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Parametric generation of planing hulls

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ABSTRACT

This paper presents a mathematical method for producing hard-chine ship hulls based on a set of numerical parameters that are directly related to the geometric features of the hull and uniquely define a hull form for this type of ship. The term *planing hull* is used generically to describe the majority of hard-chine boats being built today. This paper is focused on un-stepped, single-chine hulls. B-spline curves and surfaces were combined with constraints on the significant ship curves to produce the final hull design. The hard-chine hull geometry was modeled by decomposing the surface geometry into boundary curves, which were defined by design constraints or parameters. In planing hull design, these control curves are the center, chine and sheer lines, as well as their geometric features including position, slope and, in the case of the chine, enclosed area and centroid. These geometric parameters have physical, hydrodynamic and stability implications from the design point of view. The proposed method utilizes 2D orthogonal projections of the control curves and then produces 3D definitions using B-spline fitting of the 3D data points. The fitting considers maximum deviation from the curve to the data points and is based on an original selection of the parameterization. A net of B-spline curves (stations) is then created to match the previously defined 3D boundaries. A final set of lofting surfaces of the previous B-spline curves produces the hull surface.

1. Introduction

Defining a ship hull is one of the most limiting processes in initial ship design. A hull form is usually designed by modifying an existing hull (template or parent hull), which can include direct manipulation of the surface control vertices when B-spline or NURBS (non-uniform rational B-spline) surfaces are used. Although this has become a standard practice and produces good results, it necessitates much manual work because the designer must manipulate individual control vertices. Furthermore, this process does not allow for rapid creation or modification of the hull surface in the initial phases of the ship design process. Finally, using this method, important characteristics of the ship hull cannot be determined until a later calculation is made, which necessitates a trial-and-error procedure. Thus, a hull form should be generated as early as possible to provide demanded design calculations that are important for subsequent design stages, such as stability, hydrostatics, lift, drag, and layout drawings.

The parametric generation of a ship hull can ensure that a set of design parameters are met and preserved when creating a complete hull form and that the design algorithm generates an appropriate hull that is constrained by the design parameters without further human interaction. However, a parametric method is limited to the range of hulls that can be generated. In this particular method, these fixed formulations allow enough flexibility in the number of hull shapes that can be generated for a planing hull. Specifically, semi-displacement and recreational planing crafts, trawler yachts and patrol boats can be formulated, but stepped, multi-chine and multi-hull crafts cannot.

Computational optimization techniques based on computational fluid dynamics (CFD) can be used with systematic constraint definitions of a ship hull to produce faster, more comfortable and safer planing hulls. These optimization methods require complete geometric details of the design and correct management of hull information so that one can understand the relationship between the optimization method and the constrained design of the hull.

This paper presents a parametric design method for defining planing hulls with the previously mentioned range of applicability. Practical examples will be used to show how the proposed method affords reliable hull design solutions. Fig. 1 presents an example of a hull that can be automatically defined with the presented method and shows the boundary curves that define that hull.

This paper is organized as follows. First, Section 2 provides a background on parametric design. Then, Section 3 describes the proposed method beginning with the conception of the boundary curves shown in Fig. 1, based on their orthogonal 2D projections. A B-spline scheme for these curves is adopted, and linear or nonlinear problems are solved to obtain a constrained definition

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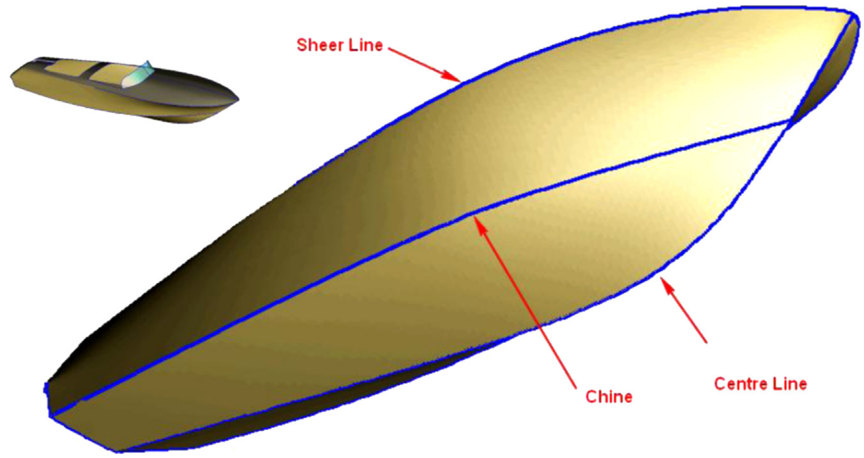

Fig. 1. Geometry of a planing hull.

that agrees with the geometric design parameters selected by the designer. A direct 3D approach to boundary curve definition would require a great number of parameters to uniquely define the curves, and some of these parameters would be purely mathematical, such as curvatures or derivatives that are either difficult to define in the initial design stage or are not of practical use for a naval architect. For this reason, an initial 2D approach was used.

