn to F_a and F_b are found to be parallel in all views.

Figure 2 is easy to construct, but if the directrix has a variable ratio of torsion to curvature the surface soon becomes impossible to render intelligibly by orthographic projection. In practice, however, we do not know the directrix and may get along very well without it, especially when the surface to be defined is only a small segment of the infinite real surface. Most of the developable surfaces encountered in the skins of vessels are convolute surfaces. Figure 1 is in fact a convolute surface. According to Theorem 1 a developable surface (usually a convolute) may be constructed between two curves which meet satisfactory general specifications, and Theorem 2 provides a means by which isometric planes may be located. From this point on, the procedure must be by admitted approximations, although the approximations may be reduced to infinitesimal magnitude.

6. How to Project a Developable Surface.

These approximations occur in the location of plane curves, cut by the intersection of surface S with parallel planes, in coincidence with or very close to the boundary curves of S, sheer, chine and fairbody. If these lie in plane curves -- the fairbody curve usually does -- then the given boundary curve will lie exactly in the finished surface. But the likelihood of the finished surface not containing the boundary curves increases the more the intersecting planes are removed from them.

The location of intersecting planes therefore requires some judgment. To achieve maximum exactness with minimum labor, the attitude of intersecting parallel planes should be chosen in that view where the projection of boundary curves conforms most closely to parallel lines, so that when projected to the adjacent views the resulting plane curves will coincide most closely with the given boundaries. Fortunately the adjacent views of these plane curves do not have to be in true size, since the only aim is to find parallel tangent lines which define tangent planes and hence define the surface.

The number of intersecting parallel planes necessary for suitable exactness depends on the degree of torsion of the given boundaries and on the mutual slope of the boundaries. To elaborate, if the fairbody lies in a plane, as it usually does, then its torsion is zero, and an intersecting plane may contain it completely. On the other hand, the chine seldom lies in one plane through much of its length, and furthermore it will be oblique to the plane of the fairbody, in which case a succession of planes, parallel to the centerplane or to whatever other plane whose attitude may have been chosen, will have to be passed.

But from proved theorems we know exactly how to proceed.

