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THE DESIGN OF DEVELOPABLE AND NEARLY DEVELOPABLE HULLFORMS

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NOTATION:

$\vec{r} = \{x, y, z\}$: position vector and cartesian components. Vector quantities have an arrow above the symbol letter.

$\vec{r}_1(u_1), \quad \vec{r}_2(u_2)$: parametric spline functions defining boundary curves C1, C2 to a developable hull panel.

$\vec{t}_1 = \dfrac{d\,\vec{r}_1}{du_1}$, $\vec{t}_2 = \dfrac{d\,\vec{r}_2}{du_2}$: tangent vectors to curves C1, C2.

$\vec{c}_1 = \dfrac{d\,\vec{t}_1}{du_1}$, $\vec{c}_2 = \dfrac{d\,\vec{t}_2}{du_2}$: curvature vectors to curves C1, C2.

$\vec{g}$: straight generator line between curves C1 and C2.

$\vec{G} = \alpha.\vec{g}$: extension of generator from C1 to the local vertex position.

$\dot{\vec{r}} = \dfrac{d\,\vec{r}}{ds}$, $\ddot{\vec{r}} = \dfrac{d^2\,\vec{r}}{ds^2}$: first and second derivatives with respect to arc length s.

$\vec{r}_u = \dfrac{d\,\vec{r}}{du}$, $\vec{r}_{uu} = \dfrac{d^2\,\vec{r}}{du^2}$: first and second ordinary or partial derivatives w.r.t curve parameters.

$\vec{a} \times \vec{b}$: vector cross product (vector).

$\vec{a} \bullet \vec{b}$: vector dot product (scalar).

1.0 INTRODUCTION

Many small craft are made from flat sheet material where single sheets form a substantial part, or even the whole of, the hull surface. The surface is formed by bending the sheet and, possibly, by stretching the sheet within limitations imposed by the properties of the sheet material and the forces that can be applied to the sheet in the manufacturing process.

Surfaces formed from a flat sheet by bending only are called DEVELOPABLE surfaces. Such surfaces possess only single curvature, lines of minimum principal curvature being straight lines running right across the surface. The curvature in the other principal direction is limited by the surface stresses set up in the sheet by bending and the loadings that can be applied to the sheet. In many cases, particularly with slender hulls, it is possible to stretch the sheet by small amounts. A simple way of doing this is to form a developable surface and, regarding this as a structural beam, to subsequently distort the beam by bending or twisting it to produce a NEARLY DEVELOPABLE surface. The degree of bending and twisting achievable is, again, limited by material properties and the loads that can be applied. Catamaran hulls, such as the Tornado, produced from plywood as nearly developable forms have been called “Tortured ply” forms.

This report describes the characteristics of developable and nearly developable surfaces, the mathematics involved and the software for the design of such surfaces that runs in conjunction with the Wolfson SHIPSHAPE package. This software reads SHIPSHAPE .HFG files containing data for curves bounding one or more developable surfaces, creates sets of straight generator lines crossing each surface (as two point section curves), together with extensions to a local vertex position, and adds these curves to the .HFG file. This file can be saved and read back into SHIPSHAPE. The generator curves can be edited within SHIPSHAPE and linked to form a network for the final hull form. Facilities exist for developing the outlines of the hull panels laid out as flat sheets. SHIPSHAPE retains the facility to interpolate plane sections, waterlines and buttock lines for the hull form together with the options to transfer information to hydrostatics and CAD programs.

2.0 THE GEOMETRY OF DEVELOPABLE SURFACES

In the simplest form a developed surface can be formed by joining straight line generators from a fixed vertex to points along a three dimensional curve as shown in fig 1:

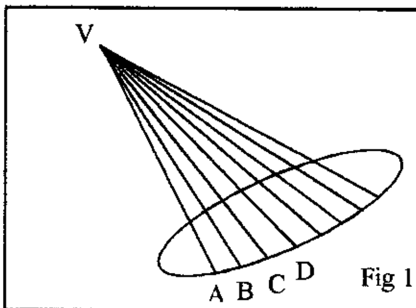


Fig 1

If it is imagined that each element of fig 1., such as the triangles VAB,VBC etc., are a joined set of plane triangles they can clearly be laid out flat on a plane surface to represent a development of the three dimensional faceted surface. This process can be continued by inserting more generators until, in the limit, a continuously curving surface is produced which still retains the capability of being laid out flat without stretching the sheet.

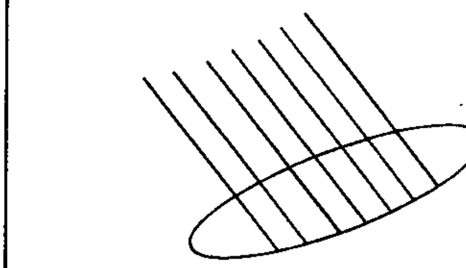


Fig 2

The surface will have parallel generator lines if the vertex V is removed to an infinite distance from the boundary curve, as shown in fig 2. Such a surface is called a RULED SURFACE.

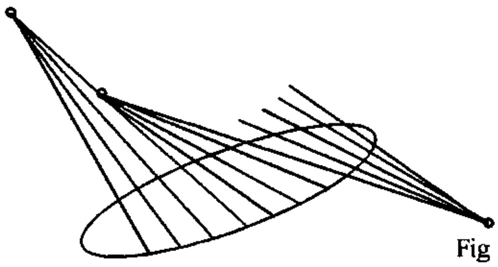


Fig 3

More vertices can be added provided each new vertex is placed on a generator line from the previous vertex. This increases the flexibility of the surface definition and gives finer control of the way curvature varies over the surface. See fig 3.

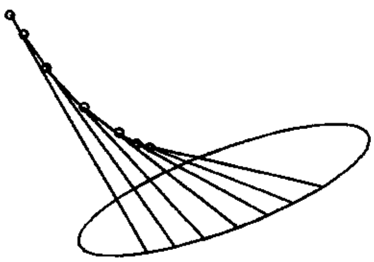


Fig 4

As more and more vertices are added the vertices begin to lie on a continuous curve in such a way that all the generator lines touch the curve tangentially. The curve through the vertices is said to be the ENVELOPE of the generator lines. In its most general form a developable surface is defined by an assembly of isolated vertices and generator envelope curves.

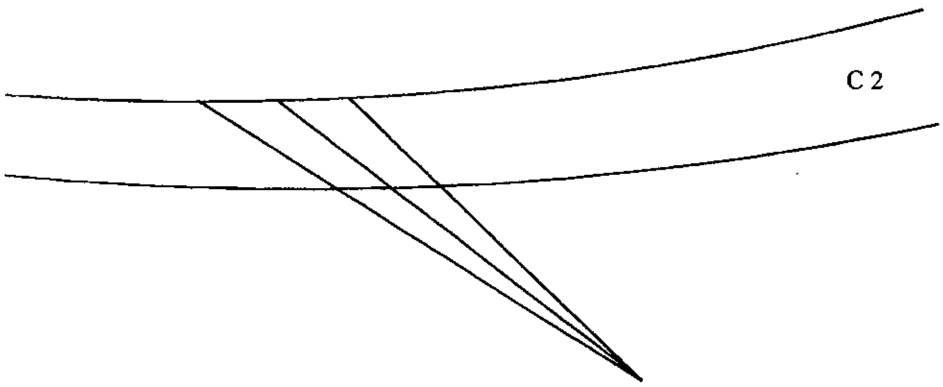


Fig 5

In practice a hull form is created from a number of surfaces, each bounded by curves such as the line of keel, chine lines, deck lines and so forth. Fig 5 illustrates a developed surface bounded by two such lines C1 and C2. Although it is possible to chose a number of vertices and to generate the surface from these vertices using either C1 or C2 as the boundary curve, it is not guaranteed that the other curve, when drawn to lie on the surface as defined, will conform to the designer's intentions. The problem is that it is not obvious where to place vertices in order to produce the hull form the designer has in mind. A more useful approach is for the designer to chose both C1 and C2 as appropriate to his intention and to allow the computer to find a suitable set of vertices and, possibly, generator envelope curves to define a developed surface containing both boundary curves. This can be done using an algorithm to be described later in this report.

3.0 SURFACE CURVATURE CHARACTERISTICS AND VERTEX CROSSOVER

The curvature of a developed surface in a direction perpendicular to the generators increases as the distance from the local vertex decreases. That is, the local radius of curvature becomes smaller closer to the local vertex. It follows that, in order to avoid excessive bending of the sheet material, local vertices should be kept far enough away from both boundary curves defining the part of the developable surface to be included in the hull surface itself. This requires particular care if the vertices cross over from one side of the surface to the other. The preferred method of cross over is illustrated in fig 6.

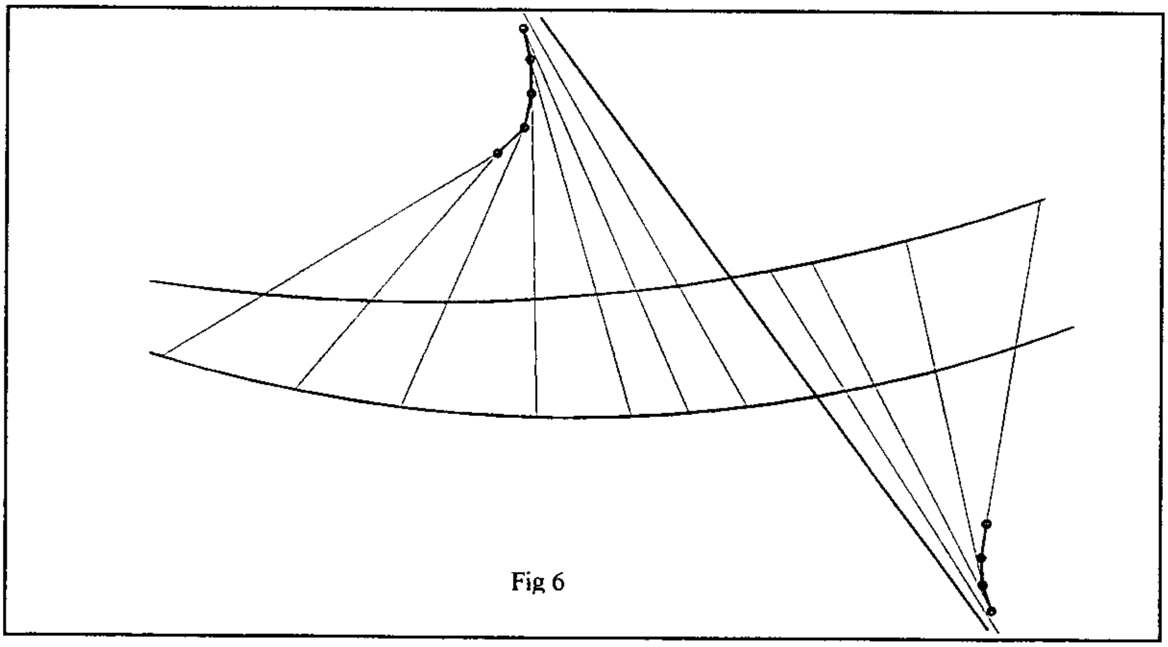


Fig 6

Approaching the crossover the envelope curve for the vertices move away from the boundary curves rather than toward them, so that the surface is locally a ruled surface. The arrangement shown in fig 6 will arise naturally in the algorithm referred to above without the need for intervention by the user. However, the user should be aware of the likelihood of such vertex behaviour and should not be worried by it.

