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# Optimization of a twin-skeg container vessel by parametric design and CFD simulations

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**Abstract**

The model tests results for the original lines of an 10000TEU container vessel show that the delivered power is higher and could not satisfy the requirement of energy saving effects and design targets. In this paper, the lines optimization of the 10,000 twin-skeg container vessel was carried out by parametric modeling and CFD simulations. At first, the CFD methods for twin-skeg hull form were validated by the comparison with the experimental results. Then more than one hundred parameters were adopted for the establishment of the fully parametric model. Based on the parametric model of the twin-skeg container vessel, the preliminary optimization was carried out by tight coupling of FRIENDSHIP-FRAMEWORK with potential flow of SHIPFLOW. Then several important parameters related to the after part of twin-skeg vessel were investigated by viscous flow computation. The final optimized variant PM11, which the total resistance was reduced by about 8.3% in model scale, is obtained within the constraints of general arrangement. And the model tests for variant PM11 was carried out in CSSRC, which shows that the resistance of optimized variant PM11 is decreased by about 8.6%.


*Keywords:* Lines optimization; Twin-skeg hull form; Container vessel; Parametric design; Resistance

## 1. Introduction

The size of container vessels increasingly becomes larger and larger; the 19000TEU container vessel has been delivered recently. The loads for the propeller of large container vessel become very heavy, which may cause inevitable cavitations and corrosion for single propeller. An useful solution is to adopt the twin-skeg hull form which equips two propellers and two engines (Tillig, 2010). This kind of ship could be designed with low resistance, well-maneuvering performance, which employs propeller of larger diameter and lower rotation speed, while the wetted surface of twin-skeg vessel will be slightly increased in comparison with that of the single crew hull form. Usually, the twin-skeg hull from is adopted for the full form ships, such as tankers (Tillig, 2010) and LNG carriers (Kim et al., 2014).

In the present paper, the model tests results of original hull form of this container vessel indicates that the delivered power is a bit higher and could not satisfy the requirement of energy saving effects and design targets. China Ship Scientific Research Center (CSSRC) has a lot of experiences in the line optimization for single crew hull form by Chen et al. (2008, 2010). Traditionally, parent hull transformation and/or design methods based on experts' experience are usually adopted for the optimization of single crew hull form, but these methods are not flexible for the optimization of twin-skeg vessels with complex after body. In order to systematic investigate the influence of parameters on the resistance of difference variants, the lines optimization of the 10000TEU twin-skeg container vessel was carried out by parametric modeling (Friendship Systems GmbH, 2012; Couser et al., 2011) and CFD simulations by SHIPLOW (Flowtech, 2012). The resistance and wave field of original lines were analyzed by CFD

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simulations, the model test results of the original lines are compared with that of CFD analysis, which shows that the agreement between the model test and computed results are very good.

A fully parametric model of the 10000TEU twin-skeg container vessel was established by using more than 100 parameters. And the parameters of bulb length, inlet angle of forward waterline, distance and angle of two skegs et al., were selected to explore the space of design variants. After establishment of the fully parametric model, the wave-making resistance and total resistance of the 10000TEU container vessel with respect to different parameters was investigated by the integration platform. A preliminary optimized variant was obtained by systematic investigation of the parametric models. Based on the initial optimized variants, the influence of twin-skeg parameters on total resistance was studied by CFD analysis, and an optimized variant PM11 with smallest resistance was obtained. And the model tests for variant PM11 was carried out in CSSRC, which shows that the resistance of optimized variant PM11 is decreased by about 8.6% in model scale.

## 2. Numerical methods

In this paper, the numerical method is based on domain decomposition, which means the whole fluid is divided into three parts according to flow characteristics: the first part employs nonlinear wave-making numeric methods (Larsson, 1997), the second part solves boundary integral equation, the last part adopts viscous numeric method to simulate the flow fluid of after body of ships (Flowtech, 2012).

### 2.1. Wave-making numerical method

The ship moves at constant speed $U$ along the positive direction of $x$-axis. Coordinate system $o$-$xyz$ is fixed to the ship, the $xy$-plane is located at the clam water surface, and $z$-axis is positive in upward direction. The fluid is potential flow, ignoring surface tension and water depth is infinite.

With the foregoing assumptions, a velocity potential $\phi$ which satisfies the Laplace equation and boundary condition below is introduced around the ship.

The velocity potential $\phi$ satisfies Laplace equation in the flow field:

$$\nabla^2\phi = 0 \tag{1}$$

On the free surface, it satisfies the kinematic boundary condition:

$$\phi_x\zeta_x + \phi_y\zeta_y - \phi_z = 0 \quad z = \zeta(x,y) \tag{2}$$

Besides, the dynamic boundary condition:

$$\zeta = \frac{1}{2g}\left(U^2 - \nabla\phi\cdot\nabla\phi\right) \quad z = \zeta(x,y) \tag{3}$$

On the wetted hull surface, Neumann boundary condition should be satisfied:

$$\phi_n = 0 \tag{4}$$

The radiation condition is satisfied at infinity:

$$\phi = -Ux \tag{5}$$

The problem of ship wave-making is to solve above equations. The difficulties of solving ship nonlinear wave-making resistance lie in that the free surface boundary conditions are nonlinear and are satisfied on the initially unknown wavy free-surface. Generally, the method of solving this nonlinear problem is to linearize the free surface condition on the basis of known basic solution (Janson, 1997).

With the above considerations, there are some other assumptions:

$$\phi = \Phi + \varphi \tag{6}$$

$$\zeta = H + \eta \tag{7}$$

where $\Phi, H$ denote the velocity potential and wave surface of last iteration, respectively, and $\varphi, \eta$ denote the new disturbance which are small quantity. Then taking Eq. (6) and Eq. (7) into Eq. (2) and Eq. (3), the combined linearization free surface boundary condition and kinematic boundary condition are obtained:

$$\begin{aligned} &-\frac{1}{2g}\left(\Phi_x\frac{\partial}{\partial x} + \Phi_y\frac{\partial}{\partial y}\right)(\nabla\Phi\cdot\nabla\Phi + 2\nabla\Phi\cdot\nabla\varphi) + \varphi_x H_x \\ &+ \varphi_y H_y - \Phi_z - \varphi_z = 0, \quad z = H \end{aligned} \tag{8}$$

$$\zeta = \frac{1}{2g}\left(U^2 - \nabla\Phi\cdot\nabla\Phi - 2\nabla\Phi\cdot\nabla\varphi\right) \quad z = H \tag{9}$$

The combined free surface boundary condition is Raven's free surface boundary condition (Raven, 1998), this boundary condition doesn't include transfer item of the linearization free surface boundary condition, because the transfer item could cause numerical oscillatory. During the iteration process, the wave height is solved by linearization kinematic free surface boundary condition in Eq. (9).

### 2.2. Viscous flow numerical method

The flow, described everywhere, satisfies the Navier–-Stokes equations and the continuity equation. In cases of ship hydrodynamics, the fluid is water which allows the assumption that the fluid is incompressible. So the continuity equations:

$$\frac{1}{\rho}\frac{\partial\rho}{\partial t} + \frac{\partial U_i}{\partial x_i} = 0 \tag{10}$$

can be simplified as:

$$\frac{\partial U_i}{x_i} = 0 \tag{11}$$

In Eq. (11) the changes of density are neglected. $U_i$ denotes the velocity in $i$ direction and $x_i$ is the related coordinate. So the momentum equation can be written as: