HULL FORM DESIGN AND FAIRING: TRADITION RESTORED

H.J. KOELMAN
Scheepsbouwkundig Advies en Reken Centrum SARC
Bussum, the Netherlands

Abstract

The traditional approach of the design of lines of the ship is based upon sections lying in mainly orthogonal planes. Fairness and coherence was maintained and judged by a human designer, partly in a heuristic way.
Contemporary CAD methods which follow this traditional approach are inefficient, because they lack heuristics.
CAD methods which are based upon state-of-the-art mathematical formulae for surface modeling, such as B-splines or NURBS, cannot handle sections lying strictly in orthogonal planes. Due to the inflexibility they are unsuitable for production fairing.
After a discussion of popular computer methods, the new hullform modeling program "Fairway" will be described.
The Fairway approach is demonstrated in an example, and subsequently hull forms designed and faired with Fairway are presented, showing that with Fairway on the subject of hull design there is only one constraint left: The human imagination and skill.

Brief history of Computer Aided Ship Design

Since the dawn of the computer era many methods have been developed to define a hull form of a ship in a computer, for calculations, manipulations, drawings and logistics. In a few decades the mathematical formulations have evolved considerably :

1950 - 1975	Polynomials and composite circular arcs
± 1965	Extension of polynomials to "Bezier curves", developed by the French automotive industry.
1974	Extension of Bezier curves to Basis-splines, abbreviated to B-splines. When used parametrically they can be parametrized uniform or non-uniform, thus leading to Uniform B-Splines (UBS) or Non-Uniform B-Splines (NUBS).
± 1980	Implementation of an idea from the sixties: Inclusion of an additional denominator in the B-Spline formula. Because the ratio between numerator and denominator is governing the shape of the spline, this was baptized Rational B-Spline. It comes in two flavors: Uniform parametrized Rational B-Splines (URBS) and Non-Uniform parametrized Rational B-Splines (NURBS)
± 1990	Bezier curves and surfaces, B-Splines and NURBS are de facto standard in CAD.

All discussed formulae can be used 2D and 3D, implemented in line or surface methods respectively.
With line methods lines of the hull surface, such as ordinates or waterlines are defined, which together form an implicit surface. The major advantage of the line method is the simple definition of existing hull forms.
With surface methods the hull surface is described by one or more regular networks of defining lines (also called "mastercurves"), which extend over the complete surface.

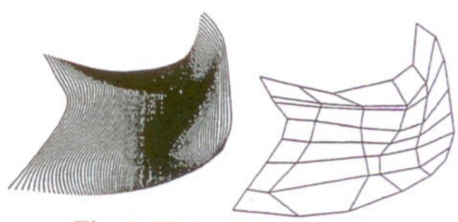


Fig. 1 Network and surface

See figure 1, where the lefthand surface is defined by the righthand network. A 1:1 relationship exists between surface and network: Manipulation of the surface is performed by manipulation of the network. The main advantage of the surface method is the possibility of deriving an intersection or cross section (such as waterlines and buttocks).

Examples and discussion of the popular computer methods

With these methods many successful implementations of hull form systems have been made, as illustrated in the figures 2 to 4, and by most appealing examples of output with color, light sources, and rendering as can be found in leaflets and brochures.