Because curvature decreases continuously with increasing distance from the vertex, maximum curvature will exist along one or other of the two boundaries C1 or C2. It is possible to calculate the variation of curvature along these two boundaries. This information can then be used to check that local sheet bending is not excessive. The degree of bending that can be tolerated depends on the thickness of the sheet and its material. A judgement of the maximum allowable curvature can be made either on the basis of previous experience or by a calculation based on the relation between bending stresses and curvature.

4.0 THE LOCATION OF GENERATOR LINES

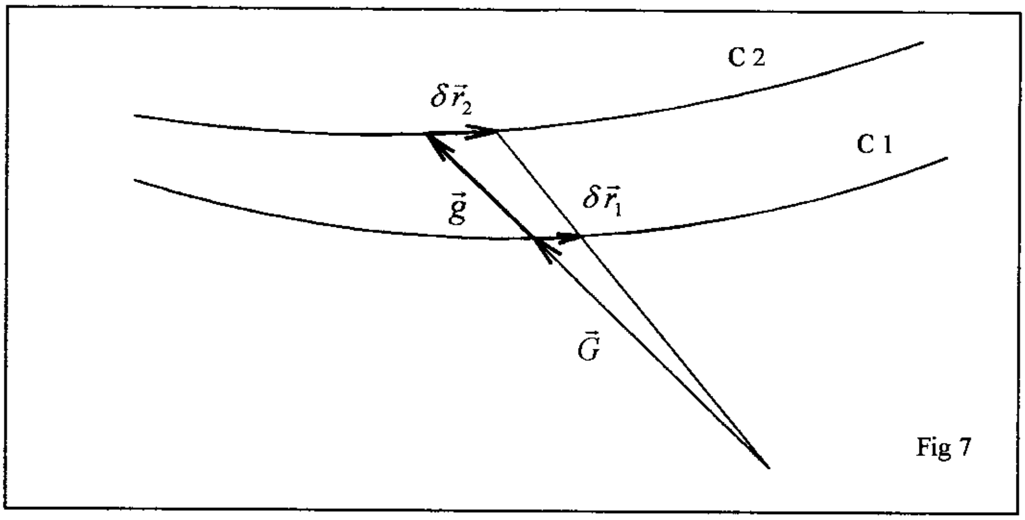


Fig 7

The element of the developable surface shown in fig 7 has to form part of a plane triangle extending to the local vertex. This implies that the part of the generator lying between the two boundary curves and the local tangent vectors on C1 and C2 are coplanar. A search routine can be used to find the end on C2 of a line drawn from any chosen point on C1 that satisfies this required property. The generator so found can subsequently be extended back to a local vertex by calculating the distance from the vertex to curve C1 measured along the generator. The mathematics of the process are set out below:

The extension of $\vec{g}$ to the vertex is given by $\vec{G}=\alpha.\vec{g}$. By considering small changes to a neighbouring vertex, as shown in fig 7, it follows that:

$$\delta\vec{G} = \delta\vec{r}_1 = \vec{t}_1\,\delta u_1 \quad \text{and} \quad \delta\vec{g} = \delta\vec{r}_2 - \delta\vec{r}_1 = \vec{t}_2\,\delta u_2 - \vec{t}_1\,\delta u_1$$

Thus, since $\delta\vec{G} = \delta\alpha.\vec{g} + \alpha.\delta\vec{g}$ it follows that

$$\vec{t}_1\,\delta u_1 = \delta\alpha.\vec{g} + \alpha.\left\{\vec{t}_2\,\delta u_2 - \vec{t}_1\,\delta u_1\right\} \quad \text{or, since} \quad \vec{g}\times\vec{g} = 0 :$$

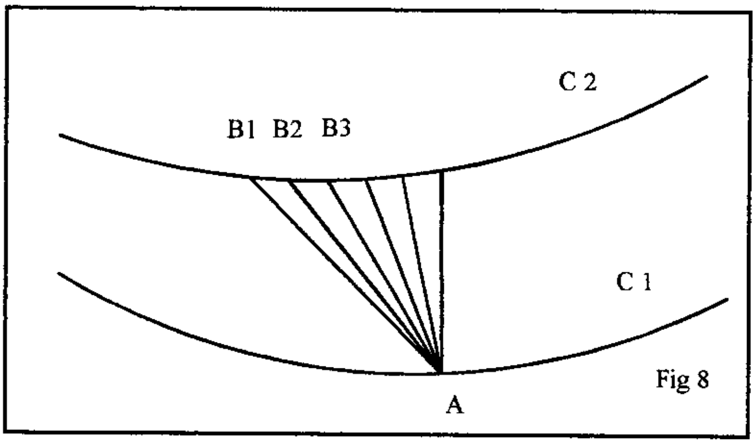
$$\vec{g}\times\vec{t}_1\,\delta u_1 = \alpha.\left\{\vec{g}\times\vec{t}_2\,\delta u_2 - \vec{g}\times\vec{t}_1\,\delta u_1\right\} \text{..........(1.1)}$$

or $$\vec{g}\times\vec{t}_1\bullet\vec{t}_2 = -\alpha.\left\{\vec{g}\times\vec{t}_1\bullet\vec{t}_2\right\} \quad \text{since} \quad \vec{g}\times\vec{t}_2\bullet\vec{t}_2 = 0.$$

Now, in general, the vertex does not lie on the boundaries C1 or C2, so that $\alpha \neq -1$. It follows that the generators must satisfy the condition that

$$f = \vec{g} \times \vec{t}_1 \bullet \vec{t}_2 = 0 \ldots\ldots\ldots\ldots(1.2)$$

This condition implies that the vectors $\vec{g}, \vec{t}_1$ *and* $\vec{t}_2$ are coplanar, as expected.



Generators between curves C1 and C2 can be located by drawing rays from point A on C1 to various points B1,B2, B3 etc. on C2 and calculating the corresponding values of the function f using eqn 1.2. An interpolation can be used to find points for which $f = 0$.

By choosing a set of points A, a set of generators can be found covering the whole of the surface between C1 and C2. Each generator can be extended back to a corresponding local vertex by finding suitable values of α using eqn 1.1.

For a complex developable surface there may be several possible generators through a given point A on C1 to different points on C2. If there are two or more such generators with vertices outside the area between C1 and C2 the most likely correct choice is the generator having the shortest length. The program SKIN described below takes this choice.

5.0 FINDING LOCAL VERTICES

Again by considering small changes occurring between neighbouring vertices, eqn 1.2 can be used to show that:

$$\delta f = \delta\vec{g} \times \vec{t}_1 \bullet \vec{t}_2 + \vec{g} \times \delta\vec{t}_1 \bullet \vec{t}_2 + \vec{g} \times \vec{t}_1 \bullet \delta\vec{t}_2 = 0$$

or $$\left\{\vec{t}_2\, \delta u_2 - \vec{t}_1\, \delta u_1\right\} \times \vec{t}_1 \bullet \vec{t}_2 + \vec{g} \times \vec{c}_1 \bullet \vec{t}_2\ \delta u_1 + \vec{g} \times \vec{t}_1 \bullet \vec{c}_2\ \delta u_2 = 0.$$

since $$\vec{t}_2 \times \vec{t}_1 \bullet \vec{t}_2 = \vec{t}_1 \times \vec{t}_1 \bullet \vec{t}_2 = 0$$

it follows that $\delta u_2 = \left[\dfrac{\vec{g} \times \vec{c}_1 \bullet \vec{t}_2}{\vec{g} \times \vec{c}_2 \bullet \vec{t}_1}\right]\delta u_1$ or $\delta u_2 = \lambda \delta u_1$ where $\lambda = \left[\dfrac{\vec{g} \times \vec{c}_1 \bullet \vec{t}_2}{\vec{g} \times \vec{c}_2 \bullet \vec{t}_1}\right]$.

This can be substituted back into eqn 1.1 to yield: $\vec{g} \times \vec{t}_1 = \alpha\left\{\lambda\, \vec{g} \times \vec{t}_2 - \vec{g} \times \vec{t}_1\right\}$

From which: $\alpha = \dfrac{1}{\left[\lambda\left(\dfrac{(\vec{g}\times\vec{t}_1)\bullet(\vec{g}\times\vec{t}_2)}{(\vec{g}\times\vec{t}_1)\bullet(\vec{g}\times\vec{t}_1)}\right)-1\right]}$ ....(1.3)

Thus, once the generators have been found, the corresponding local vertices can be found by calculating α using the tangent and curvature vectors for the two curves C1 and C2. Clearly, these local vertices must not lie on or between the two curves as this would result in a point or kink on the surface itself.

6.0 CURVATURE OF A CONIC SURFACE

The final piece of mathematics relates to the estimation of the curvature of the developed surface, which must be kept within suitable manufacturing limits. Surface curvature is zero along the generator lines and greatest in a direction normal to the generators. The surface curvature is the same as that of a curve of intersection of the surface and a plane normal to the generator at the point at which the curvature is required.

