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PARAMETRIC HULL FORM DESIGN – A STEP TOWARDS ONE WEEK SHIP DESIGN

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ABSTRACT

This paper presents a parametric modelling approach to the design of ship hull forms which allows to create and vary ship hulls quickly and efficiently. A design-oriented parametric definition language is introduced which features high-level descriptors of hull characteristics well-known in naval architecture. A modelling system is presented that produces a complete mathematical description of the hull via geometric optimisation, enabling effective shape variations by keeping selected parameters constant while adjusting others automatically. All curves and surfaces yield excellent fairness. Examples illustrate parametric shape design and variation. Thus, the parametric modelling approach provides the ideal basis to hydrodynamic optimisation and one week ship design.

INTRODUCTION

In order to be competitive on the market, preliminary ship design has to be performed in continually decreasing time spans. Accurate estimation of weights, building cost and performance are essential for the success of a bid. Decision-taking at the early design stage fixes the major expenses while uncertainties about the upcoming costs have to be reduced as much as possible. A considerable number of design alternatives and their thorough evaluation increases the competitiveness of a shipyard. Selecting a design from a larger stock or being able to create designs of high quality on demand offers a huge advantage. The ultimate goal of advanced modelling systems for future developments is to provide a complete generic model for the entire ship which includes production as well as lifecycle costs. However, software tools applied in the preliminary design phase today generally feature a different view of ships than geometric modelling systems. Moreover, using state-of-the-art computer simulations, for instance CFD and FE methods, require a complete geometric representation of the ship – mostly in discretized form.

This paper therefore aims at introducing a new approach to hull form design based on a parametric, design-language-oriented definition. Different descriptors used by the various partners involved in the design process have been analysed and a top-down hierarchy of design elements has been identified. Within the novel approach the high-level descriptors used in the shipyard's daily optimisation process can be translated directly into a geometric definition. Physical properties of the hull shape are maintained automatically and the resulting curves and surfaces yield excellent fairness. The naval architect's craftsmanship of geometric modelling has become part of the internal generation process without compromising his or her freedom of creativity. The flexible set of parameters and the fully-automated adoption of patch arrangement makes the program a powerful tool. The designer can thus concentrate on the optimisation of the ship to improve its performance and thereby its value as well as the competitiveness of the designing yard.

In the sections to come a classification of design language is presented. Subsequently, the modelling approach and the hierarchical character of design parameters and their implementation in the generation process of complex hulls are outlined. Global variations induced by single parameter changes as well as local changes typically applied in the hydrodynamic optimisation process illustrate the applicability of the parametric design methodology.

DESIGN LANGUAGE

The geometric design of ship hull forms consists of several subsequent procedures based on a wide range of abstraction levels. The description of specific properties of a ship may vary from a global expression like *a post pan max container carrier with draft restriction* to a mathematical detail like *the weight of the second-to-last control point on that frame should be slightly decreased.* Both descriptions are needed to carry the necessary information from one partner to another without burdening the communication with excessive data.

The view on a ship, and therefore the language applied for its description, depends basically on the context which governs the particular situation. While at the global level of description the appearance of a ship dominates the vocabulary, at the stage of hydrodynamic optimisation the communication on the basis of functional descriptors, e.g. form parameters, is more useful. The CAD-system which is applied to model the ship shape again requires a completely different language since it is based on patch arrangements, vertex coordinates and weights defining the hull by means of a specific mathematical method.

The modelling process of a hull can be performed independently at any of these three levels. The selection of features used to describe the hull form at any of these levels has to follow a topological description. For a better distinction let us introduce three topology levels that we call

- *Topology of Appearance,*
- *Topology of Design and*
- *Topology of Representation.*

All three levels are applied within the design process in close relation, see Figure 1.

Applying state-of-the-art CFD-programs represents today's standard for performance evaluation of ships in the early design stage. Due to their reliable ranking, see e.g. (Harries and Schulze 97), they can be utilized in the optimisation process. Shape variation and decision-taking is generally performed on the basis of functional descriptors – at the level of topology of design, i.e., the second level in Figure 1. However, the numerical simulation programs (CFD) require a complete geometric description stemming from the lowest level, i.e., the third level in Figure 1. Even though the simulation expenses in terms of computing time play a significant role, the implementation of the desired shape variation is of even higher magnitude since it is usually brought about by hand. Consequently, the limited period of design refinement restricts the number of iterations possible and systematic variations cannot be performed in general.

The different languages applied to the description of ship characteristics represent a major bottleneck in hull form development. Design decisions are usually taken on a more abstract level and the lack of automated mapping of functional descriptors into a corresponding mathematical representation makes optimisation a time-consuming, highly interactive process. In most cases no comprehensive optimisation process is achieved. In order to improve this situation the new method of hull modelling is developed such that the design-oriented parameters are directly translated into a mathematical hull representation. New geometry generation procedures based on hierarchical rules ensure variability and applicability of the approach.

MODELLING APPROACH

Traditional CAD-based geometric modelling is characterized by employing mathematically defined curves and surfaces which are manipulated by means of a graphical user interface (GUI). The model generally consists of a considerable number of free variables which have to be modified in a highly concerted manner. The initial set-up of a feasible arrangement of entities requires knowledge about both the ships topology of appearance and the mathematics of its representation. Once the set-up is done for a specific hull form, global changes cannot be accomplished easily and modifications of functional parameters remain time-consuming tasks.

Requirements of the mathematical representation

For further utilization within the design process a complete geometric model – in the meaning of a computer internal representation (CIR) – is required. CAD-models based on B-spline technology are employed successfully in many marine-related software packages. The B-splines' advantageous characteristics with regard to local shape control, internal continuity and variability makes them a powerful element for all kind of shape representations.

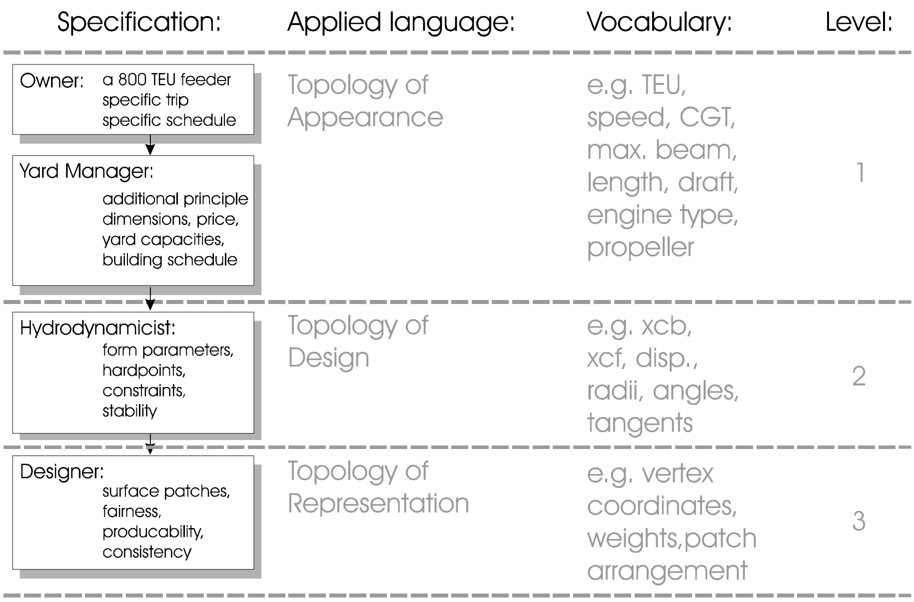

Figure 1: Levels of topology

The arrangement of surface patches for a feasible representation of a given shape depends basically on shape characteristics which make up the general appearance of the hull, e.g. flat areas, knuckle lines, curved regions. Moreover, gaps and overlaps within the representation have to be avoided which possibly leads to a more complicated arrangement, depending on the complexity of the desired shape. The quadrilateral nature of standard B-spline surfaces may cause additional subdivisions to avoid discontinuities in unfavourable regions. An example surface patch arrangement for a fast RoRo-ferry is depicted in Figure 2. In addition to these formal requirements, the resulting surface has to display excellent fairness, which normally is realized interactively by the designer who creates the CAD-model. Manually, however, these requirements are typically non-trivial to fulfil. Naturally, any automated hull generation process has to accomplish a result which complies with these requirements, too.

