An investigation into fishing boat optimisation using a hybrid algorithm

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ARTICLE INFO

ABSTRACT

The optimisation of high-speed fishing boats is different from the optimisation of other displacement type vessels as, for high-speed fishing boats, the wave-making resistance decreases while the splashed resistance increases sharply. To reduce fuel consumption and operating costs in the current economic climate, this paper presents a fishing boat optimisation approach using a Computational Fluid Dynamics (CFD) technique. The RANS-VoF solver was utilised to calculate total resistance, sinkage and trim for a fishing boat in calm water. The Arbitrary Shape Deformation (ASD) technique was used to smoothly alter the geometry. A hybrid algorithm was presented to solve the complicated nonlinear optimisation problem. Herein, a Design of Experiments (DoE) method was applied to find an optimal global region and a mathematical programme was employed to determine an optimal global solution. Under the same displacement with the original hull, two optimisation loops were built with different design variables. After completion of the optimisation, two optimal hull forms were obtained. The optimisation results show that the optimisation loop presented in this study can be used to design a suitable fishing boat in the reduction of the total resistance in calm water.

1. Introduction

The ship hull form optimisation process is a crucial aspect of the early stages of ship building. To obtain a ship with optimal hydrodynamic performance, the hull form needs to be optimized. In recent years, Simulation-Based Design (SBD) techniques have gained particular attention worldwide. This creates the potential for hull form optimisation design (Li, 2012) for fuel efficiency, which results in the minimization of the running cost. An SBD-based ship hull form optimisation framework includes three parts, as shown in Fig. 1:

- Geometry reconstruction: a method used for altering the shape of a ship.
- Computational Fluid Dynamics (CFD) techniques: an evaluation method for a ship's hydrodynamic performance, such as total resistance, wave-making resistance, sinkage and trim.
- Optimum techniques: a mathematical method used to obtain the optimal solution for a linear or non-linear space.

Geometry reconstruction is a bridge between CFD techniques and optimum techniques that directly determines the optimisation

efficiency of the hull form optimisation design. Up to now, many geometry reconstruction methods have been widely used for ship hull form optimisation. For example, Park et al. (2015) applied the parametric modification functions for the optimisation of the KSUEZMAX ship. Zhang et al. (2011) utilised the Kazuo Suzuki's hull form modification function to change the hull lines of a patrol boat. Zhan et al. (2012) applied a parametric morphing method to obtain different ships. Zhang and Zhang (2015) used the parameters of the B-Spline function as design variables to alter Series 60 ship's hull lines. All the methods above can alter the geometry with fewer design variables; however, the configuration space is very small. In recent years, Free Form Deformation (FFD), a 3-D deformation method first proposed by Sederberg and Parry (1986), has been used extensively to alter the original geometry in the hull form optimisation design. Chen et al. (2015a) used the FFD method to change the bulb bow shape of a super-large container ship. Peri (2016) applied the FFD method to alter a container ship with nine design parameters. Subsequently, four examples of hull deformation were reported to demonstrate the variety of shapes potentially considered during the optimisation process. In addition, Wu et al. (2017) also used the FFD method to change the bulb bow shape of a DTMB5415 ship. Their studies showed that the FFD method is a

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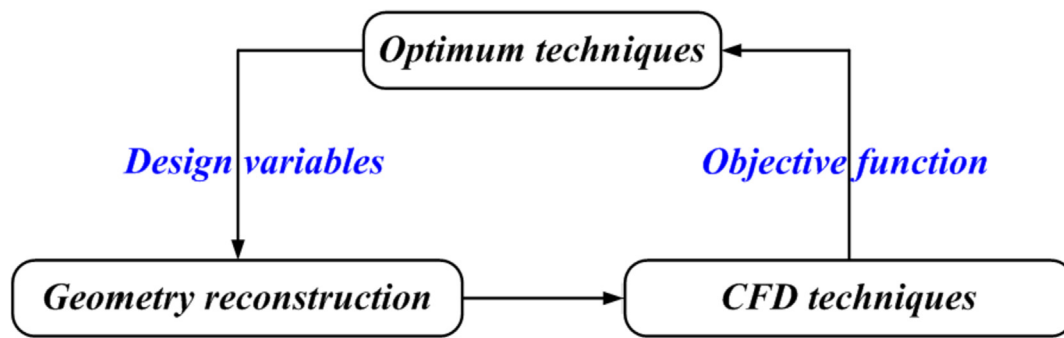*E-mail address:* tahsin.tezdogan@strath.ac.uk (T. Tezdogan).

Fig. 1. SBD based ship hull form optimisation framework.

Table 1
Geometrical properties of the fishing boat used within this study.