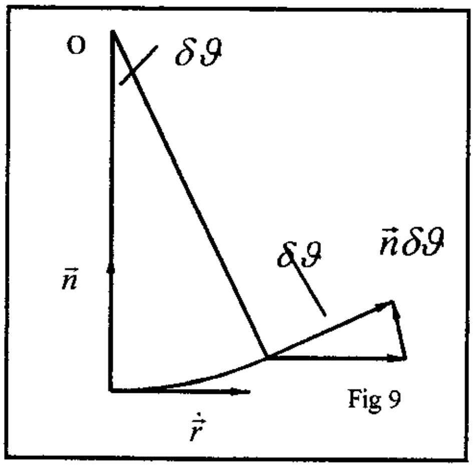


Fig 9

Fig 9 illustrates a small portion of a three dimensional space curve. The principal normal to the curve $\vec{n}$ points towards the local centre of curvature O. By convention the normal vector is taken to be of unit length.

$\dot{\vec{r}} = \dfrac{d\vec{r}}{ds}$ is a unit length tangent to the curve.

Moving along the curve a small distance δs the tangent rotates through a small angle $\delta\theta$ whilst remaining one unit long. As a consequence, the change in the tangent vector is $\vec{n}\,\delta\,\vartheta$.

That is: $\ddot{\vec{r}}\,\delta s = \ddot{\vec{r}}\,R\,\delta\vartheta = \vec{n}\,\delta\vartheta$ or $\kappa\,\vec{n} = \ddot{\vec{r}}$ ....(2.1)

where $\kappa = 1/R$ is the principal curvature of the curve.

This result can be applied to a curve drawn on a conic surface defined parametrically from a local vertex as:

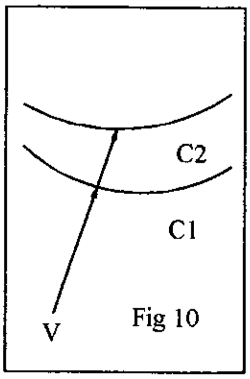


Fig 10

$\vec{r}(u,v) = v.\vec{G}(u)$ where $v =$ 1.0 on C1

or

$1.0 + 1/\alpha$ on C2.

Where α is given by eqn. (1.3).

The arc length derivatives for a curve on such a surface can be written in terms of parametric derivatives to yield the following:

$$\dot{\vec{r}} = \vec{G}\,\dot{v} + \vec{G}_u\, v\dot{u} \;\ldots\ldots(2.2)\quad \text{(unit tangent to curve).}$$

Particular cases $\dot{u} = 0$ and $\dot{v} = 0$ show that $\vec{G}$ and $\vec{G}_u$ are vectors tangential to the conic surface. As a consequence the vector $\vec{N} = \vec{G} \times \vec{G}_u$ is a normal to the surface, but not necessarily a unit vector.

Further $\quad \kappa\,\vec{n} = \ddot{\vec{r}} = 2\vec{G}_u \dot{v}\dot{u} + \vec{G}_{uu} v\dot{u}\dot{u} + \vec{G}\ddot{v} + \vec{G}_u v\ddot{u}$

The curvature of the surface is that of a curve lying in a plane normal to the surface,

from which $\quad \kappa\,\vec{n} \bullet \vec{N} = \kappa\, N = \vec{N} \bullet \vec{G}_{uu} v\dot{u}\dot{u} \;\ldots\ldots(2.3)\;$ (since $\vec{N} \bullet \vec{G} = \vec{N} \bullet \vec{G}_u = 0$)

Now, for a curve in a direction normal to the generator $\quad \dot{\vec{r}} \bullet \vec{G} = \vec{G} \bullet \vec{G}\,\dot{v} + \vec{G} \bullet \vec{G}_u\, v\dot{u} = 0$

giving
$$\dot{v} = -\frac{\vec{G} \bullet \vec{G}_u}{\vec{G} \bullet \vec{G}}\, v\dot{u} \;\ldots\ldots(2.4).$$

Also, for a unit tangent $\quad \dot{\vec{r}} \bullet \dot{\vec{r}} = 1.0 = \vec{G} \bullet \vec{G}\,\dot{v}\dot{v} + 2\vec{G} \bullet \vec{G}_u\, v\dot{v}\dot{u} + \vec{G}_u \bullet \vec{G}_u\, v^2\dot{u}\dot{u}$

leading to
$$1.0 = v^2\dot{u}\dot{u}\left\{\vec{G}_u \bullet \vec{G}_u - \frac{(\vec{G} \bullet \vec{G}_u)^2}{\vec{G} \bullet \vec{G}}\right\}$$

or
$$\dot{u}\dot{u} = \frac{\vec{G} \bullet \vec{G}}{v^2\left\{(\vec{G} \bullet \vec{G})(\vec{G}_u \bullet \vec{G}_u) - (\vec{G} \bullet \vec{G}_u)^2\right\}} \;\ldots\ldots(2.5)$$

This can be substituted into eqn.(2.3) to yield the following expression from which the curvature of the conic surface can be evaluated:

$$\kappa = \frac{(\vec{N} \bullet \vec{G}_{uu})(\vec{G} \bullet \vec{G})}{N\, v\left\{(\vec{G} \bullet \vec{G})(\vec{G}_u \bullet \vec{G}_u) - (\vec{G} \bullet \vec{G}_u)^2\right\}} \;\ldots\ldots(2.6)$$

Clearly, as could be expected for a conic surface, the curvature κ decreases, and hence the radius of curvature increases, as v increases. Along any given generator the greatest and smallest values of curvature lie on the two boundary curves C1 and C2.

7.0 EXAMPLE HULL FORMS

Two hull forms are included in this report to illustrate the application of the techniques discussed above. The first example is of a hard chine form similar to a Mirror dinghy, with a bow transom in addition to the stern transom. This hull form is constructed from strictly developable surface panels. The second example is of a catamaran demi-hull of similar form to a Tornado catamaran. This hull form is a tortured hull-form created by bending a developed surface in a horizontal plane.

7.1 THE MIRROR DINGHY FORM

Figures 11,12,13,14,15 and 16, placed at the end of this report, relate to this hull-form. Fig 11 is a three dimensional view of a conventional set of lines of this form, showing waterplanes, sections and buttock planes as created in the output segment of SHIPSHAPE. This hull form consists of two developable panels, one topside panel defined by the chine line and deck line, and one bottom panel defined by the keel line and the chine line. The hull is closed by a plane stern transom and an equally plane bow transom.

Fig 12 shows the three boundary curves, in plan and elevation, with each curve extended beyond the hull itself at both ends. The purpose of the extensions is to allow the sweep algorithm to produce generators covering the whole of the area of each hull panel. The boundary curves and their extensions were created in SHIPSHAPE to suit criteria set by the designer. If necessary, a preliminary curve network with straight line sections can be set up to check approximate values of hull particulars such as displacement, LCB, prismatic coefficient, etc. as part of the process of producing suitable boundary curves. Strictly speaking, the straight line sections will not lie on the final developed surface and can be erased once they have served their (purely temporary) purpose. The boundary curves, once saved in an .HFG file, can be read into the program SKIN which produces an extensive set of generator and vertex lines for the hull panels using the sweep algorithm described previously. These two point, straight line, curves are appended to the .HFG file and the amended file is written out to a new file named by the user. The new file can be read by SHIPSHAPE.

Fig 13 shows the generator and vertex lines for the bottom panel of the Mirror form in plan view. This graphics output has, in fact, come from SHIPSHAPE. It can be seen that the surface approaches a ruled form at each end, as the envelope of the vertices moves away from the panel. In the centre of the panel the envelope curve for the vertices curves inwards towards a cusp, about half way along the panel, and then moves away again towards the other end of the panel. This behaviour is not that of a conical surface. It would be difficult to find a set of vertices for a conical development of an approximately similar panel, however, it is neither necessary nor desirable to do so.

The set of generator curves produced by SKIN needs to be edited so as to trim the panel to the transom edges at the bow and the stern. This will probably involve adding generators to define the keel/transom and chine/transom corners in order to create a suitable panel network. Adding generators in this way may also make it desirable to re-space some of the neighbouring generators in order to maintain a reasonably regular spacing on the panel. A further editing operation will be to trim the generators to end on the transom edges. These editing operations are easily carried out in SHIPSHAPE by creating additional section curves and placing them using the snap to curve options. A knowledge of the local vertex positions is essential to the creation of new generators and the editing of existing ones. Once a final set of generator curves has been achieved, the vertex lines lying off the panel can be erased.

The panel network consists of the generator curves, as a set of sections, together with longitudinals for the panel edges, including the bow and stern transom edges. The generators should be placed on the network first. The longitudinals should be created as dummy curves and linked to the generators.

Figs 14 and 15 show the final network for both panels of the Mirror dinghy form as a logical net diagram and as a three dimensional view, respectively. Fig 14 is a screen dump from the linker segment of SHIPSHAPE, the curve directory showing the first 16 curves. All of these curves are generator curves which are given names of the form **gen***x* by SKIN. Correspondingly, the vertex curves, from the boundary to the local vertex, are given names of the form **ver***x*. Curve 1 has a different name format. It is a manually inserted generator created by the user during editing. Curves 1-40 form the bottom panel. Longitudinal curves 36 and 37 form the chine edge for the bottom panel whilst curves 38,39 and 40 are, respectively, the stern transom edge, the keel line and the bow transom edge. The net appears to be "upside down". This is forced by the point order in which the generator curves were created within SKIN. Curves 41-45 form the topside panel. Longitudinals 41 and 42 form the chine edge for the panel whilst curves 43,44 and 45 are the stern transom, the deck edge and the bow transom edge. This panel is the "right way up" on the network. The user will need to check the way that the generator points have been ordered and plan the network layout accordingly.

It should be noted that there are two versions of the chine line in this network and that the two panels are not joined logically. Because the generator ends for both panels lie precisely on the original boundary curve for the chine, the two versions of the chine will butt closely together in space, sufficiently so for production purposes. Fig 15 shows that over most of the length of the chine the end points of the topsides panel and the bottom panel coincide. SKIN requires the panel boundaries to be designated "First line" and "Second line", respectively. If the chine is designated the first line for both topsides and bottom panels the generator ends on the chine will be common to both panels on exit from SKIN. There are differences towards the ends of the panel where additional generators have been edited in SHIPSHAPE to locate the corners of the panels properly. The first point of each generator lies on the first boundary line.