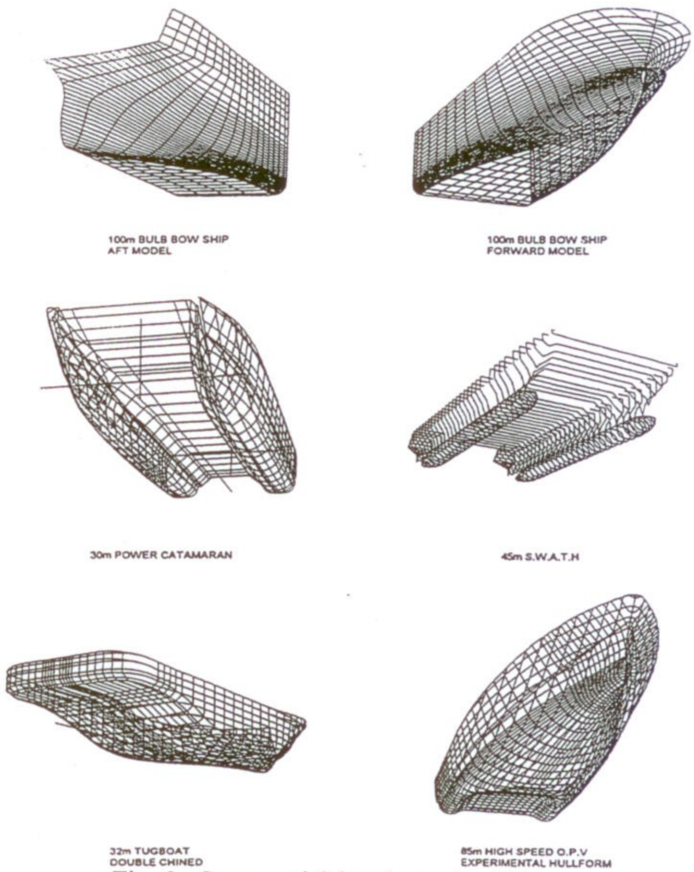


Fig. 2 Commercial brochure abt. 1990

Unfortunately, to our experience, gradually complaints began to rise in the shipbuilding community about major drawbacks of the available computer methods:

- It is one-way traffic on the road from surfaces to lines.
  Indeed it is possible to derive specific lines from surfaces, but *in general* it is not possible to generate a surface from an arbitrary composition of lines. Such a possibility is really missed, because it would enable the generation of additional lines, via the surface.

- The defining lines of the regular network are *in general* not parallel to the main orthogonal planes of the vessel. So the user must be prepared to work with more or less arbitrary 3D lines over the surface. For exact modeling (fairing!) or specific control (for example waterline entrance angles) this is cumbersome.

- The regular network is too rigid. As men-tioned all surface methods work with a regular network, while real-life vessels can more effectively be described by a non-regular network, allowing for, for example, partial waterlines, additional local shape information, integrated stem round-offs etc.

- Neither with line methods, nor with surface methods it is possible to perform production fairing, including local refinements, such as bulb

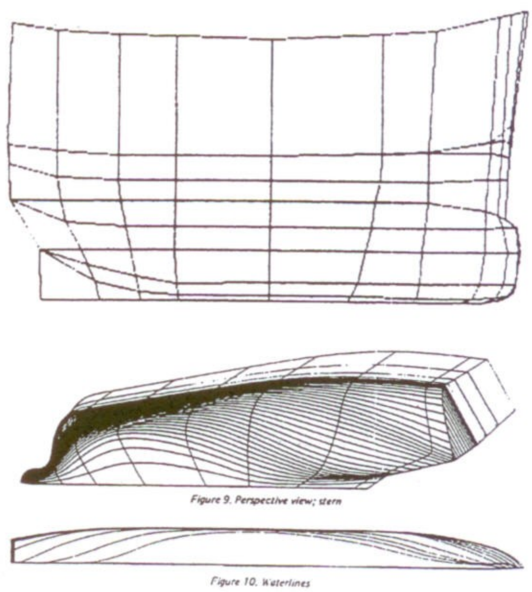


Fig. 3 Spline net and surface (from [1]), 1984

shapes or specific radii in stern or stem, and taking into account that the naval architectural definition of "fairing" differs from the mathematical one:

For example in the midship section a naval architect likes a straight bottom line, a circular bilge, followed by a straight side, leading to discontinuities of curvature (the straight lines have curvature zero, the curvature of the bilge is 1 / bilge radius). These discontinuities are in conflict with the mathematical definition of "fair", and indeed the transitions between the three segments are being smoothened out when mathematical fairing techniques are used.