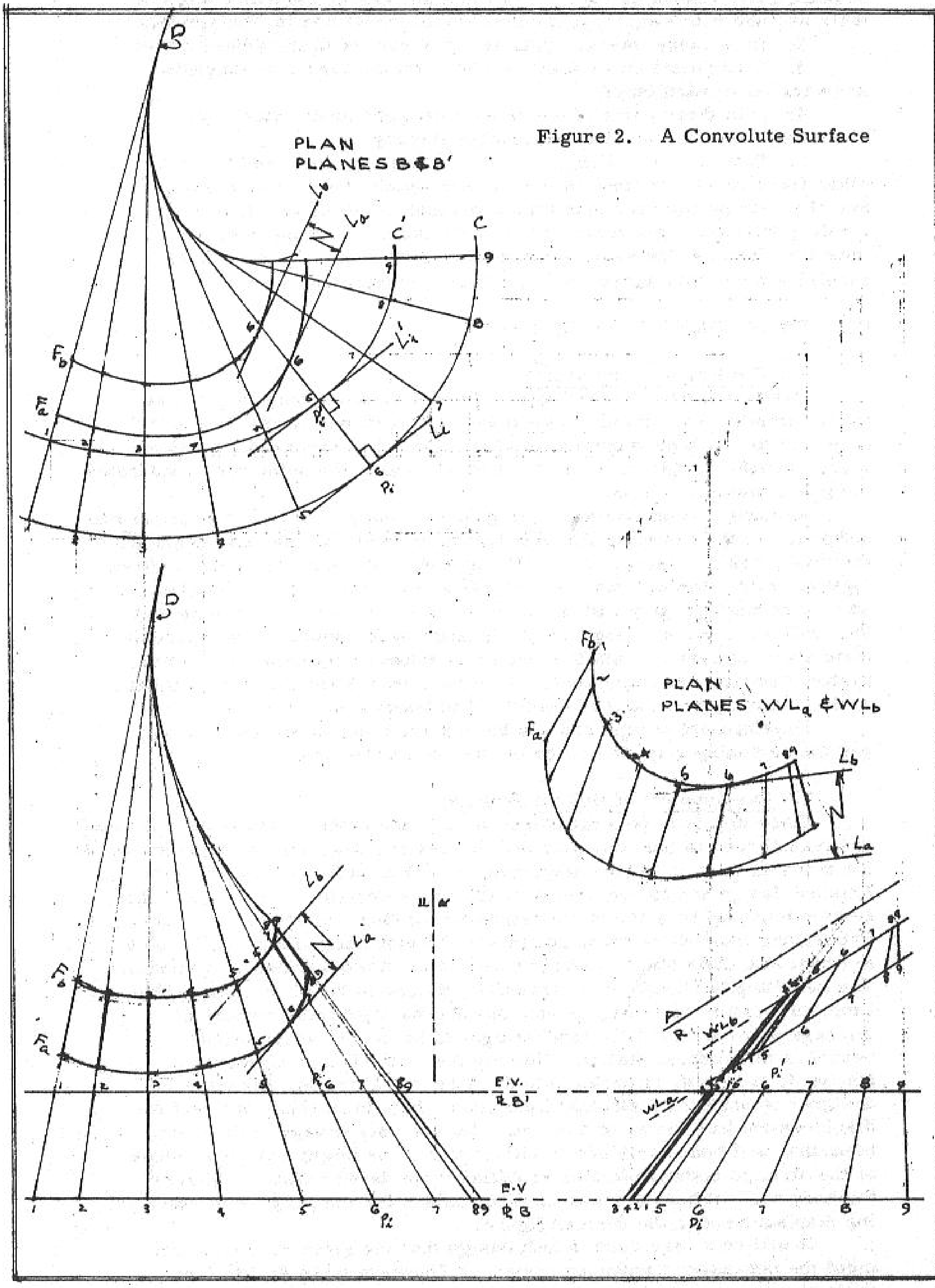


Figure 2. A Convolute Surface

1. Wherever convenient, intersect the surface with two parallel planes at the boundary curves, or as near to them as possible, by showing these planes as edge views (straight lines), remembering that their attitude with respect to the orthogonal directions is immaterial.

2. Show these intersections as plane curves in the adjacent view.

3. Find points on each curve where their respective tangents are parallel to each other.

4. Join these pairs of points with straight lines, which by Theorem 2 are rulings of a developable surface.

5. Extend these rulings to sheer, chine, fairbody and to any other fixed curves or lines in the surface which they may intersect, and check these intersections for agreement in all views. Obviously a ruling intersecting a curve in the halfbreadth plan must intersect the same curve at the same point on the sheer plan. If the work was carefully done, this agreement will occur automatically.

III. FROM THEORY TO PRACTICE.

1. The Preliminary Sketch.

The hull illustrated in Figures 3 and 4 is an example of a typical job for which development is demanded, although not by any means the only type to which development is applicable. Not produced as a showpiece of yacht design, it is easy to execute and at the same time illustrates the problems encountered.

Assume that preliminary design has already indicated the dimensions and shape of the desired hull, and that the drawing of lines has begun with the laying down of sheer, stem and chine in halfbreadth and profile views, together with several tentative sketches of sections. These sketches have been made largely with straight lines, with the understanding that they will not remain straight in the finished development. The approximate shape of desired tumble home is sketched on the transom section. Bottom sections have been made to conform to a desired curve of areas while matching the proposed deadrise and buttock configuration.

Development of topsides and bottom are independent operations, and the beginning may as well be on the one as the other.

2. Development of Bottom Surface.

Since this is to be a monchedron hull, the chine points of all stations are transferred to the body plan and the desired deadrise drawn on Station 8, the transom station. If the displacement and center of buoyancy of the finished design are to conform to preliminary decisions, the area of this section must agree with the corresponding ordinate of the curve of areas. Proceeding from these chine points, the bottom lines of Stations 7 and 6 are next laid down straight and parallel to the bottom frame of Station 8. The resulting fairbody curve, transferred back to the sheet plan at this time, is found to be so nearly straight that no significant amount of warpage will result if it is kept straight to Station 4, which in this vessel is the midship station. Holding the fairbody now straight to Station 4, it is bent up to fair into the stem at chine. At this point the designer would sketch straight lines from chine to fairbody and test for displacement and center of buoyancy, for the only change in displacement that will henceforth occur will be due to the slight change in shape of the straight bottom sections resulting from development. Chine or fairbody will not henceforth be moved, unless for the purpose of adjusting displacement to the desired figure.

