Properties, resemblances and differences between CAD programs for hull form design

For many years this journal has presented a quarterly CAD/CAM Update section, where news from software providers worldwide is presented. Because, basically, the material for this section is provided by software manufacturers themselves, the emphasis generally concentrates on details and gadgets. Here, Dr Herbert J Koelman, from the Dutch software house and consultancy SARC, returns to the basics, and discusses a more general framework of underlying concepts and methods which are employed in hull form design.

IN times past, the spatial shape of a ship hull design was laid out in a lines plan, which shows essentially two-dimensional sections. It was up to a (trained) human to interpret that drawing and construct a mental model on the basis of those lines. Today, we all want to employ computers in the ship design process, and we can no longer rely on human heuristics in the reasoning process from 2D to 3D. Thus, a lines plan can no longer form the basic representation of the shape of a hull - a genuine 3D model must be used instead.

The purpose of this article is to present the basics of the 3D modelling methods, which are used throughout the industry, and to discuss their properties and applicability.

Contemporary modelling methods

Apart from some experimental approaches, the methods which are used by various specialists fall in one of the following categories:

- curve models
- surface models
- solid models.

In a curve model, the hull is represented by curves lying on its surface. The curves can be loose, in which case they have no explicit mutual connection, or they can be connected to each other, ie, a wireframe model.

A surface model represents the shape by one or more surfaces, which may be connected or not. In general with a curve model or a surface model only, the *geometry* (the shape) is represented, but not the *topology* (the 'coherence' of the shape). With a solid model, on the other hand, the hull is represented by a collection of curves and surfaces, while additional topological information is maintained by explicit connections between curves and/or surfaces.

For a representation of the shape of curves and surfaces, the majority of CAD systems today use non-uniform rational B-splines (NURBS). With the NURBS equation of a curve, the shape is more or less a smooth approximation of the straight lines between the vertices.

The shape of a NURBS surface is determined by vertices, which are arranged in a rectangular mesh; Fig 1 shows an example of this. Although NURBS representation has become the de-facto standard in the industry, other techniques are also in use, such as the Coons patch, where a surface is embedded in a network of curves, and the surface shape is derived from the shape of curves in the vicinity. Good results have also been obtained by surface skinning (eg, in Ref 1), where the shape of the surface is determined by smooth interpolation of a set of non-intersecting curves.

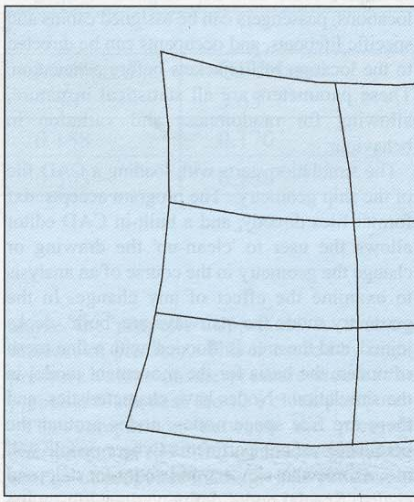


Fig 1. An example of a rectangular mesh.

Merits of different modelling methods

Working on the basis of a collection of unconnected curves has one major advantage, which is the ease of definition and manipulation. Because no curve has a relation with any other curve, it can freely be digitised and edited. However, this lack of coherence also implies its major weakness, for no unambiguous surface interpolation or even curve interpolation can be performed on the basis of un-connected curves.

From a practical point of view, a NURBS-based surface method possesses two important properties:

- The ability to represent a conic, such as a parabola or a circular arc, exactly
- Shape modifications can be performed very quickly by manipulation of the vertices, but in many practical situations, applicability can be hampered by the required rectangularity of the mesh of vertices. Many regions of a ship do not fit within a rectangular mesh, but require an irregular mesh instead (eg, as shown in Fig 2). In subsequent paragraphs, this aspect will be further elaborated.