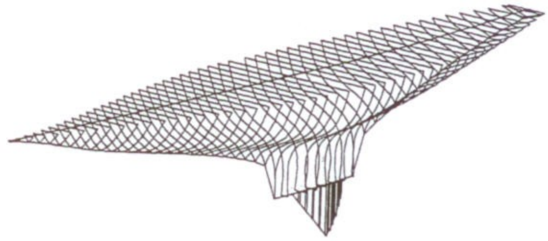


Fig. 4 PIAS Hullform generation (1988)

Summarized: the main problem of line methods is the inherent incoherence of the lines, and the main problem of surface methods lies in the rigidity of the network. Mathematicians have invented powerful surface methods based on *regular* networks, but practically all networks in shipbuilding practice are *irregular* (Fig. 5). Of course one can try to simulate irregularity by using multiple networks, but in the first place that does not solve the basic underlying problems of regularity, and in the second place such an approach would give additional difficulties in the regions where the different networks meet.

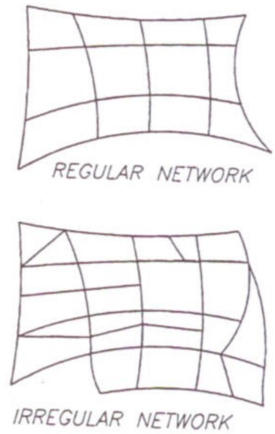


Fig. 5 Network regularity

At a closer inspection we see indeed that all examples presented sofar do have a nature where one or a few regular networks can be used to model the hull. For hull forms of a more complex nature however it is very hard, or sometimes practically impossible, to map the network(s) on the hull form. Please note in this context that all vessels of figure 2 have longitudinals, except for the SWATH vessel, where only ordinates are drawn. Apparently for the vessels with the longitudinals a surface model was used, but the SWATH was only defined by editing or digitizing simple lines: the SWATH did not fit into the net.

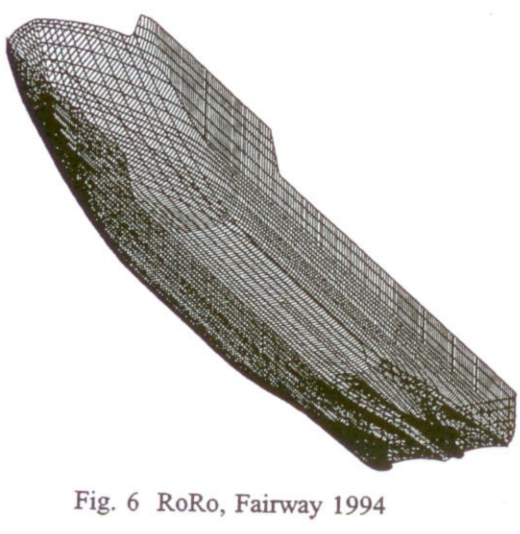


Fig. 6 RoRo, Fairway 1994

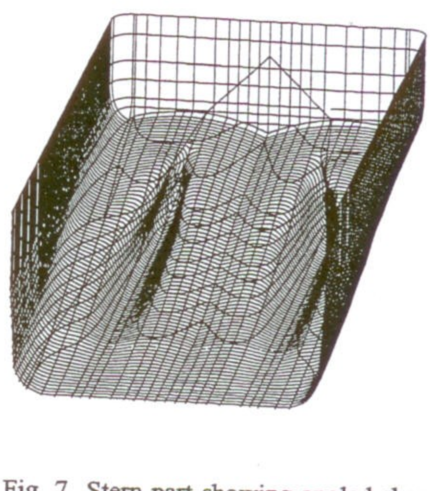
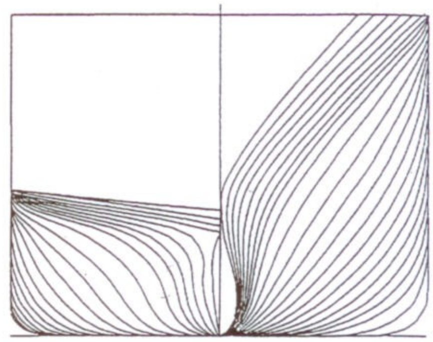


Fig. 7 Stern part showing angled skegs

Or look for example at the hull of figures 6 and 7, where a regular network would not fit around the stern portion. The network lines over the skeg should stop at the aftside of the skeg, while the network lines over the bottom should continue further afterwards. Besides there is an important definition line, namely the "centerline" of the skeg (figure 6), which does not need to cover the whole hull surface (preferably not !) and which makes the network irregular.