Property	Value
Length betw. perp., L_{pp} [m]	5
Breadth at water line plane, B [m]	1.934
Depth to 1st deck, D [m]	1.196
Loaded draft, T [m]	0.35
Displacement, Δ [t]	1.9
Block coefficient, C_B	0.5367
Mid-boat section coefficient, C_M	0.764
Wetted Surface Area, Aw [m²]	10.201
Froude number, Fr	0.59

practical approach for hull form deformation. Although this method provides a powerful modelling tool for hull form modification, it is challenging to control the shape and satisfy the given constraints in some cases (Yang and Huang, 2016). To overcome this problem, Yang and Huang (2016) utilised a NURBS-based Free Form Deformation (NFFD) method to alter Series 60 hull. Compared with the classical FFD method, the NFFD adopts the non-uniform B-spline solid function with non-uniform divisions and variations of basis order to provide greater flexibility in deforming the 3-D control lattices.

With the rapid development in computer technology, CFD-based numerical simulation approaches have been widely used to investigate the hydrodynamic performance of a ship in calm water or in waves. Ahmed (2011) used a CFX code to simulate the ship motions of a DTMB 5415 model in calm water, integrating the standard k-ε turbulence model and a Volume of Fluid (VoF) method. The results obtained using the RANSE code solver agreed well with the experimental data. Carrica et al. (2011) presented two computations of KCS in the model scale, utilising the CFD Ship-Iowa software to simulate the performance of a model-scale KCS ship in calm water and in regular waves, by including three conditions at two different Froude numbers (Fr). Zhang et al. (2011) employed an in-house multifunction solver (naoe-FOAM-SJTU) to study the resistance and wave-making performance of a high-speed catamaran sailing at different speeds in calm water using the RANS-VoF method. Tezdogan et al. (2016) investigated the total resistance, flow field and motions for a full-scale 200kDWT class large tanker in shallow water using the STAR-CCM + software. They found that as water becomes shallower, heave motions decrease, whilst pitch motions increase at low frequencies and a slight decrease was observed in pitch responses as the water depth decreases at high frequencies. Saha and Miazee (2017) performed a resistance, sinkage and trim calculation for a container ship for speeds ranging from 8 knots to 10 knots using the SHI-PFLOW code.

The optimisation technique is essential in engineering design. It can help designers to obtain the best solution for their needs. Many optimisation algorithms have been developed and applied to solve different kinds of optimisation problems in the past 20 years. Generally, these optimisation approaches can be divided into two categories: (a) meta-heuristic methods and (b) mathematical programming (Garg, 2016).

Meta-heuristic methods have been widely used to obtain global or near global optimal results, like Particle Swarm Optimisation (PSO) algorithm (Azimifar and Payan, 2016; Garg, 2016; Tungadio et al., 2016; Zhang et al., 2017), and Genetic Algorithm (GA) (Bagheri and Ghassemi, 2014; Gammon, 2011; Lowe and Steel, 2003). Although meta-heuristic methods are a good compromise between exploration and exploitation of the research space, they could still get trapped into a local solution and the convergence to a global minimum cannot be proven (Garg, 2016). Following on from the PSO algorithm, Li et al. (2014) developed a new IPSO algorithm. The optimisation results show that the IPSO algorithm has a better solution than the original PSO algorithm. Following on from the GA algorithm, Zhu and Zhao (2017) presented an improved GA algorithm. Their results show that the improved GA algorithm can effectively escape from a local optimal solution and can overcome premature convergence. Barroso et al. (2017) developed a PSO-GA algorithm to solve the optimisation of laminated composites. Many mathematical programming methods are also employed to solve the optimisation problem, such as Sequence Quadratic Program (SQP) method (Gill et al., 2002; Yu and Lee, 2016) and Non-Linear Programming (NLP) method (Zhang et al., 2009; Zhang and Zhang, 2015). Serani et al. (2016) pointed out that if the research region is known a priori, local optimisation algorithms can also obtain an accurate solution of the local minimum. For instance, Attaviriyanupap et al. (2002) used the Evolutionary Program (EP) method to obtain an optimal global region, and utilised a SQP method to determine the optimal global solution. Zhang (2012) presented a hybrid optimisation method integrating the GA and NLP to optimise a Wigley ship. To improve the performance of mathematical programming methods, a hybrid algorithm is developed in this study, combining the Latin Hypercube Design (LHD) technique and Non-Linear Programming by Quadratic Lagrangian (NLPQL) algorithm. It is expected that this hybrid algorithm can improve the accuracy of optimisation.

With an increase in ship speed, the bow of a fishing boat rises, resulting in a decrease in the wave-making resistance, while the splashed resistance increases sharply. Therefore, fishing boat optimisation is always a difficult issue for designers. For this reason, a traditional fishing boat geometry found in the East Java seas in Indonesia has been used in this paper as a case study. This study therefore aims to provide an optimisation method for a high-speed fishing boat. The novelties of this paper are as follows. Firstly, by combining the LHD and NLPQL algorithm, we put forward a new optimum technique for the evaluation of hull form optimisation, called a hybrid algorithm technique. Secondly, two sets of design variables are used to alter the fishing boat to study the relationship between the bow geometry and the total resistance. Lastly, the heave and pitch of the fishing boat are considered in the ship hull form optimisation in accordance with the actual navigation situation.

This paper is organised as follows. First, the primary ship properties of a fishing boat are described, along with numerical modelling methods for evaluating the total resistance in Section 2 and Section 3. Subsequently, a hybrid algorithm and the validation of its efficiency are