It will be a rare case in hull design that the given curves do not meet the necessary conditions proved in Theorem 1 (II. 4). Unless their shapes are abnormal, it is very likely that the sheer, chine and fairbody curves, which have now been fixed, will fit into sheets that we propose to bend around them.

The first step is to select two suitable parallel planes intersecting the bottom surface. The centerplane of the vessel already intersects the bottom surface along the fairbody curve. All that is needed is another buttock plane slicing the hull as nearly as possible in coincidence with the chine.

Buttock "a", judged to be at a satisfactory location, is drawn in the halfbreadth plan intersecting the chine at A and B (Fig. 3), but so far it has only these two known points. The bottom lines of Stations 8, 7 and 6, however, have already been permanently fixed, making it possible to determine additional points on the profile view of buttock "a" by extending the lines of Stations 8 and 7 to intersect buttock "a" in the body plan and then transferring these heights to the sheer plan. The direction of this buttock curve now being determined through three points in its after length, it is held there while being swept up to intersect the chine at B. The bottom is now cut by the required two parallel planes.

In the sheer view, a straight edge is now laid tangent to buttock "a" as near as possible to its after intersection with the chine, near A. This point of tangency is one end of a ruling on a developable surface. The other end of the ruling is at the point where a tangent line parallel with the first one touches the fairbody curve. Ruling numbered 1 on the bottom, from just forward of Station 6 on buttock "a" to just abaft Station 3 on the keel, is now drawn. Moving forward, additional lines are drawn in the same manner between the contact points of parallel tangents on our two plane curves.

As each ruling is drawn on the sheer plan, it is projected on the halfbreadth plan. It should go without statement that a constant check is kept on all projected points in all views.

Ruling number 4 is the limit of utility of buttock "a", but it is now possible to find points for the projection of a second buttock plane, and at a convenient position buttock "b" is drawn. In a good many cases the regular spacing of the planes in the grid would do very well, but here they have been drawn arbitrarily. Its points determined by its intersections with the finished rulings, buttock "b" is projected to the sheer plan and then faired to its intersection with the chine.

In Figure 4, bottom rulings numbered 5 and 6 are found in the same manner as before, and then buttock "c" must be drawn by fairing it between its known points and its intersection with the chine. The last of the rulings on the bottom may now be found. All projected points having been checked in both views, the bottom is now finished and it is time to transfer offsets to the body plan where the fairness of bottom lines is again checked.

3. Development of Topsides.

To project the surface of the topsides, again an initial pair of parallel planes must be selected. It is noted that the chine from Station 8 forward almost to Station 5 is virtually horizontal, so that an intersection of the side with a horizontal plane drawn at this mean height of the chine would in the halfbreadth view be indistinguishable from the chine itself. Such a horizontal plane, though not necessarily drawn, will be named WL_a. (Fig. 4).

Another horizontal plane, WL_b, is selected at about the mean height of the sheer curve. Forward of Station 3 this plane cuts the section lines, which so far have been sketched straight, and abaft Station 3 the sketched sections must be produced above the sheer to intersect WL_b, thus providing the necessary offsets for the projection of the plane curve determined by the intersection of WL_b and the proposed developable surface. It is assumed that WL_b is so near the sheerline that the change in shape of the transverse sections will make no measurable difference in the position of the sheer.

This step concluded, the development of the topsides is begun as far aft as possible, the first point of tangency being chosen (in the halfbreadth plan) at Station 8 on WL_a (actually the chine, remember.) The straight edge is moved up to WL_b and a parallel tangent is found in contact with WL_b just forward of Station 6, the two end points determining topsides ruling numbered 1. Projected on the sheer plan, all its intersections are promptly checked. Rulings numbered 2 and 3 are found in the same manner, but now the chine in the sheer view is departing from the horizontal direction so that it can no longer be used. By this time, however, several points are available for a second horizontal plane.

Naturally it is desired to complete the job with all possible economy, but if the chine and sheer are to be kept in the positions already drawn, the intersecting planes must be kept close to them. Plane WL_c seems a reasonable compromise. Its offsets are determined by intersections with the three rulings already found, by its intersection with the chine, and by extending the tentative straight lines of stations 1 and 2 on the body plan to WL_c. At Station 2, WL_c is not far below the chine so that whatever curvature occurs in the topside section will not cause significant error in this offset; but at Station 1, on the other hand, WL_c is too far below the chine to expect accuracy, and we use this offset only to prevent flatness in the half-breadth view of WL_c as it sweeps across an unknown region. (Fig. 4).