Even examples can be found where the designer experienced difficulties in matching the network to the hull form, and for the sake of convenience skipped the complete bow and stern regions (Fig. 8).



Final body sections derived from B-spline surface.

Fig. 8 From [2], 1986

The quest for a better method

Most appropriate for ship modeling would be a surface system based on a irregular network, with geometry formulae allowing for fairing in the naval architectural sense of the word.
The reductionist paradigm has not yet been beaten, so we tried to advance by splitting up the complex problem into partial ones:

1 - Definition and fairing of single lines.
2 - Maintaining a coherent irregular network, which glues all lines together.
3 - Surface description, automatically derived from the single line definition.

For each of the partial problems a satisfying, be it sometimes exotic, technique was discovered in literature :

ad 1 Definition and fairing of single lines

B-Splines and NURBS are quite adequate to model a variety of curved lines. We have favoured the NURBS, because in some specific forms they are the vehicle to represent arbitrary curved lines, straight lines, circles, parabolas, ellipsoid and hyperbolas, all with one formula.
The line fairing problem has been tackled by implementing an adapted least-squares algorithm. This scheme gives the user the possibility to fair a line automatically, taking into account the user-specified mean deviation between the original points and the final line. Secondly for each individual point the user may specify an individual weight factor, so that the resulting fair line is more attracted by points with a higher weight factor. This mechanism resembles the traditional batten, where the mean deviation models the (reciprocal of the) stiffness of the batten, and the weight factors model the weight of the leaden ducks.

ad 2 Maintaining a coherent irregular network

A simple combination of 3D lines cannot describe an unambiguous 3D object. Take for instance the object of figure 9, where a geometric definition only is insufficient (left side). The geometric 3D left hand figure can be any of the three right hand real-life objects. One might question the relevance of this issue, but suppose the object is part of a vessel, then when making a horizontal section through the object (e.g. when generating a waterline), the outcome for the three cases is quite different! Additional information about connection of lines is lacking, as well as the surfaces that may exist between them.

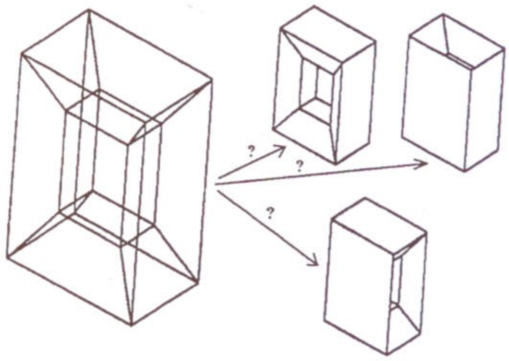


Fig. 9 Geometric definition only is ambiguous

The required additional information can be delivered by the technique of the so-called "Boundary Representation" [3], where a complete list of relations between points, lines and surfaces is maintained. It is beyond the scope of this paper to describe the Boundary Representation in detail, but is has been proven in theory and in practice that its use eliminates ambiguity.

ad 3 Surface description

On top of the network of lines lies a surface description. Techniques have been developed which recognize regular sub-surfaces. These regular sub-surfaces are modeled by Gordon patches ([4]) or Coons patches ([5]). After mapping the main surfaces this way some small non-rectangular surfaces remain (triangles, pentagons, hexagons), which are mapped with methods of [6]. The constructed surfaces are of help when making cross sections, and are needed for visualisation purposes (light sources, shading etc.).
It must be emphasized that the complete process of recognizing, mapping and modeling of the surfaces is performed fully automatically. No user interaction is required, or even possible.

Functions of Fairway

The new approach described above has been implemented in a new software module, baptized "Fairway". Fairway is part of SARC's PIAS suite of naval architectural programs for hull design and numerous design calculations, such as hydrostatics, intact and (probabilistic) damage stability, longitudinal strength, weight estimation and resistance and propulsion. PIAS is used by nearly a hundred organizations.