The final figure of this set, fig 16, shows the two panels of this hull form laid out flat by a process that is described later in this report. The hull is formed from panels cut to these flat sheet shapes together with appropriate bow and stern transom panels. The shaping of these transom panels and any additional internal bulkhead panels are obtained by interpolating within SHIPSHAPE.

7.2 THE TORNADO HULL FORM

Figs 17 to 21 relate to the Tornado hull form. As with the mirror hull form, these are placed at the end of this report. Fig 17 is a three dimensional view of the form showing conventional plane transverse sections, waterplanes and buttock planes. The form is the final outcome of a process of bending a developed surface in a horizontal plane to produce a nearly developable form.

The process was started by defining an extended transom and a keel/stem line suitable for the final hull form, together with a possible deck line. The points along the keel/stem line were next displaced laterally to bend the line in a horizontal plane in the opposite sense to that required in the final hull form. The amount of the displacement was chosen to straighten the deck line in the x-y plane. The transom was also displaced by the same amount as the keel endpoint. The displaced transom and the bent keel/stem line were used as the two boundary curves of a developable surface. This produced a set of generators and vertices in which the local vertices all lay abaft the transom; these vertices most closely approach the transom near the bilge corner and move aft to produce a ruled surface form at the deck level. After editing the set of generators, a network of generators and boundary curves was created as shown in figs 18,19 and 20. In fig 18 curves 5 to 20 are the set of generators (edited to include a generator at the transom/deck corner) whilst curves 21 and 22 form the new transom edge and curves 23 and 24 form the new keel/stem line. These boundary curves are formed by linking dummy curves to the generator ends. As for the mirror form, the net appears upside down as a consequence of the point order in which the generators were created. Fig 19 shows the network in plan and elevation and fig 20 in three dimensions. It should be noted that the outlines of the flat panels required to form this hull are obtained by laying this developable surface out flat.

The final process to be carried out within SHIPSHAPE is to form the further network of curves shown in fig 21. This is the network from which fig 17 was derived by interpolation. To define this network a set of sections were created at suitable fore and aft positions by snapping points onto the generators of fig 19. The number of points for each section was chosen to match the number of generators crossing the plane of the section concerned. These snapped sections were used as templates around which the final network sections and longitudinals were formed, again by using the snap facility and a suitable manipulation of the end condition data. The last operation involved translating the network sections laterally so as to bring the end points back onto the centreline plane to reverse the bending process imposed on the hull form at the outset. This procedure bends the true developable surface into a nearly developable form having the character required of this hull. Of course, bending the developable form in this way imposes bending stresses in the 'beam' formed by the developable surface. Strictly speaking these stresses should be estimated from the deflection curve in order to ensure that the sheet will not be over stretched in the process of skinning the hull and also to ensure that the loads to be applied to force the sheet into place can be exerted by the tools available. This exercise was not carried out for this illustration of the method of forming nearly developable hull forms.

8.0 DEVELOPMENT OF PANEL OUTLINES

The process of laying out a three dimensional developable panel onto a flat sheet is called the development of the panel. The method adopted within the program for this purpose is illustrated in fig 22. This fig shows one segment of the topsides panel for the mirror hull form lying between two generators AB and CD. In order to develop this segment of the panel, the lengths of the vectors AB AC and AD, together with the angles between them, are calculated from the co-ordinates of the points A,B,C,D in three dimensions. Having developed the earlier segments of the panel as a flat sheet as far as the development of AB, it is then possible to add the development of the segment ABCD to the flat sheet by adding the vectors AC and AD rotated from AB by the appropriate angles. The first non-zero length generator for the panel is laid off in a pre-set direction and the panel development proceeds segment by segment from this point. There may be triangular segments before the first non-zero length generator and after the last.

In order to leave the developed panel in a sensible orientation, the completed panel is rotated until the surrounding rectangle, bounded by sides parallel to the sheet axes, has the smallest attainable area. The algorithm creates a SHIPSHAPE network for developed panel for the purposes of transferring from SHIPSHAPE to AutoCAD and plotting.

9.0 RUNNING THE PROGRAM "SKIN.EXE"

The process of creating a developable surface starts by creating an .HFG file within SHIPSHAPE containing the boundary curves for the hull form required. Where necessary, these boundary curves should be extended beyond the hull proper to allow SKIN to create generators over the whole surface. This is particularly true where the hull terminates with a transom.
When running SKIN the program first asks for an input file name: This should be supplied with the full path and the file extension .HFG. SKIN expects an existing file name and will ask for a repeat input if the file cannot be found. Subsequently the user is asked to select a program mode: Mode 1 will form a set of generators and vertex extensions to fit a selected pair of boundary curves whilst Mode 2 will take a specified linked network for a developable surface and replace it by a linked network for the corresponding developed flat panel.

In Mode 1 the program displays the curve directory of curve names and asks the user to select two curves as first and second boundary lines. Only curve names listed in the directory are acceptable. The program will add generator and vertex lines to the end of the .HFG file constructed so that the first point of each two point generator lies on line 1. After completing this process, the program calculates curvature data along the boundary curves. The final operation is to ask for output file names: the name for the generator/vertex file may be a repeat of the input file name or, alternatively, a new file name can be given. A file name for the file to contain the curvature data must also be given. The full file name, including the path and extension, may be given for each file. Alternatively the path and/or extension may be omitted. The default path is that specified for the input file, as is the extension for the generator/vertex file (this should be .HFG). The default extension for the curvature data file is .DAT.

In Mode 2 the program again displays the curve directory and asks the user to select one curve on the upper boundary and one on the lower boundary. The program will then scan the curve links to identify the complete panel boundary. After finishing the development of the panel the users is asked for an output file name. The original curves are deleted from the file before writing the replacement curves. Since it is required to retain the original curves, a new filename should be specified as the output file.

Between the operations of forming generators and development it is necessary to carry out some editing operations using SHIPSHAPE. These will include editing the generators as necessary, creating dummy upper and lower boundary curves and forming the panel network for the panel. In the linker segment generators should be placed on the network first and the dummy boundary curves should then be linked to them. Each panel forming the complete hull should be a separate network not directly connected to the other panels. The outcome of the editing process is a developable surface network that can be used to interpolate a conventional lines plan within SHIPSHAPE for output to hydrostatics and stability software or to a CAD program, or for re-input to SKIN in mode 2 to produce a flat development of the panel. Once the editing process is complete the vertex rays that indicate the local vertex positions are no longer required and may be erased.

9.1 TIPS AND WRINKLES

- The first point of each generator 'curve' lies on the curve declared as the first line when running SKIN. These points must lie on the lower edge of the SHIPSHAPE network for that panel even if in physical space the panel is the other way up.

- The boundary curves are separately defined on the network even though they should butt together in physical space. The closest join is obtained if, so far as possible, the adjacent ends of the generators on joining panels coincide. This is achieved in SKIN by declaring the common boundary curve as the 'first line' for both panels.

- If the surface is locally a ruled surface SKIN may be unable to decide whether the local vertex is above the panel or below it. The vertex lines may be randomly placed either side of the panel. This is not a problem and should be ignored.

- If the panel is locally flat any line across the panel will be straight and, therefore, potentially a generator. In this case SKIN may produce a set of generators which do not vary smoothly in direction across the panel. Check the curvature data for a nearly flat panel behaviour before deciding to tidy up the generators, either by editing in SHIPSHAPE or by re-fairing the boundary curves and re-running SKIN. If the panel is flat enough it may not be necessary to edit the generators at all.

- When creating additional generators or altering the position of a generator in SHIPSHAPE a useful device is to construct a suitable ray from a suitable local vertex position through a point on either one of the panel boundary curves. Once this is in place a new generator can be snapped in place on top of the ray with end points on the appropriate boundaries.

- Where there appears to be a flat portion of a developable surface, as detected by SKIN, it will be appropriate to place generators at either end of the flat region and to place boundary curve end points at these generators. This will ensure a truly flat area in the final form. It is unnecessary to have any additional generators on the flat region. Curving boundaries connected to the flat region should be slope matched to the flat part boundaries.