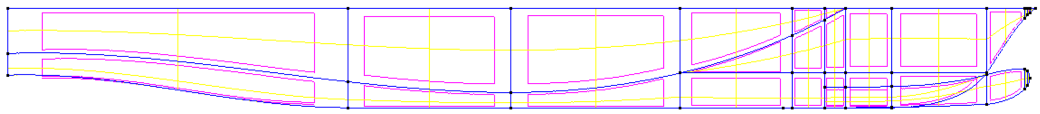

Figure 2: Example surface patch arrangement

Parametric Design Approach

The modelling technique presented in this paper is based on a parametric curve generation approach developed by Harries and Abt (1997) and has been successfully utilized for the generation and automated optimisation of bare hulls by Harries (1998). The method utilizes a parametric curve generation process where the vertices of all B-spline curves are computed from a geometric optimisation, employing fairness criteria as measures of merit and capturing global shape characteristics as equality constraints. Properties of the hull, such as the shape of the centerplane curve or the shape of the deck for instance, are represented as curves created from form parameters. Parametric curves – e.g. for the flare angle or the submerged sectional area – reflect the properties of the sectional shape of the ship at any longitudinal position. Once this set of so-called basic curves is created from the specified input, a numerical algorithm is applied to create a set of sections at selected locations and, subsequently, a skinning (Woodward 1988) is performed to create a surface definition from the skeleton of design sections. A suitable arrangement of design sections is determined automatically from an analysis of the basic curves.

The geometric modelling system developed by the authors – called FRIENDSHIP-Modeler – is based entirely on parametric principles. The parameterisation is implemented on the basis of a user-readable, marine design-oriented model-file. An excerpt of a model-file is depicted in Figure 3.

The model-file features a number of blocks representing elements from a very high modelling level, i.e., levels 1 and 2 of Figure 1. In the example principle dimensions and selected properties of the midship section and the design waterline are displayed. The entire model-file features between 30 and about 150 parameters, depending on the desired detail of specification. While some of the parameters are mandatory for the generation process many are optional. If a parameter is not specified, either its value is set to a default or, alternatively, a change in topology is performed, depending on the modelling context. An example for the creation and modification of a midship section is given in Figure 4 to Figure 7. The rule-based generation process is described in the following paragraphs.

```
// PRADS01, ferry variation, March 01

//------------------------ principle dimensions --------------------------------
MAIN {
        length          176     m               // to forward perpendicular
        lax             0.5     MAIN.length
        lenOfPar        0.0     m
        beam            25      m
        draft           6.4     m
        freeboard       12      m
}

//------------------------ midship section -----------------------------------

MIDSEC {
        draft           1.0     MAIN.draft
        beamAtDec       1.0     MAIN.beam
        freeboard       1.0     MAIN.freeboard
        beamAtDwl       0.9     MAIN.beam
}

//------------------------ design waterline ----------------------------------
DWL {
        angleAtEntrance 11      deg
        areaCoeff       0.65
        .....
        ...
        ..
```

Figure 3: Part of the FRIENDSHIP model file

Rules of creation

Instead of expecting a comprehensive specification of each element utilized to model the desired shape, an inverse procedure is applied to most features within the FRIENDSHIP-Modeler. A midship section for instance could be specified and set up with just a single information, namely the beam at the design waterline. Without any additional information, all necessary parameters would be derived from the principle dimensions, see Figure 3. The parameters *draft*, *beam* and *freeboard* have been included in the MIDSEC block in order to simplify the picture. Any additional information given by the user specializes the shape of this design feature and possibly induces changes in topology. Figure 4 shows the extract of the midship section's block complemented by a parameter called *deadrise.* Its default value is zero but here it has been modified to 4°. Figure 5 extends the specification by a straight part at its bottom. The corresponding shapes of the initial section and the modified ones are depicted in Figure 7.

```
//------------------------ midship section -------------------------------

MIDSEC {
        draft           1.0     MAIN.draft      //
        beamAtDec       1.0     MAIN.beam       //
        freeboard       1.0     MAIN.freeboard  //
        beamAtDwl       0.9     MAIN.beam       //
        deadrise        4       deg
}
```

Figure 4: Midship section specification (Part 2)

```
//------------------------ midship section -------------------------------

MIDSEC {
        draft           1.0     MAIN.draft      //
        beamAtDec       1.0     MAIN.beam       //
        freeboard       1.0     MAIN.freeboard  //
        beamAtDwl       0.9     MAIN.beam       //
        deadrise        4       deg
        flatOfBottom    0.6     MAIN.beam
}
```

Figure 5: Midship section specification (Part 3)

As stated above, the generation process follows a methodology which depends on the existence of specific parameters. According to the naval architects' language, a set of parameters has been introduced and chosen as the basis for a generation hierarchy. Figure 3 to Figure 5 depict the parameterisation of the midship section applying parameters located at a similar priority level. Other parameters exist at higher and lower levels, respectively. The parameter for the design waterline beam for example is located one level below since a combination of draft, a large deadrise angle combined with a straight part from the flat of bottom may cause a dependency. (For conventional merchant ships this case is not relevant.)

```
//------------------------ midship section -------------------------------

MIDSEC {
        draft           1.0     MAIN.draft      //
        beamAtDec       1.0     MAIN.beam       //
        freeboard       1.0     MAIN.freeboard  //
        beamAtDwl       0.9     MAIN.beam       //
        deadrise        4       deg
        flatOfBottom    0.6     MAIN.beam
        bilgeRadius     3.2     m
}
```

Figure 6: Midship section specification (Part 4)

In contrast to the set of coexisting parameters in the previous figures, an example of a higher level parameter is the bilge radius, see Figure 6. Stating a bilge radius dominates the generation process and causes the parameters for the flat of bottom and the beam at the design waterline to be overruled and, thus, ignored. In addition, a straight part for the flat of side is created which makes the section become a typical midship section.