The description of the method continues with the definition of the 3D boundary lines in Section 3.6, using constrained B-spline fitting of the points obtained from 2D curves. This fitting utilizes a parameterization based on the distance from the data points to the B-spline. This is useful for manufacturing purposes as it enables an assessment of the maximum or average deviations from the original curves.

A net of B-spline curves (stations) is then created in Section 3.7 that matches the previously defined 3D boundaries. A final set of lofting surfaces from the previous B-spline curves produces the hull surface.

Finally, Section 4 presents two hulls designed with the presented methodology to demonstrate the validity of the proposed method. Section 5 presents the major conclusions of the paper.

2. Background

Parametric design methodologies can be traced back to Kuiper (1970), who generated hull shapes in the 1970s using conformal mapping techniques from hull parameters, rather than from offset hull data points. Kuiper generated hulls by constructing different waterline polynomials according to coefficients controlled by draught functions. The hull representation techniques of that time did not allow the development of hull shapes in a convenient and accurate way.

Reed and Nowacki (1974) developed a compromise between polynomials and conformal mapping techniques; namely, polynomials were used to represent the hull above the waterline, and conformal mapping techniques were used for the underwater part of the ship. B-splines and NURBS functions were used by Creutz and Schubert (1978) for ship hull design. They developed a procedure to generate B-spline curves from form parameters. These early studies demonstrated how NURBS and B-splines could adequately represent the geometry of a ship hull.

Keane (1988) developed simple hulls using constrained generation techniques based on conformal mapping and studied the influence of certain parameters on ship stability. This is one of the first optimization procedures to be based on parameter variation.

Yilmatz et al. (1999) determined hull stations parametrically by applying a regression technique to a large database of hulls. This method can only be used for certain fishing vessels because those ships were used to construct the database. Mancuso (2006) used parametric methods to define sailing ship hulls and the authors of the present paper developed a method for round bilge hulls (Perez et al., 2008).

Different authors, such as Nam and Parsons (2006), Kim (2004) and Bole (2002), researched this topic by subdividing the ship hull into multiple domains, such as the entrance, flat bottom, and flat side. The proposed method will subdivide planing hulls into one domain below the chine line and one above the chine line. In the case that a spray rail is present, a third domain will be implemented.

Based on the previous references, it can be observed that the use of parametric techniques in ship design is not unusual in the literature. However, the applicability of these techniques to hard-chine planing hulls is quite limited. We found only two notable references, Calkins et al. (2001), that defined a planing hull using a parametric methodology, but it did not include B-spline modeling, which is a standard in naval architecture; rather, it covered the hull shape with straight stations, which is unrealistic most of the time. The second reference is Ghassabzadeh and Ghassemi (2013) that model parametrically planing hull tunnel vessels (or Cathedral Hulls) producing a wire model and then a NURBS surface.

The use of parameters to study the hydrodynamic properties of hard-chine hulls is quite common, like in the significant papers in this field written by Savitsky (1964), Savitsky and Brown (1976), Blount and Codega (1992) and Clement and Blount (1963). These papers motivated the present work.

Commercial hull design software packages now include modules for the basic, constrained generation of ship hulls, demonstrating that designers have a clear need for such a technique.

These commercial software modules were reviewed by Bole (2002). Some of the software packages use non-intuitive parameters such as curvatures, derivatives or numerical weights. Other packages are limited on the other end, producing very simple hulls based only on primary dimensions that do not cover specific parameters for a planing hull, such as the dead-rise angle, enclosed chine area or stem angles.

The transformation of a parent hull is limited due to the numerical techniques that are used. These methods (Lackenby transformations) are based on relocating and scaling hull sections while maintaining the desired dimensions in a trial-and-error manner until a selected displacement and longitudinal center of buoyancy (LCB) is reached.

The main reason that these methods are not appropriate for planing hulls is that a planing hull is not a volumetric ship; this