The plan view of $W.L_c$ now being swept around in a sweet curve, rulings numbered 4, 5, 6, 7 and 8 are found between points of parallel tangency on WL_c and WL_b. All points are checked in both views.

Topside ruling number 8 is the last reliable ruling which can be drawn at this time, for forward of Station 2 WL_c is only approximate. It would be possible to cut the hull with several more horizontal planes and to continue the development in the same manner as will be recalled from the handling of the bottom. As a display of versatility, however, planes Q and Q'are constructed, chiefly to demonstrate that the only requirement of parallel planes is that in one projection they show as edge views and that their attitude otherwise is immaterial.

The edge view of planes Q and Q' having been drawn on the sheer plan as dotted lines, their known points are projected down to the half-breadth plan. In the case of each, a spline anchored at the known points on rulings 5, 6, 7 and 8 is bent freely around to the proper projected point on the centerplane. The resulting curves are known to lie in parallel planes, and they are known to lie in our proposed surface. Therefore we may find the rulings of that surface, and so we do.

4. The Use of Cylinders and Cones.

Thus are drawn rulings numbered 9, 10, 11, 12 and 13. At least one more ruling is needed to determine the shape of the stem, which hitherto has been sketched as a straight line between chine and cheer. The surface is therefore finished out by assuming it to be cylindrical in the short distance forward of ruling 13. Number 14 is drawn parallel to 13 in both sheer and halfbreadth views and its intersection with the centerplane projected to find the point where it lands on the stem in the profile view. (Halfsiding of stem has been left out of this drawing.) A curve between chine and sheer through this point shapes the stem, which fortuituously fairs with the stem profile beneath the chine.

This one point is the only instance in the entire job where good fortune will be admitted. It is not always apparent at the beginning of a drawing that the finished development will result in a smooth stem. If no interruptions in this curve can be allowed, or if the plasticity of plating will not be sufficient to allow the necessary distortion, sheer or chine will have to be modified to suit the need. If a straight stem is desired, the ruling at the stem must be parallel to the stem in all views.

This use of the cylinder demonstrates the kind of instance where it is convenient, and valid enough, to consider the surface to be cylindrical or conical. The cylinder was chosen here because its projection is simply by drawing its rulings parallel to each other in all views. A similar case may occur at the stern of a hull.

It is now time to cut the hull horizontally with LL and to project the offsets of LL to the body plan, assuming that this plane plus WL_c between chine and sheer are enough to establish the shape of topside sections. LL is allowed to take its own course abaft the point fixed by its intersection with topside ruling numbered 1. The tumble home of the transom is thereby found to be not quite so bold as hoped in the preliminary sketch. If more tumble home is desired, the offsets of the sheer will have to be altered between Stations 3 and 6, thereby altering LL.

Note on the body plan that development produces a slight inverted V between topside and bottom at Station 0. This may be corrected only by increasing the offsets of the chine in this region, or by decreasing the offsets of the sheer, and such would have to be done before the lines were finished, for nobody would wish to design a boat which looked like this. This result has been left uncorrected to demonstrate that a formula for development is not necessarily a formula for beauty.

The aim was not to illustrate matters of taste in design, but to demonstrate the projection of convolute surfaces. That aim has been accomplished.

5. <u>Some Time-Saving Tricks.</u>

In the establishment of the adjacent view of the curves determined by any horizontal, vertical or oblique cutting planes, accuracy is promoted if a large number of known points are available. If any considerable open span must be crossed with a spline, a sufficient number of known points must be available to establish its initial direction firmly while it is swept into at least one known point on the other end, and two if possible. For this reason, places on the hull that provide such initial directions are good places to start. Regions of parallelism are especially handy. For instance, stations lines already are parallel both in sheet and halfbreadth views. Now if they appear parallel also in the body plan, a cylindrical surface is already established in the region where this parallelism extends, and that much of the whole surface is thereby defined.

On the example hull, advantage was taken of the circumstance that a segment of the chine was nearly horizontal. On most vessels fairly long segments occur where chine and sheer are close to parallel, and such segments save drafting while providing starting points.