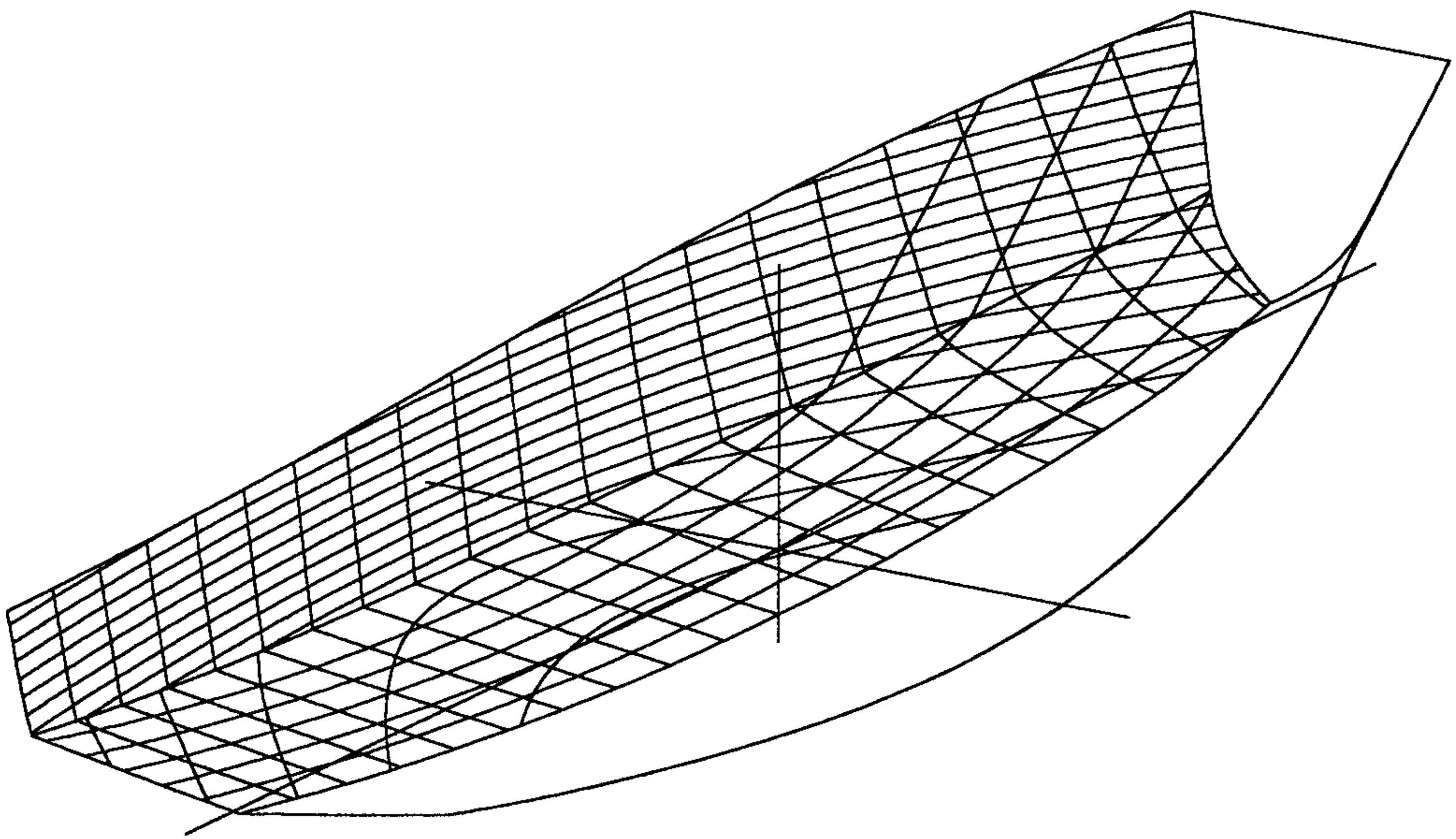


Fig.11 MIRROR DINGHY FORM

3D VIEW OF LINES.

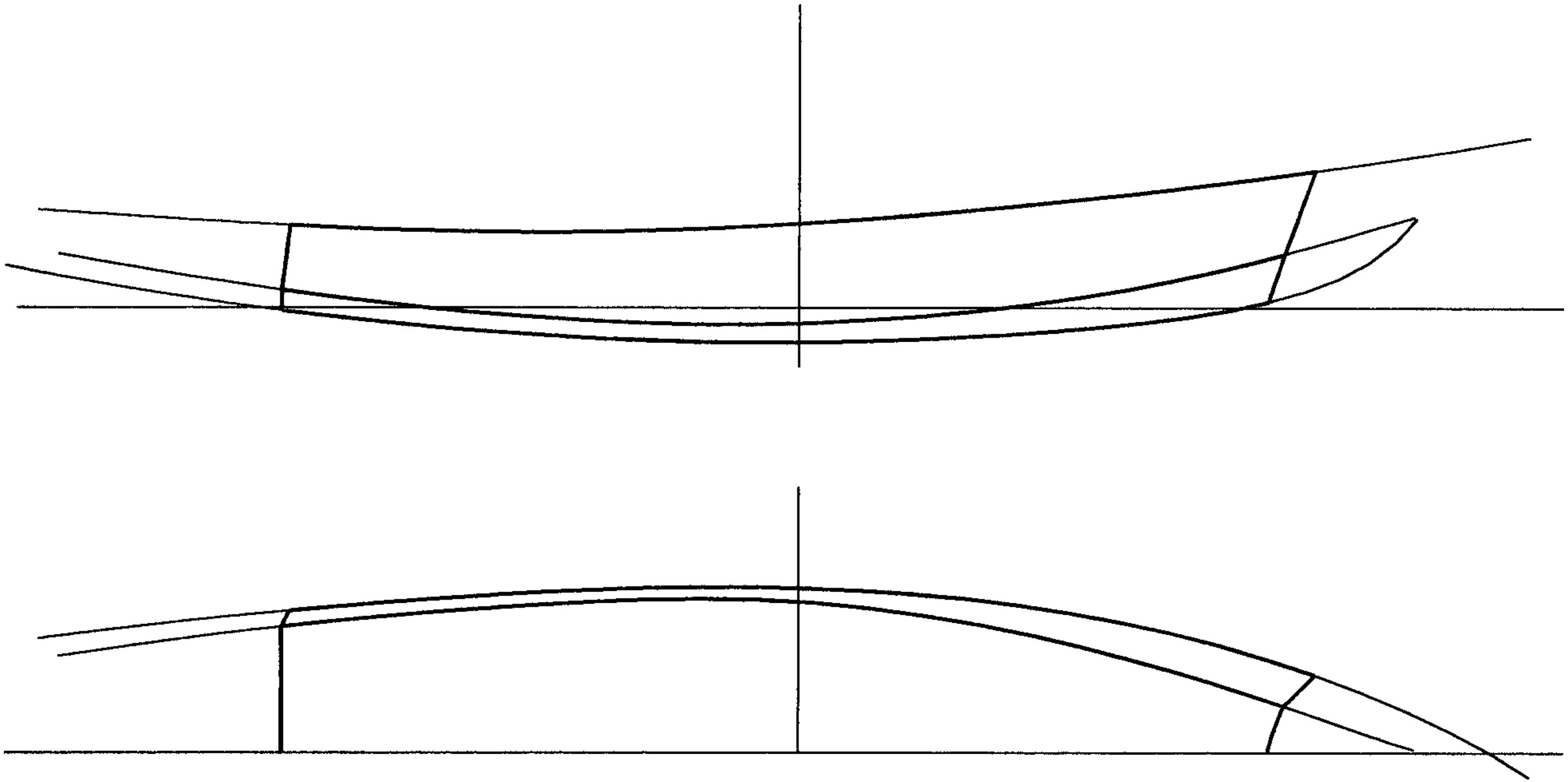


Fig.12 MIRROR DINGHY FORM
PANEL BOUNDARY CURVES.

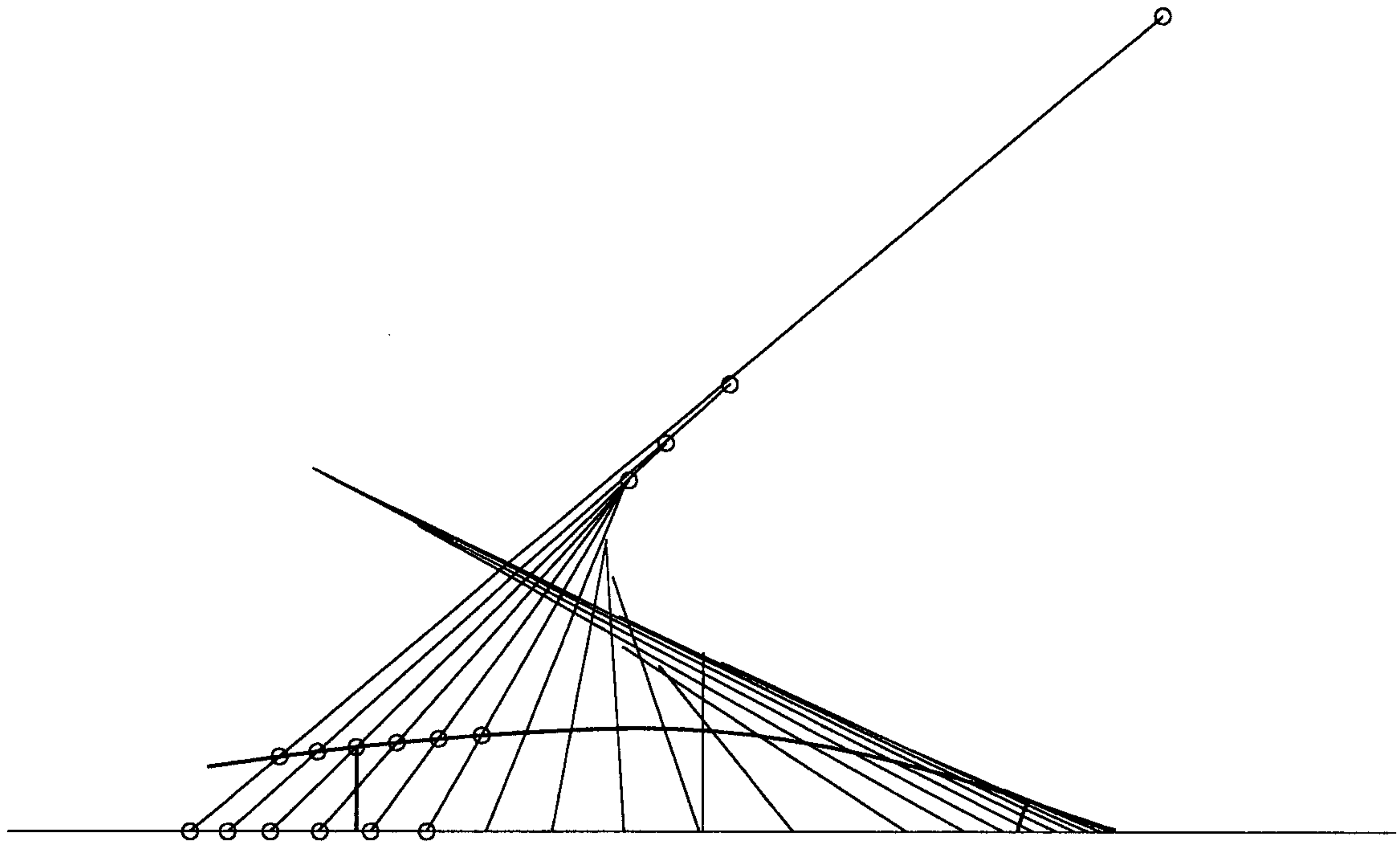


Fig.13 MIRROR DINGHY FORM

GENERATORS AND VERTEX LINES
FOR BOTTOM PANEL.