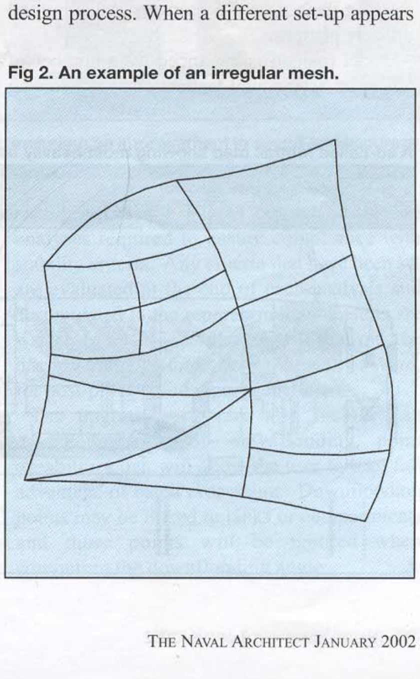
Systems based on a solid model, eg, those described in Ref 2 and Ref 3, can in principle combine the advantages of both curve and surface methods. On one hand, they have the flexibility of working with curves, while on the other hand unambiguous curved surfaces can be generated (eg, with the Coons patch). A disadvantage of the solid model is the far greater design and implementation complexity of the software itself, especially when not only the outer shell has to be modelled, but also the internal subdivision. The author is not aware of any commercial naval architectural implementation of the latter.

Initial hull form design

Because of the lack of surface generation capabilities, curve methods are not suitable for *ab initio* design. A surface method, especially with NURBS surfaces, is outstandingly suitable for surface manipulation, and this property has been demonstrated with many examples in *The Naval Architect*. However, for vessels with more complex shape characteristics, the rectangularity of the mesh may cause some trouble, for example:

- the location and nature of the mesh curves must be defined at the beginning of the surface design process. When a different set-up appears

Fig 2. An example of an irregular mesh.



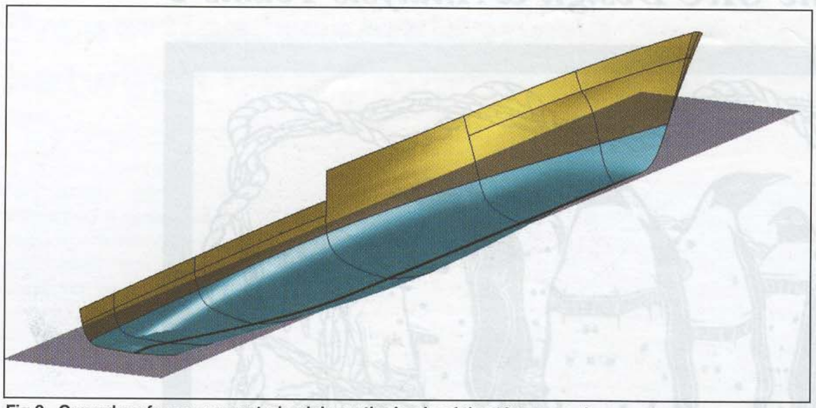


Fig 3. Curved surfaces, generated solely on the basis of the 13 curves shown.

to be more appropriate later on, modification to a new arrangement is difficult. It is often quicker and easier to drop the work done so far and to start with a new arrangement

- the curves in the rectangular mesh cannot be chosen arbitrarily. This means the ship designer cannot choose exactly those curves that deliver important shape characteristics, but they have to be created instead by projection or intersection
- additional mesh curves may be necessary for a precise definition of local shape details. However, if they run over the complete surface (in order to maintain rectangularity of the mesh), they might cause undulations in the regions where they are superfluous. This effect is caused by the fact that in these regions simply too many mesh curves determine the shape of the ship hull. From design practice, it is well known that the fairest surface is obtained with a minimum number of mesh curves.

Software houses have created additional functions to overcome these problems, such as the use of multiple surfaces or trimming functions, which allow a surface to be created which extends beyond the actual hull boundary and which is trimmed by a user-defined trimming curve. However, those types of solutions might impose further complications, such as the question of connections between multiple surfaces.

Practical examples of these aspects are presented in Ref 4, where it is concluded that experiment and experience are necessary for effective working with the NURBS-based surface method, and it is indeed a well-known fact that this method requires a significant training effort. In the author's opinion, it is questionable whether a human must be prepared to adapt himself or herself to the peculiarities of a computer system.

When solid modelling software is used for initial design, the topological correctness of the model must be maintained. Although this task can be performed by the software itself, it implies some nuisance, because new curves and surfaces must be added within the framework of the existing ones, so the user is not completely free to add curves to his or her liking.

An example of an initial design with a solid modeller is given in Fig 3, where the designer drew only the 13 plotted curves, while, with Coons patches, the software generated the shape of the curved surfaces.