Based on the analysis as discussed, Fairway offers the following functionality :

1 - A coherent irregular network, based on a full-blown Boundary Representation
2 - 3D graphical manipulation in Windows (not necessarily Microsoft), where each window gives a view on the one and only underlying 3D model. In other words: When the model is updated by an action in one of the windows, all other views, in other windows, are instantaneously updated.
3 - Automatic fairing, with the aid of *mean deviation* and individual weight factors as described above.
4 - Multiple line definitions: Generally curved (NURBS), exact circular, parabolic, ellipsoid, hyperbolical and straight.

5 - Line shape of the generally curved lines can be manipulated by means of the vertices (=master points), or by tangents at the line ends.
6 - Line segments *can* be connected by means of a master/slave relation. With this mechanism the tangent of one line end can be declared equal to the tangent of the end of the connected line segment. For example, this mechanism can be used for waterline round-offs, where after the proper definition the round-off will be modified automatically, after any waterline modification.
7 - Available surface methods :
   - Generally developable
   - Extrusion
   - Cone and cylinder (with any kind of base, not only circular)
   - Doubly curved
8 - Calculation of simple upright hydrostatics, such as volume, coefficients, metacentric height etc.
9 - Hull form transformation, according to different methods :
   - Linear scaling
   - Lackenby frame shifting
   - Inflate / deflate ordinates
   - Change parallel midbody
10- Support for Sectional Area Curve (SAC). By means of the SAC the user can work straightforward towards a desired block coefficient and LCB.
11- Composition of a lines plan, on users specification.
12- Conversion of the 3D model to Autocad (DXF, 2D as well as 3D), Dawson (MARIN's potential flow software), Eagle, NUPAS and FEM software.
13- Shell plate expansion.
14- The so-called "hull-server", where a direct link between Fairway and a drafting package is established. With the hull-server the drafting package can obtain any cross section from Fairway and treat it as if it was created by the drafting package itself. To the user Fairway remains invisible. The only interaction is with the drafting package.


Fig. 10 Tank hatch

With Fairway it is possible to define and to fair complex ships (fig. 11), but also simple elements (fig. 10).

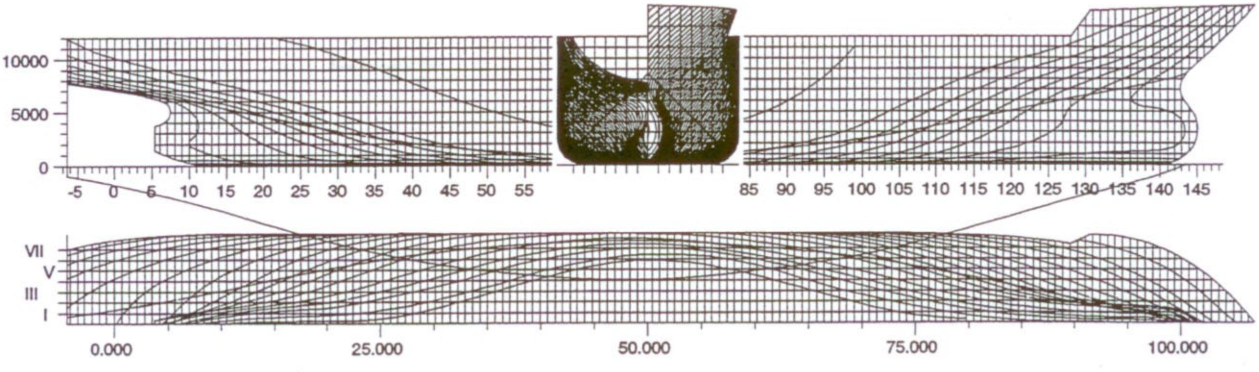


Fig. 11 Reefer vessel

Example

The Fairway approach will be illustrated with a 27 m Schooner Yacht (See appendix, by courtesy of Olivier F. van Meer Design, the Netherlands). Of course a sailing yacht must be appealing, so the visual lines (visual on the *real* vessel) must be of perfect quality, and match the artistic ideas of the designer. The design of this vessel was governed by four design criteria :

1 - The nature of the stem, and the knuckled stern contour, in combination with the overhanging transom. In one direction the transom must be cilindrical, in another direction the shape must be completely free.
2 - The line of the bulwark, with its characteristic bowsprit opening.
3 - The connection line between sheer strake and shell, which is visible on the real vessel.
4 - Displacement.

In the preliminary design stage the designer tried to define the vessel with one of the well known Spline Surface modeling systems. While doing so he experienced the following difficulties :

1 - The combination of the overhanging stern part, and the straight vertical stern line proved to be cumbersome to create. Either the network lines were chosen to run conceptually parallel to the stern line, in which case no smooth buttocks could be obtained, or the network lines were extended in the "negative" part of centerline, in which case no control over the stern line was possible. In the latter case the stern line actually oscillated.
   The choice of the network lines was a matter of trial and error, and it took multiple restarts to find the most proper option.
2 - The discontinuities of the bulwark near the stem could hardly be created.
3 - The transom line should smooth into the bulwark line, which is most clearly shown in the top view of the appendix. This proved to be practically impossible, because of the limited number of control points or control lines in this specific region.

In a later stage the designer used Fairway to achieve his goals :

1 - First the contourline was defined, including all necessary knuckles.
2 - Then the bulwark line was designed, by judging this line in a three dimensional window while manipulating in two other windows showing side view and top view.
3 - A limited number of ordinates were designed, and individually faired.
4 - The transom was designed, by specifying a cylindrical transom plane, on which the heart-shaped transom line was projected.
5 - The contourline was copied to a parallel line, in order to reflect the breadth of the keel bar. This new line was defined as a "knuckle" line, so all subsequent generated lines intersecting this one automatically receive the correct knuckle information.
6 - The construction waterline was generated by the system. Where necessary this line and its neighbourhood were faired.
7 - Buttock III was generated, and faired.
8 - The sheer strake line was "woven" into the model, judged in a threedimensional view and faired where needed.
9 - More waterlines, buttocks and ordinates were generated, and faired where needed.
10- During this process the displacement was monitored. If necessary the hullform was slightly modified to match the criterion.

The complete design process with Fairway took about 2 days.