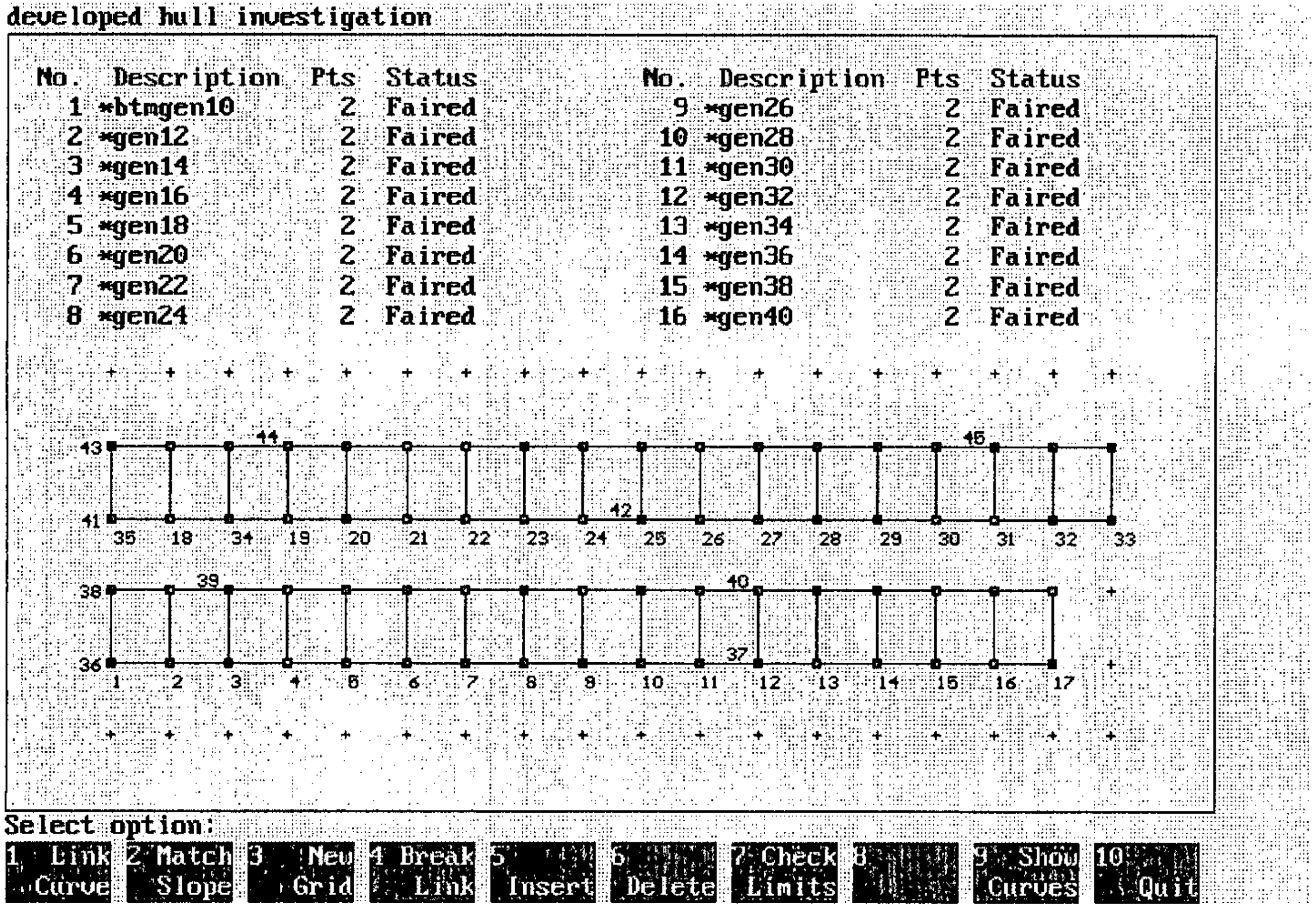


Fig.14 MIRROR DINGHY FORM

NETWORK DIAGRAM.

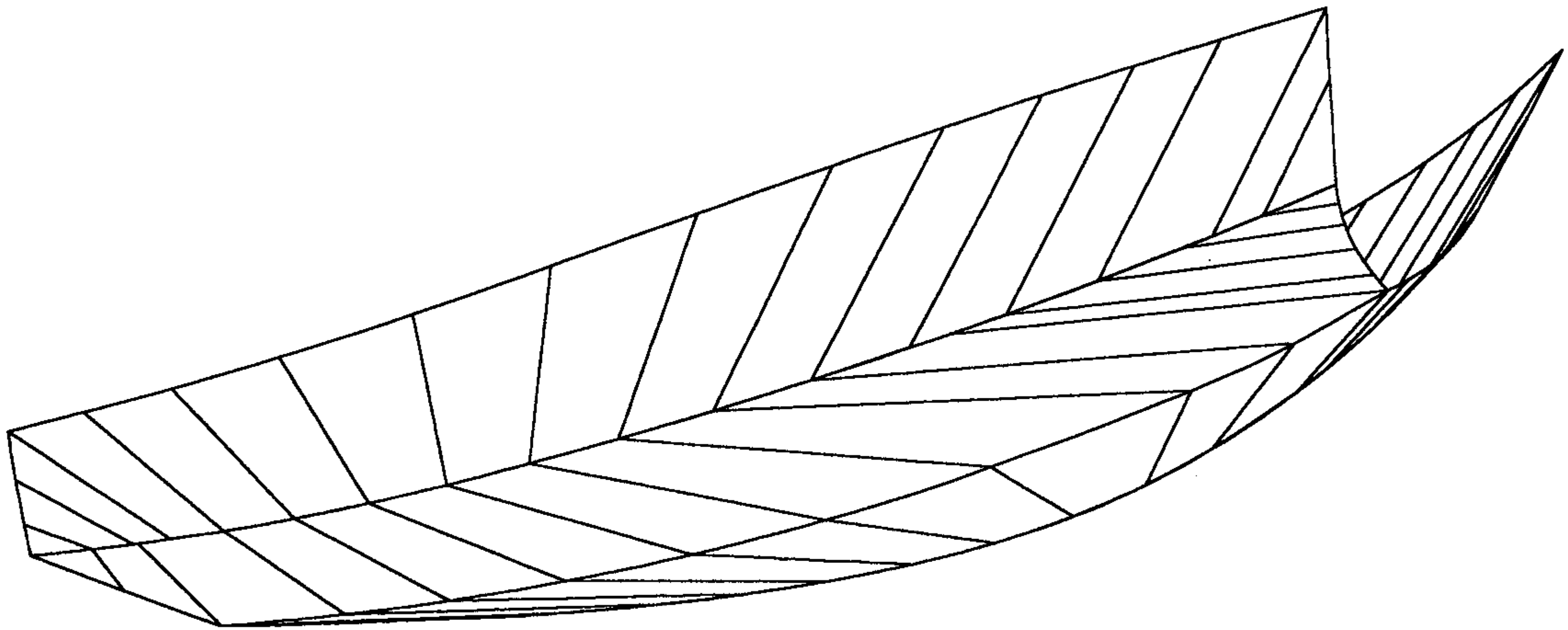


Fig.15 MIRROR DINGHY FORM

FINAL NETWORK OF GENERATORS
AND BOUNDARY CURVES.

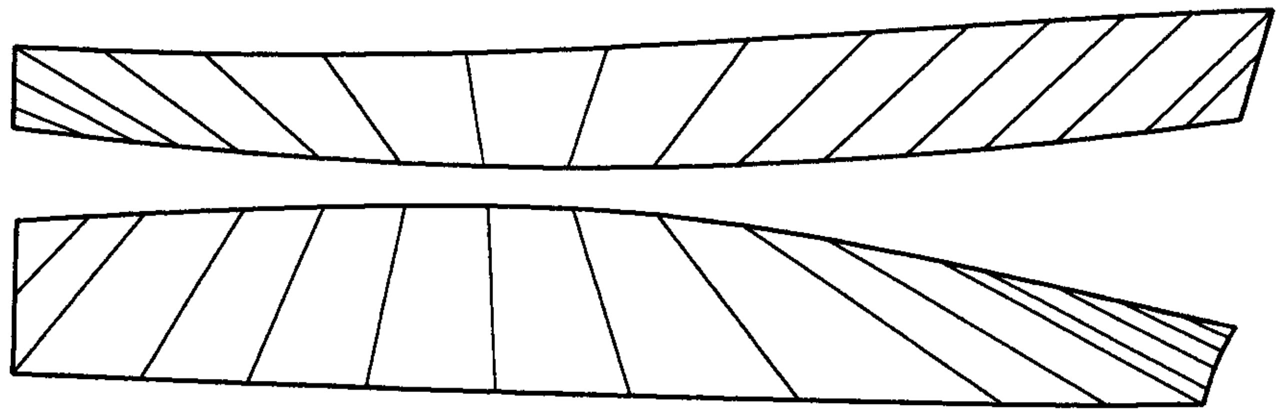


Fig.16 MIRROR DINGHY FORM

DEVELOPED PANEL SHAPES.