Hull form fairing

Although there is no common mathematical definition of *fairness*, most approaches are based on the minimisation of discontinuities of (combinations of) first or higher order derivatives (Ref 5). A simple midship section, however, consisting of the three parts, flat of bottom (FOB), bilge, and flat of side (FOS), as illustrated in Fig 4, has a curvature discontinuity at both ends of the bilge, and does not conform to any of the mathematical fairing criteria. Thus, when modelling a midship section, basically three options are open:

- split the hull surface into different regions, although this solution implies complications at the connections between the regions
- use the capabilities of the NURBS to model an exact conic as integral part of a curve or surface, which implies the direct manipulation of mathematical coefficients, or,

Fig 4. Part of a simple midship section, showing the three components, flat of bottom, bilge, and flat of side.

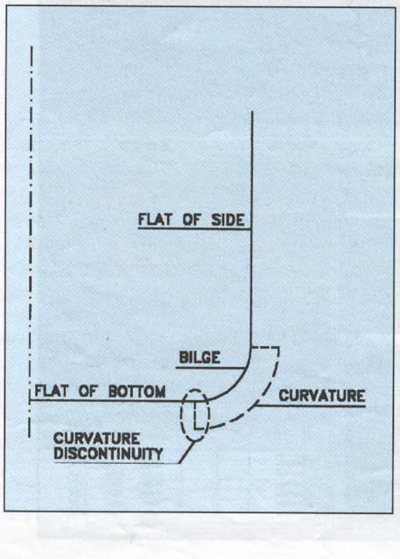


Fig 5. A NURBS surface, automatically fitted with a mathematical optimisation technique (1989).

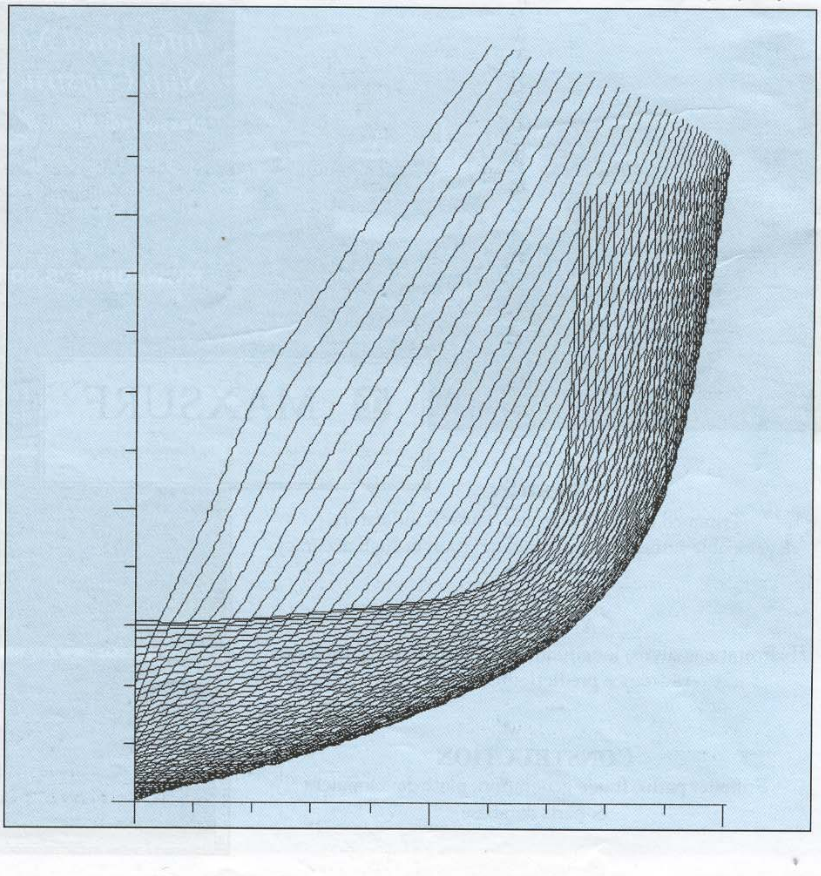
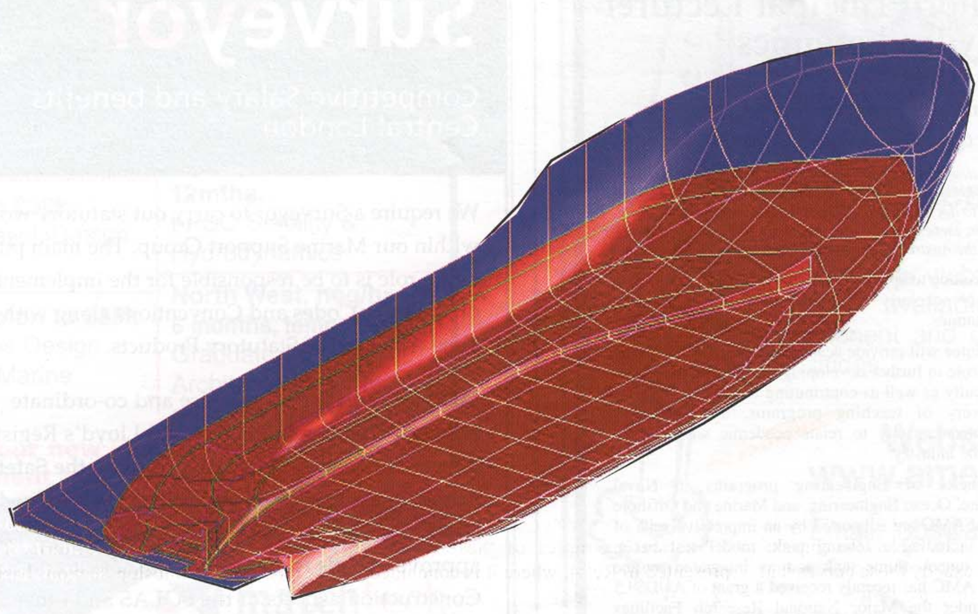