Conclusion

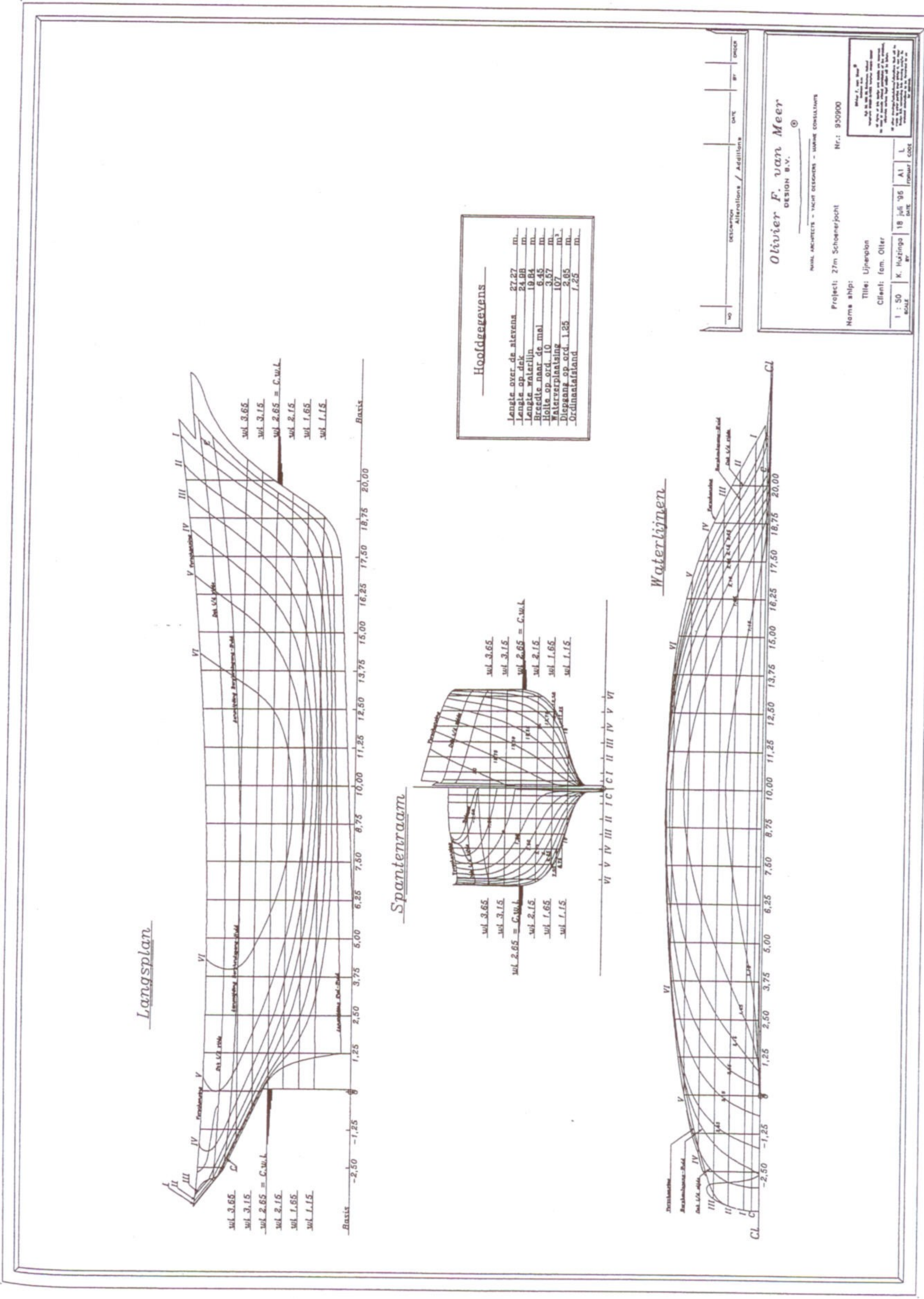
The traditional B-Spline or NURBS surface methods are inflexible due to the rigidity of the regular network, so when used for hull design the designer must spent much time and energy to try to work around the limitations. The designer must split his attention between the design process itself, and the caprices of the CAD system.
The presented combination of techniques, implemented in Fairway, allows the designer to concentrate on his or her actual job: Design a ship, in a way not dictated by the CAD system, but chosen by man.

Postscript

The question of capacities and possibilities in the CAD field is not black-white, in other words: For an arbitrary system one can hardly say that something is "impossible". In the text I have used words as "practically impossible" to indicate a vast amount of time involved. Of course when sufficient time is spent everything can be made by any method or system. I bet that, given enough time, even with the *Paintbrush* application of MS-Windows bodyplans can be created.

References

1. Creative definition and fairing of ship hulls using B-spline surface, 1984, N.G. Fog, Computer Aided Design, volume 16, July, pp. 225-228
2. An effective method of preliminary hull form design using a micro-based workstation, 1986, W. Hills and M. Welsh, International Shipbuilding Progress, October, pp. 187-194
3. K. Weiler, Edge-Based Data Structures for Solid Modeling in Curved-Surface Environments, 1985, IEEE Computer Graphics and Applications, January, pp. 21-40
4. W. Gordon, (1969), Spline-blended surface interpolation through curve networks, Journal of Math and Mechanics, pp. 931-952
5. R.E. Barnhill (1977), Representation and Approximation of Surfaces, in Mathematical Software III, ed. J.R. Rice, pp. 69-120
6. Filling Polygonal Holes with Rectangular Patches, 1989, in Theory and practice of Geometric Modeling, ed. W. Strasser and H.P. Seidel, pp. 81-91



Appendix 27 m Schooner Yacht, designed with Fairway