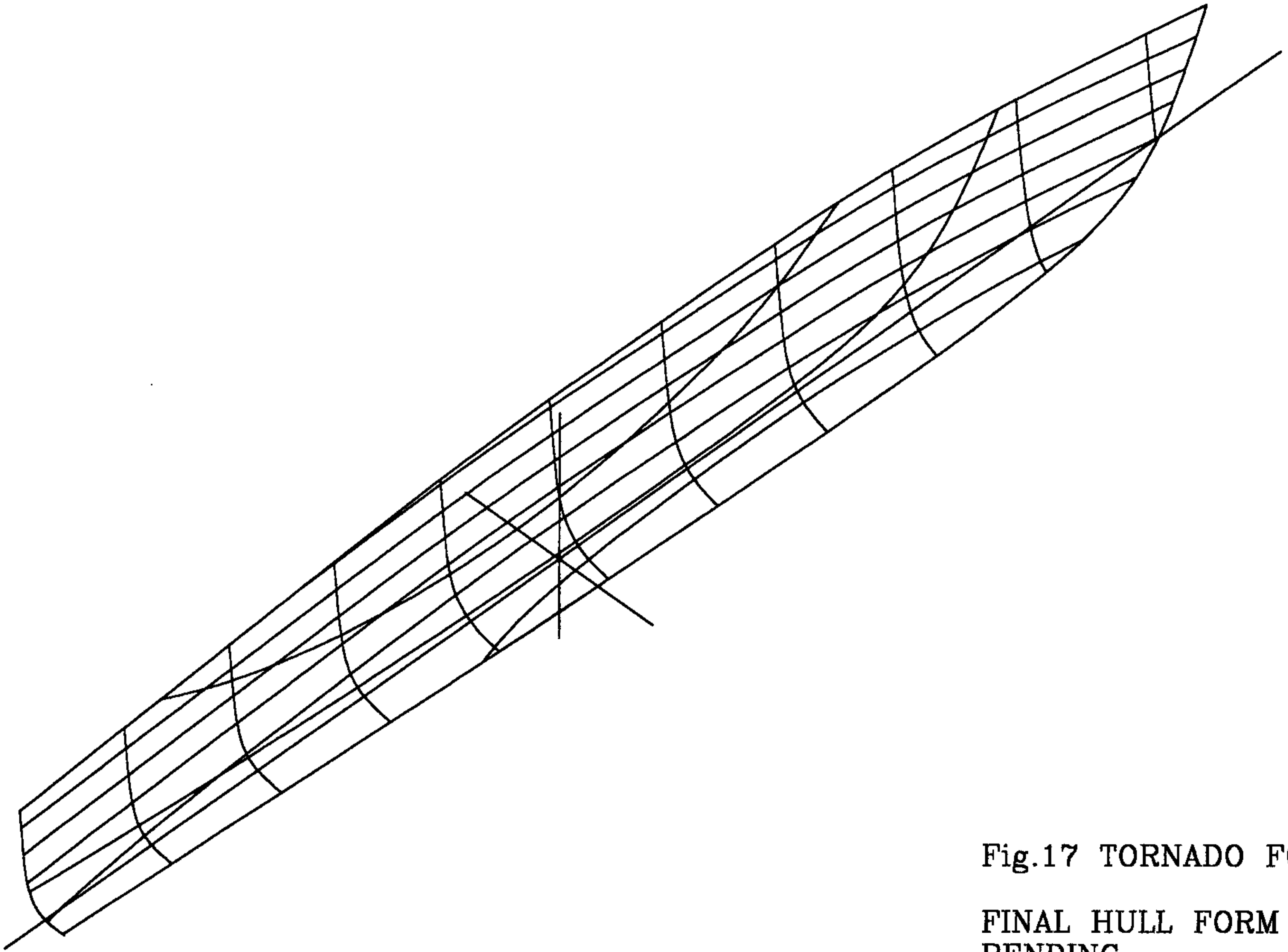


Fig.17 TORNADO FORM

FINAL HULL FORM AFTER BENDING.

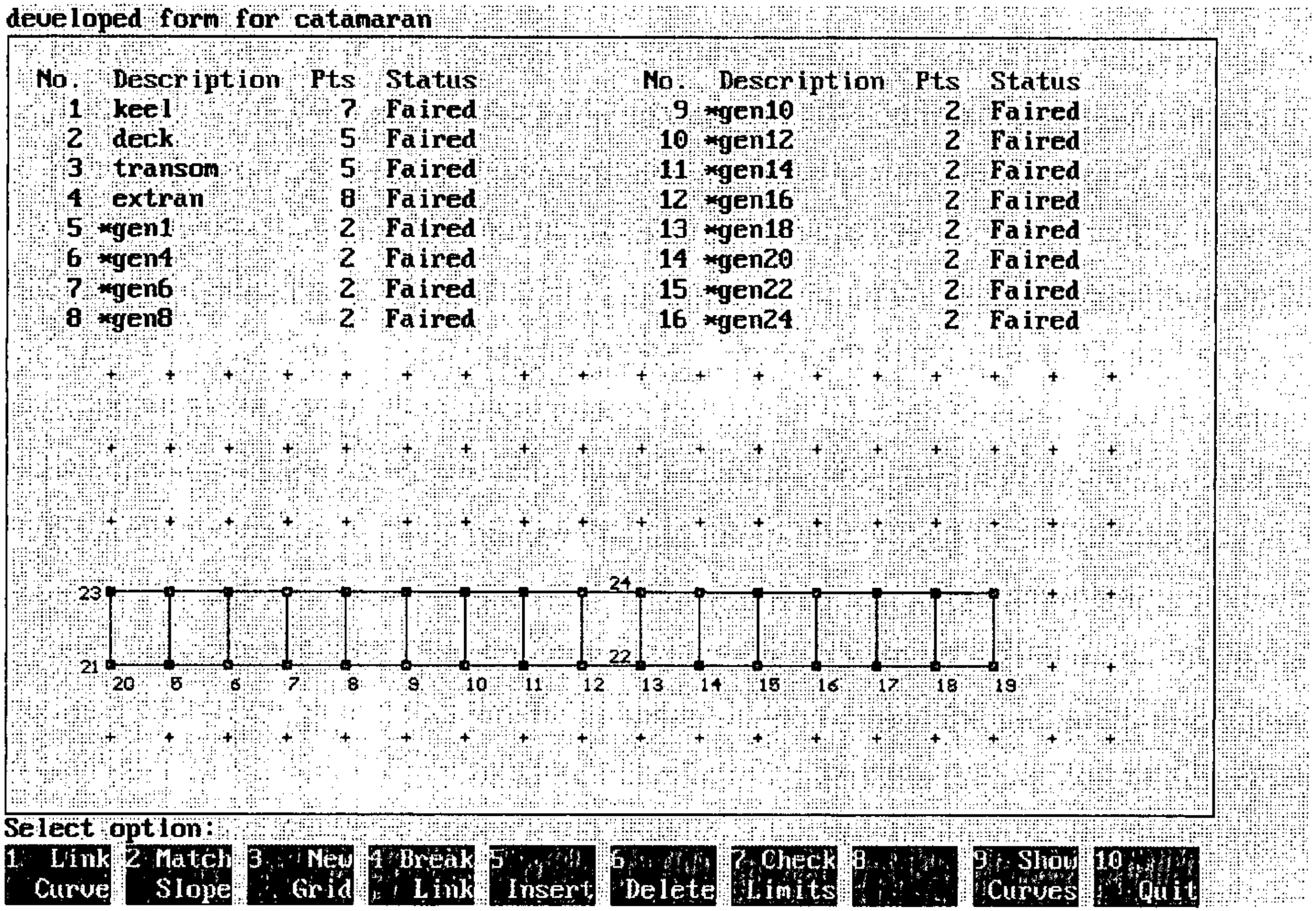


Fig.18 TORNADO FORM

NETWORK DIAGRAM

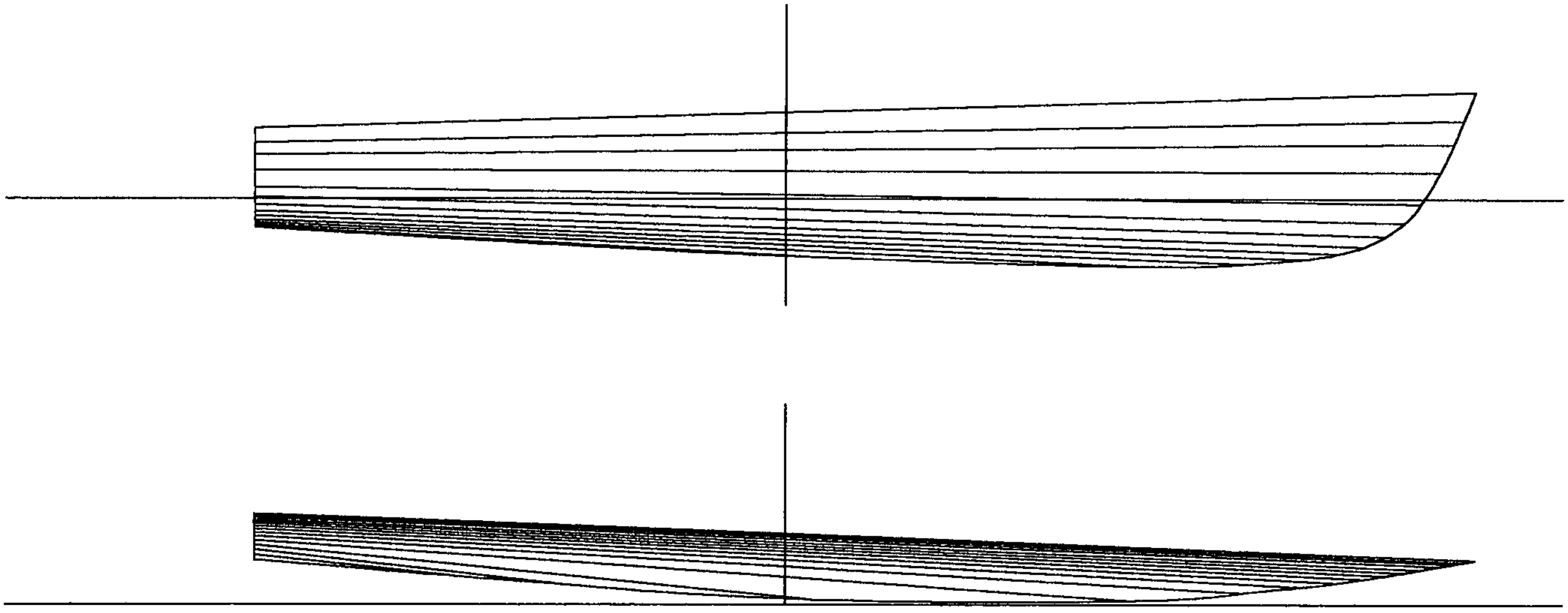


Fig.19 TORNADO FORM

GENERATORS FOR DEVELOPABLE SURFACE BEFORE BENDING.