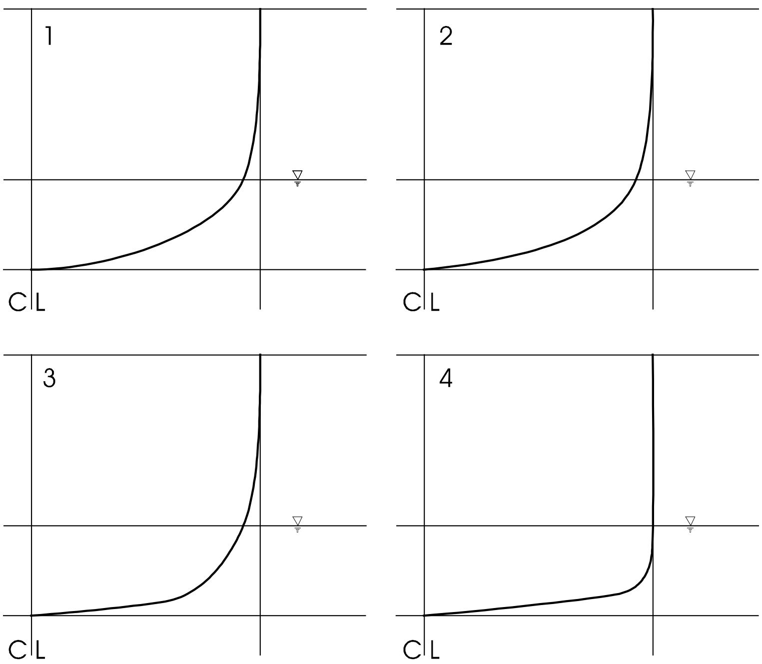

Figure 7: Shape modification of the midship section

The midship section has been selected to demonstrate the different levels of priority in the generation process of the hull shape. Every single parameter that is part of the vocabulary available in the model has to be related to a set of rules embedded in the generation process.

EXAMPLE

To demonstrate the performance of the entire modelling approach, two different shape variations – namely global and local modifications – are presented. The change of global parameters depicts the capabilities of shape generation in the early design phase. Local changes of hydrodynamic relevance have been selected to demonstrate the applicability of the modelling approach for automated shape variation without shape deformation.

Variation of principle dimensions

At the early stage of preliminary design the appearance of the ship is specified and some of the principle dimensions have to be initialised and, possibly, fixed. Typically, a subset of important parameters suffices to capture the requirements resulting from the transportation task. The freedom for shape variations is substantial and yet all desired geometric attributes are readily available in full detail. Once the model-file is created with a limited set of parameters, a complete geometric description can be created on demand. The values of parameters can be specified either in absolute terms or relative to others. Figure 8 shows three shape variations of a fast RoRo-ferry in side view. The picture shows (i) the ferry of 176 m in length without a parallel part, (ii) the hull after introducing a parallel midbody of 40 m in length, and subsequently, (iii) the geometry after a draft reduction from 8.4 m to 6.4 m. In the side view the relation of parameters can be seen: The aft end of the bulb fairing shifted upwards as the draft was reduced while the position of the bulb top was defined in absolute terms and, therefore, did not change in this example.