If the desired shape of the hull makes it impossible to develop in some restricted region, as in the flare of the bow, the advantages of development still may be largely achieved by developing the entire hull first, then modifying the non-developable region to conform to the desired shape. Obviously this cannot be done if the plating material, such as plywood, cannot be plastically deformed.

If a high order of precision is desired in locating exact points of tangency, use a mirror. It is true that on curves of long radius the point of tangency is elusive. On the other hand, consider that the longer the radius the less critical is the point of tangency, while the shorter the radius the more exactly the point may be located by the straight edge method. Therefore it seems debatable whether or not the extra time taken in finding parallel normals with a mirror would be worthwhile. It seems that if any sheet is flexible enough to bend in single curvature, it is flexible enough to bend an infinitesimal amount in double curvature.

It should be kept in mind that if the parallel cutting planes are passed very far from the boundary curves -- sheer, chine and fairbody -- these curves may have to be moved to lie in the finished surface. Often this would cause no great harm to looks or performance, but the readjustment of sheer, chine and fairbody during the process of development, once they are drawn according to calculations and good judgment, only results in loss of control over hull shape and loss of time in production. Hence the draftsman should keep the development firmly in hand as it proceeds. Where two boundary curves run nearly parallel to each other, there should be no hesitation in constructing cutting planes oblique either to waterplanes or centerplane. These planes may be passed in any view, at any angle,. wherever most convenient.

In short, this method of development is a method of close approximation, but it is not guesswork.

IV. CONCLUSION.

The fundamental nature of developable surfaces has been examined, and it is found that on the drafting board such a surface may be described by projecting the tangent planes that lie along all rulings. A theorem has been proved to provide a method for locating these tangent planes, by drawing linear tangents to the plane curves that mark the intersection of parallel cutting planes with the desired surface. It has been proved that the properties which make this method possible are common to all developable surfaces, but that developable hull surfaces may properly and conveniently be considered convolute surfaces.

This approach enables the designer to proceed directly from preliminary sketch to finished drawing without cut-and-try search for cones or cylinders whose parameters or sequence is unknowable. Hence the particulars of hull form, importantly displacement and center of buoyancy, determined in preliminary design, may be reproduced with high accuracy.

Whatever low opinion naval architects may have of the virtues of developable hulls, they continue to face clients who hope to save on capital investment by use of developable hull design. There are instances where no serious sacrifice of esthetic appeal or of performance will result from development if the designer is able to reproduce the particulars suggested by his good judgment in preliminary design. If he has a method for executing the proposed set of particulars without suffering nervous breakdown, there is no reason why the client should not have what he wants and the designer enjoy a pleasant job.