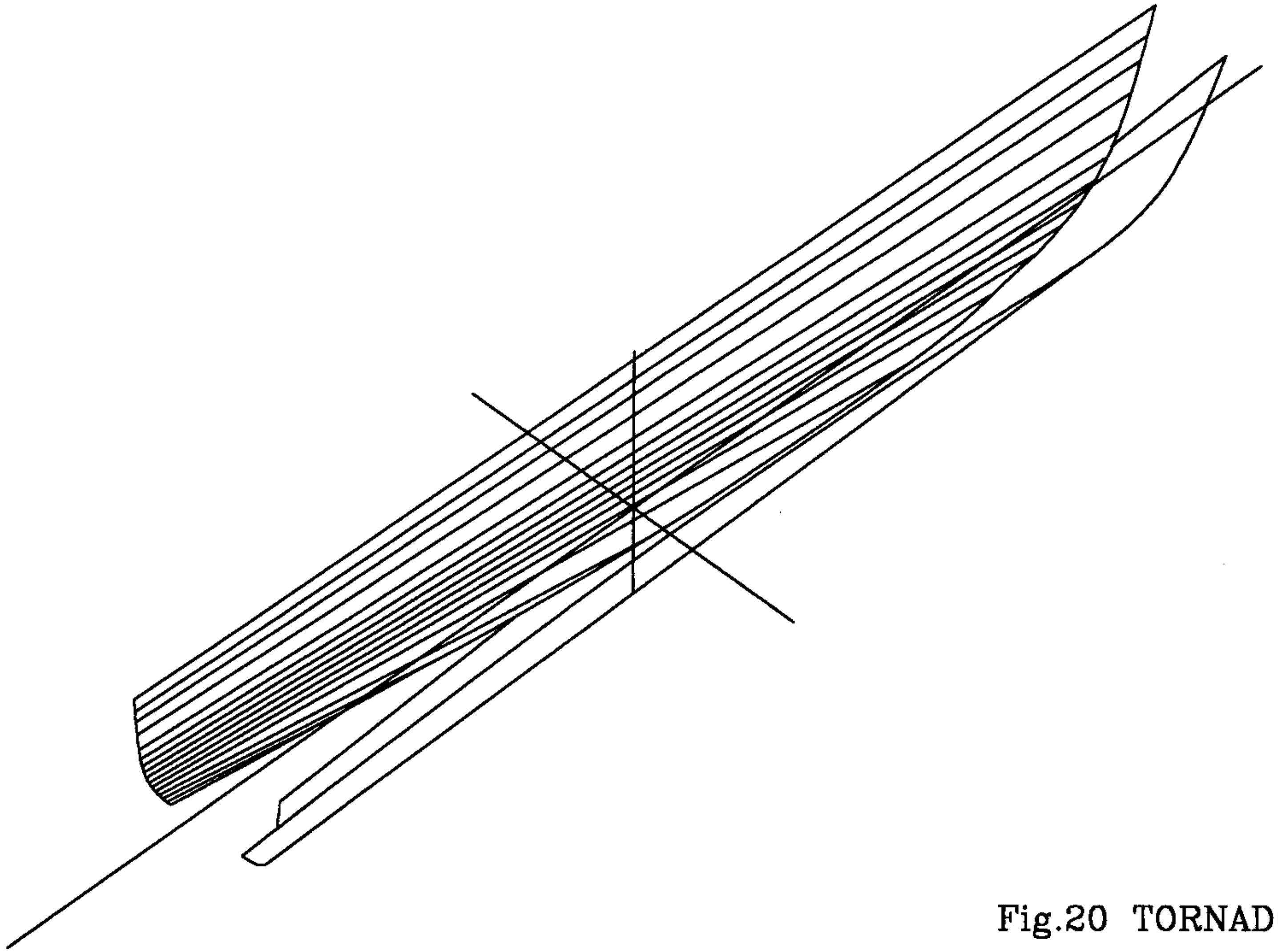


Fig.20 TORNADO FORM

DEVELOPABLE FORM
BEFORE BENDING.

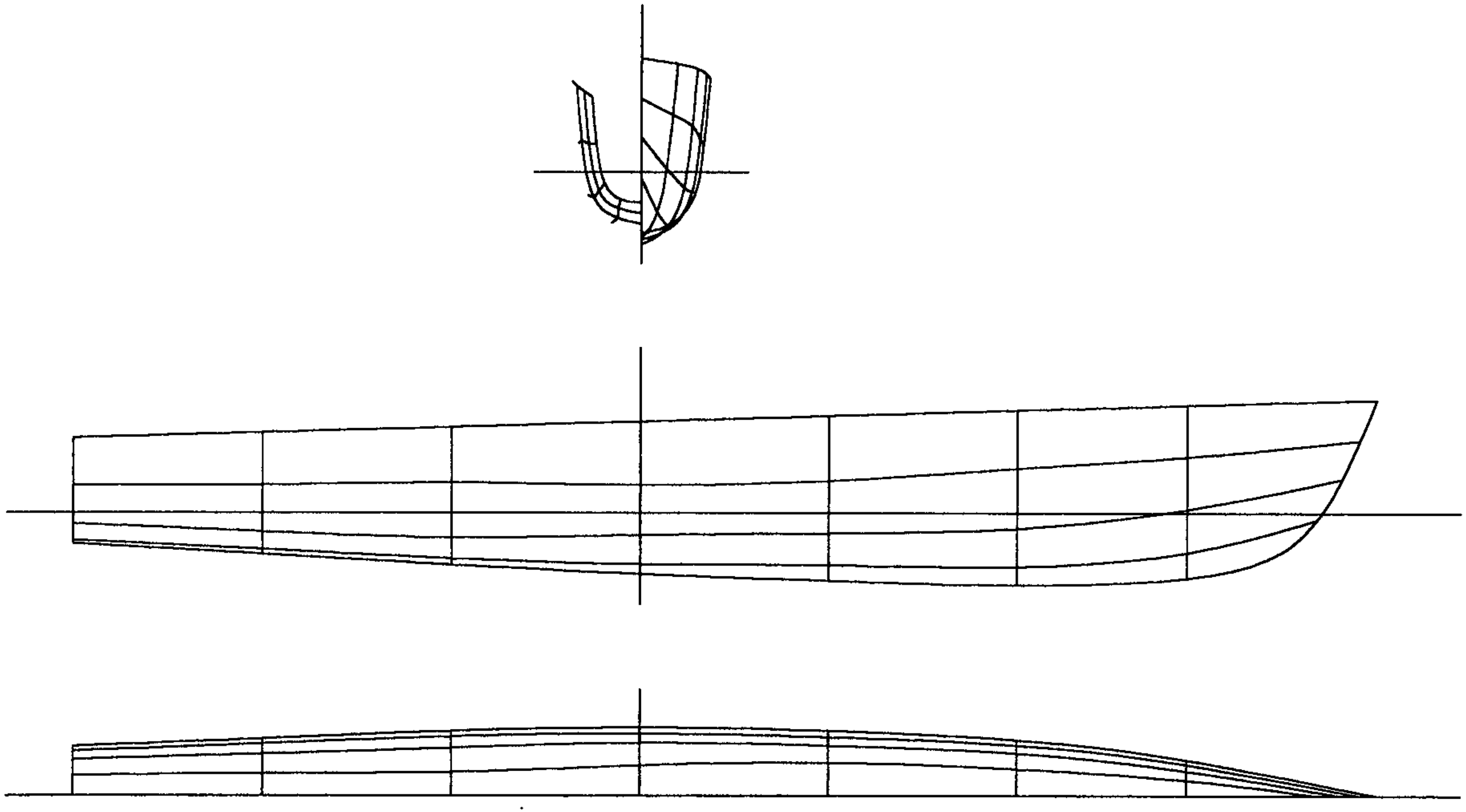


Fig.21 TORNADO FORM

FINAL NETWORK FOR NEARLY DEVELOPABLE HULL FORM.

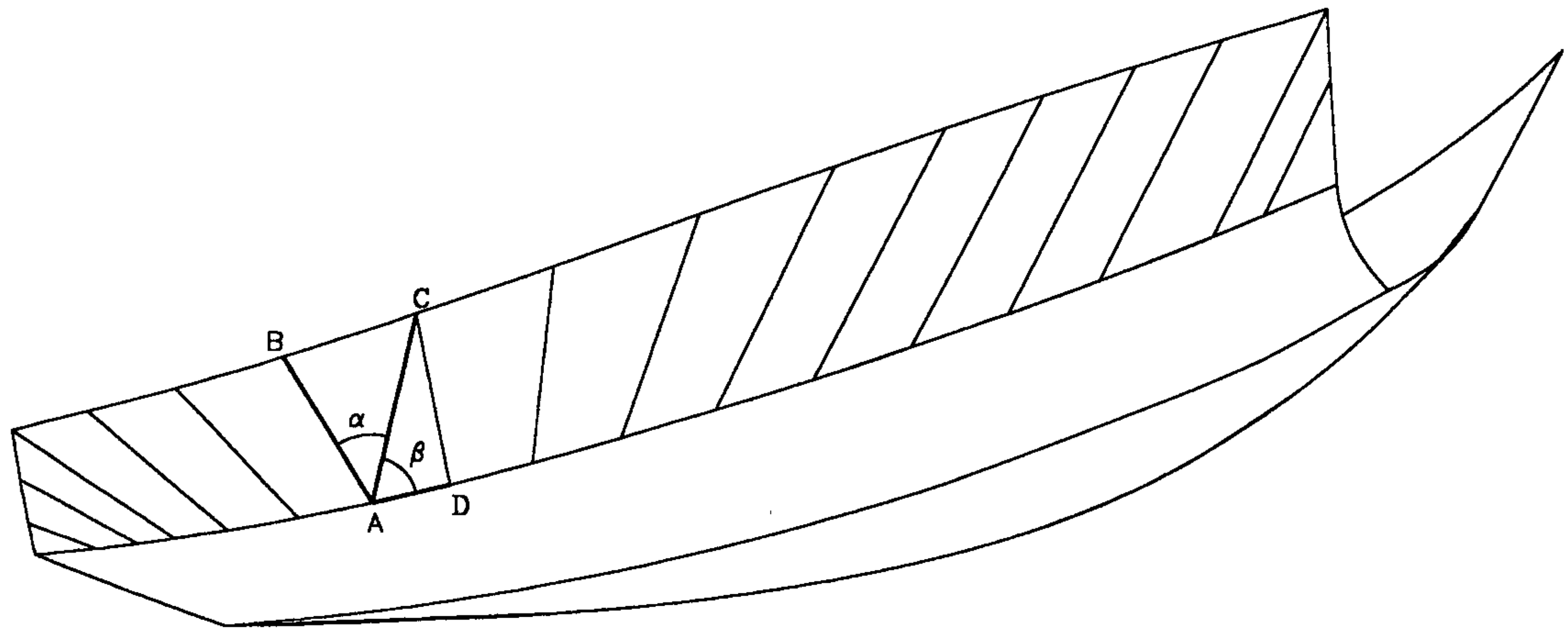


Fig.22 METHOD OF DEVELOPING FLAT PANELS.