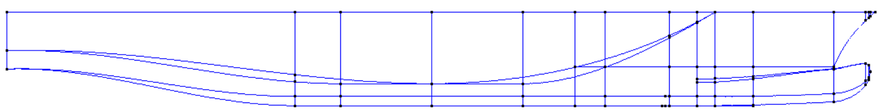

Figure 8: Global shape variation in side view

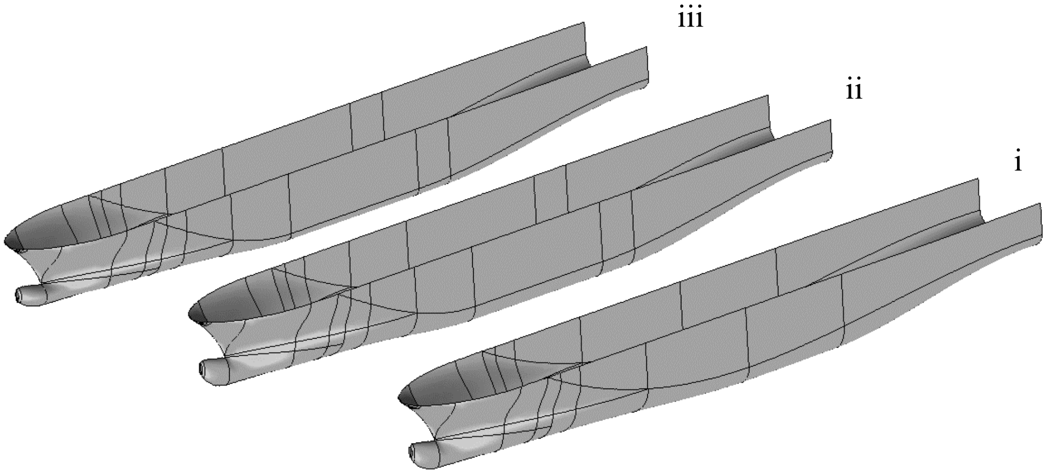

Figure 9: Global shape variation in perspective view

The rendered view depicted in Figure 9, shows the same hull variations as displayed in Figure 8. The automated adoption of the topology of representation is illustrated here clearly. The hull in the foreground, featuring no parallel midbody, consists of less surface patches than its two variations with a parallel part.

Bulbous bow variation

After several principle dimensions have been fixed as a result of economic and / or hydrodynamic optimisations, a subsequent improvement of the hydrodynamic performance is usually carried out to refine the design. Parameters typically used for the manipulation of wave resistance are related to the shape of the bulbous bow. Also, to increase the propulsive efficiency a stern gondola could be subject of changes. Figure 10 presents a variation of a single geometric parameter of the bulbous bow, namely the buttock angle of the bulb contour at the forward perpendicular. The parameterisation of the bulb is closely related to the parameters proposed by Kracht (1978). All of them have been implemented and can be applied in any suitable combination. In addition, the contour of the bulb can be defined by a number of parameters, defining the slope of the buttock, the location of the top of the bulb as well the length and height of the fairing into the bare hull. The bulb is regarded as a blister-type appendage and its volume is specified by means of a separate sectional area curve.

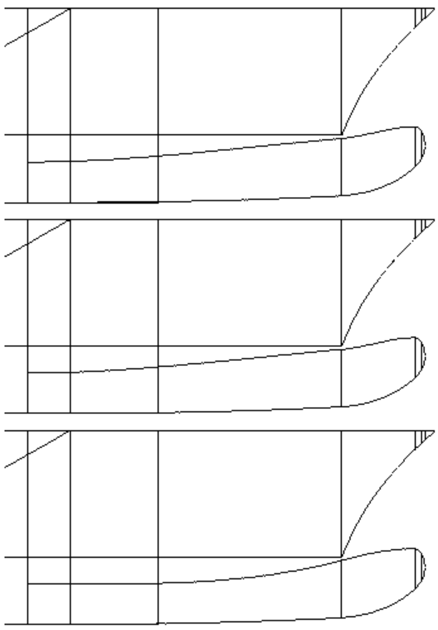

Figure 10: Local shape variation of the buttock angle at the FP

The variation depicted in Figure 10 features a variation of the buttock angle from 5° through 10° to 15° of buttock slope.

OUTLOOK

A new approach to parametric hull form design has been presented. Three prominent levels of topology have been introduced – Topology of Appearance, Topology of Design and Topology of Representation. These levels serve to characterize more clearly the various stages of specification, definition and realization typical of today’s ship design process, comprising the complete spectrum from the abstract description to the mathematical detail. The new modelling approach is placed at the intermediate level of topology of design. Form parameters are utilized as the descriptors to express design ideas. They can be specified flexibly and problem-dependently. A hierarchical, context-related and rule-based system has been presented to support the naval architect, the hydrodynamicist and the designer in their mutual task to create, vary and optimise the hull geometry quickly and effectively. Examples are given to illustrate the design philosophy and to demonstrate the applicability of the method.

The approach is well-suited for the integration into formal techniques of systematic optimisation.

Further work is needed to accommodate additional hull features like appendages, gondolas etc. Moreover, current and future applications focus on the automated optimisation of the hydrodynamic performance associated with the hull geometry, covering calm water resistance and propulsion as well as seakeeping.

ACKNOWLEDGEMENT

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