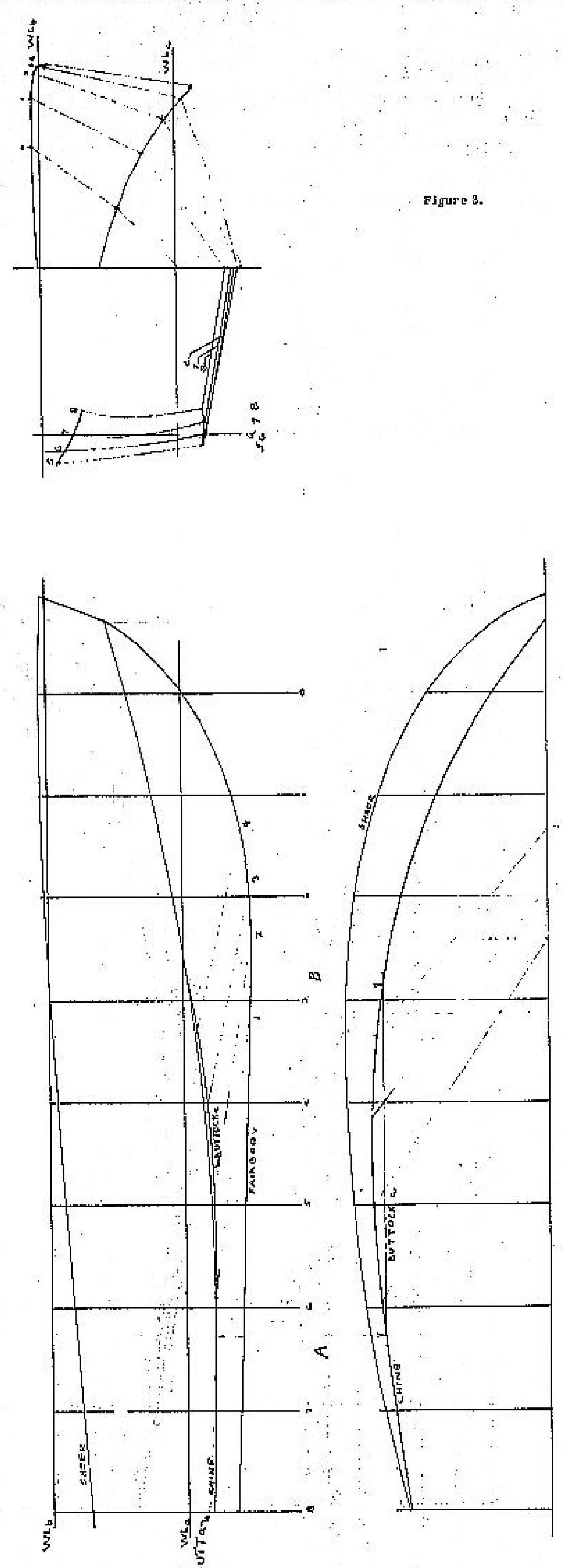


Figure 3.

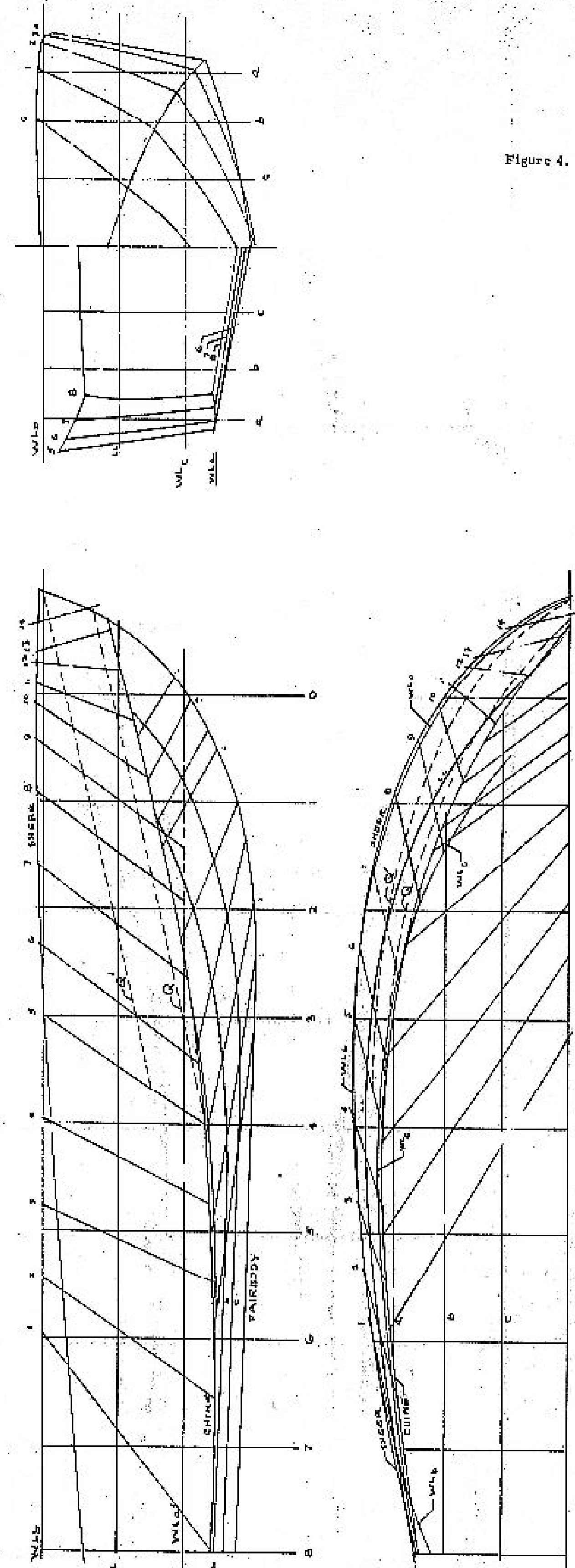


Figure 4.

TOM BEARD
1002 MT. PLEASANT RD.
PORT ANGELES, WA 98362

1-65-400