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Self-blending method for hull form modification and optimization

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ABSTRACT

A self-blending method has been developed and applied to the modification of a bulbous bow. The method is capable of transforming ship hulls automatically. In this method, few representative number of cross sections (the key points of the cross sections) of the baseline geometry are selected. New cross sections are generated through merging the two cross sections next to each other, using a prescribed weight factor. Different weight factors are assigned to the x, y and z coordinates of the key points of the cross section. The method thus can be one, two or three parameters self-blending method. The surface of the ship hull generated through the method is smooth so that it can be readily used for meshing and CFD (computational fluid dynamics) applications. Combined with CFD and DOE (design of experiment) techniques the shape of bulbous bow of a fishing vessel is optimized and the resistance is reduced by 2%.

1. Introduction

Ship hull optimization remains an active area of research due to its direct impact on fuel efficiency and green shipping. In general, a ship hull optimization process requires three components, they are, a Parametric Ship Hull (PSH) method, a hydrodynamic analysis tool and an optimization method. Among these three components, PSH plays the fundamental role. The ability to modify the hull geometry in an effective manner drives the overall optimization process.

A number of methodologies have been proposed for ship hull optimization. For example, Li et al. (2013,2014) integrated CFD analysis, along with numerical optimization and a parametric ship hull method into a SBD (Simulation-based design) technique. Using the free-form deformation (FFD) method they optimized a bulk carrier with about 5% resistance reduction obtained. Tahara et al. (2006) proposed a multi-objective optimization in which the hull form is defined in the NAPA system. Essential to this method is the blending approach which is characterized by defining the new ship hull through blending two basic hull-forms using blending parameter. Peri et al. (2001) carried out the shape optimization of a tanker using CFD technique along with a ship hull transform method using perturbation surfaces in order to reduce the number of design variables. Perez et al. (2007) discussed the bulbous form parameters and the geometric method of bulbous bow in detail using Non-uniform rational basis spline (NURBS). Peri and Campana (2005) presented a SBD environment for ship optimization and introduced a surrogate model for calculation of the ship hull resistance in order to reduce the computation time. Han et al. (2012) defined the ship hulls with parametric curves, generated by fairness-optimized B-spline, and optimized a large container and a LPG carrier with this method. Kim and Yang (2010) used two approaches to modify the ship hull, one is based on the radial basis function interpolation, and the other modifies the sectional area curve of the hull. With these two approaches, local and global optimization of ship hull can be achieved. Zhang et al. (2009) introduced a hull form modification function which can generate a new smooth hull surface by multiplying it by the offset data of the original hull surface. Chrismianto and Kim (2014) optimized a bulbous bow by shaping the ship hull surface with cubic Bezier curves and curve-plane intersection methods.

All of these parametric ship hull methods can be divided into two categories: (1) bulb features (including protrusion length, maximum beam of the bulb, height of the tip of the bulb above the Base line, etc.) are directly used as parameters; (2) parameters used to represent ship hull are related to three-dimensional geometrical models. Each of these approaches has its advantages and disadvantages. The advantages of the methods using bulb features are the following: (1) the hull transform is controlled by these certain form features, so the factors that affect optimum are clear; (2) using certain form features, to some extent, introduce some constraint conditions which can reduce the number of independent

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Nomenclature

CSX_{ij}	x coordinate of point j on the picked cross section i
CSY_{ij}	y coordinate of point j on the picked cross section i
CSZ_{ij}	z coordinate of point j on the picked cross section i
$CSX_{ij}^{'}$	x coordinate of point j on the new cross section i
$CSY_{ij}^{'}$	y coordinate of point j on the new cross section i
$CSZ_{ij}^{'}$	z coordinate of point j on the new cross section i
C_t	Coefficient of total resistance of vessel
Fr	Froude number
ω_1	Input parameter control y coordinate of points on picked cross section
ω_2	Input parameter control z coordinate of points on picked cross section
ω_3	Input parameter control x coordinate of points on picked cross section

variables for optimization; (3) The effects of these form features on the hull performance are well understood, making the selection of important design variables and the design space simpler. These methods, however, have the disadvantage of reducing the number of independent variables, they limit the potential for optimization of the geometry. A full ship hull transformation, independent of these factors, will result in sharp increase in the number of the design variables, thus increasing the needed computation time and resources. The method using parameters related to geometrical models, do not have the above limitations, however the space of optimization in these approaches are also larger, resulting in sharp increase in the number of design variables.

Tahara (2004, 2006, 2008, 2011) developed a blending approach with a few independent variables where the transformation is not limited by the traditional form features. The method introduced a blending parameter to merge the two basic hulls generating a new hull form. The basic hull-forms are defined by same numbers of control points and the merging of the two hull forms is done through these control points. The hull transformation in this method is not limited by the certain form features and since it only has one blending parameter, computation needs are reasonable. This method however requires the finding of two similar hulls. Furthermore, discretizing the basic ship hulls into the same numbers of control points is challenging. Finally, the generated ship hull does not substantially differ from the two basic ship hulls.

The parametric ship hull method developed in this paper is based on a self-blending approach. Instead of blending two or more basic ship hulls to generate a new ship hull, the method uses cross sections of the parent ship hull as basic elements and the new cross sections are generated by blending these basic cross sections. The self-blending approach shares the advantages of other blending approaches including small number of independent variables that define the geometry but it is not only limited to changing the traditional form features. Furthermore, this approach only requires one parent ship hull. As a result, the hull transformation has an enlarged field, instead of being limited by the features of the two basic ship hulls. The self-blending method can easily be applied to the optimization of hull forms and bulbous bows.

This paper presents the optimization of the bulbous bow of a fishing vessel, using the self-blending approach combined with CFD and DOE techniques. Convergence studies of grid and iteration on CFD method have been performed and the CFD results are first validated using experimental data. To accelerate the optimization process, DOE method has been introduced and a response surface has been generated using the CFD results. With these techniques an optimum geometry is identified where the coefficient of total resistance of the fishing vessel has been reduced by 2%. The high fidelity of the CFD calculations, gives confidence in the results capturing modest improvements in the resistance due to optimized bulbous bow geometry. Details are presented in the subsequent sections.

Table 1
Parameters of fishing vessel.

Parameter	Value
Scale factor	20
Waterline length	3.45 m
Draft	0.197 m
Displacement	259.146 kg
Wetted surface area	2.527 m^2
Velocity	1.6 m/s

2. Parametric bulbous bow

Self-blending method uses few parameters which are not associated with certain form features of bulbous bow. Thus the method is capable of carrying out larger transformation which is not constrained by traditional methods. The first step of the method is to pick a few cross sections from the original ship hull. To generate new cross sections, the selected cross sections are distributed with weights and merged with others. With these new cross sections, new bulbous bow can be generated. The process is carried out automatically using NX CAD, a leading CAD system.

2.1. Original ship hULL

The original ship hull used in this paper is a fishing vessel and experimental tests were carried out by DUT. The principal parameters of the model scale fishing vessel is shown in Table 1. The body plane of the fishing vessel is depicted in Fig. 1 and the bulbous bow is shown in Fig. 2.

2.2. CAD module

The standard naval architecture coordinate system has been used with the boat x-axis pointing forward in axial direction, y pointing to starboard and z pointing downward. To carry out a CFD simulation, a 3D surface of the ship hull is necessary. Fig. 3 shows the 3D ship hull surface of 73 m fishing vessel generated using NX CAD system.

The work flow of the self-blending construction and transformation of the 3D ship hull, using NX CAD platform, is depicted in Fig. 4. Through inputting cross sections picked from the original ship hull and weights,

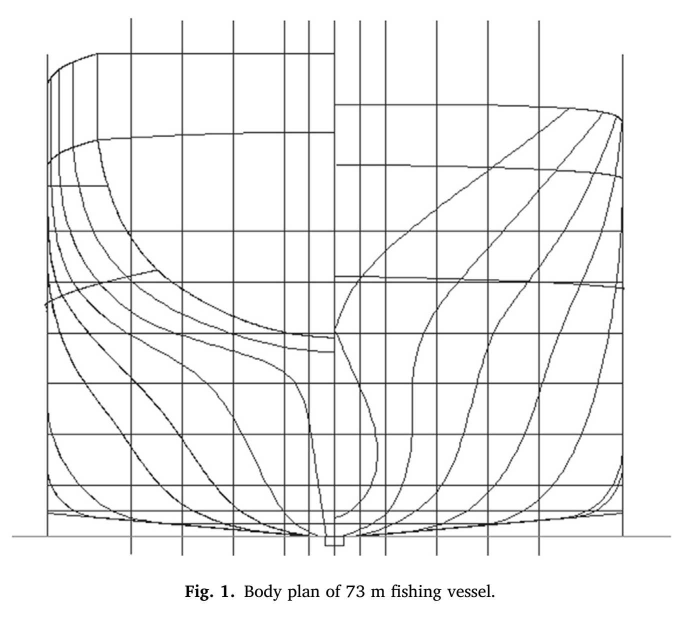

Fig. 1. Body plan of 73 m fishing vessel.