Fig 6. Fitted surfaces of a pollution control ship, re-engineered from the sketches in Ref 8.



alternatively, the use of an indirect technique from a particular modelling system which performs that job for the designer
- model the hull with mathematically fair curves or surfaces, and accept a slight 'overshoot' of the FOB and the FOS in the bilge area, and some non-roundness of the bilge itself.

Surface fitting (re-engineering)

As expected, the nature of the curve model is very suitable for re-engineering purposes, while the curve information is still sufficient for naval architectural calculations. However, due to the absence of a general-purpose conversion method from curves to surfaces, the curves cannot readily be used for surface fitting.

Different specialists use different techniques for the construction of a NURBS surface based on existing points or curves. The most popular ones are:

- force the user to choose only curves which coincide with the lines of the rectangular mesh. In this case the set of curves can, possibly after some re-arrangement of points, be converted into a NURBS surface. This method is only applicable for the simplest of shapes (ie, those whose nature of shape fits a rectangular mesh).
- show the available curves on screen, and let the user wrap one or more surfaces around them. In this case the hull is actually re-designed, which is time-consuming if some accuracy is required.
- use mathematical optimisation techniques to automatically create a surface which fits a given set of points or curves as much as possible. A genetic algorithm-based version of such a technique was presented recently in Ref 6, but was conceived in Ref 7; it is potentially very powerful because not only geometric but also numerical constraints can be dealt with (eg, displacement or LCB). However, from the examples which are presented in literature, and also the author's own explorative experiments in this field (Fig 5), application for the time being is supposed to be restricted to the simplest of hullforms (ie, those which are en-tirely mathematically fair, and can be repre-sented with a rectangular mesh).

A set of non-intersecting sections (eg, only frames, or only waterlines) can be used in a straightforward manner as the basis for a solid model that can be utilised for the generation of other sections and surfaces. The example of Fig 6 shows the following re-engineering steps:

- digitise the ordinates
- fit NURBS curves through the points of the ordinates
- create manually the chines by connecting the longitudinally subsequent knuckles of the ordinates
- generate automatically the shape of the surface on the basis of the ordinates and chines, and generate some waterlines.

Under certain presumptions even a set of mutual intersecting curves can be converted into a solid model (Ref 9), which opens the opportunity to import and process automatically DXF or other files which contain 3D curve information from other sources.

Conclusion

In this article it is argued that most contemporary hull form CAD software packages share their underlying methods and properties, and that some common problems are likely to occur even with popular modelling methods. Specific names and brands have been omitted, but the author assumes that a seasoned software user will recognise the respective aspects. ⚓

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