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Wake-Adapted Optimization for V-Bracket Attack Angle

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Wake-Adapted Optimization for V-Bracket Attack Angle

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Abstract. The energy saving of ships has become an important task in shipbuilding and shipping field globally. It relates to the fuel saving, the cost reduction of transportation, environment protection and profit of enterprises companies. Previous researches of ship energy-saving mainly focused on optimization of ship hull, and the additional energy-saving devices, etc. This paper develops V-bracket design through computational fluid dynamic (CFD) calculation and model test. First The orientation and distribution of streamline around the V-bracket under the condition of the ship economic speed were determined by the means of numerical calculation. Then, the attack angle of V-bracket was determined by the direction of wake-flow velocity vector, so that the effect of resistance will be better than other attack angles. A set of reasonable method of V-bracket attack angle procedure design is presented.

1. Introduction

The energy saving of ships has become an important task in shipbuilding and shipping field globally. It relates to the fuel saving, the cost reduction of transportation, environment protection and profit of enterprises companies.

Previous researches of ship energy-saving mainly focused on optimization of ship hull, and the additional energy-saving devices, etc, however short for optimization of ship appendages, that contributes about 20% to the total resistance. This paper launched a study on optimization energy-saving based on V-bracket design because of the reasons as below:

Firstly, appropriate V-bracket design produces less increase of appendages resistance;

Secondly, V-bracket affects much on efficiency of propeller propulsion because of a small distance close to the propeller;

In addition, it is possible to delay the occurring of cavitations and reduce vibration force of the ship by means of rational V-bracket. [1-9]

The authors made the use of computational fluid dynamic (CFD) and model experiments to summarize a methodology for the design of wake-adapted V-bracket attack angle.

2. Numerical Model

2.1. Governing equations

The motion-compliant continuity and momentum conservation equations for incompressible Newtonian fluid motion [10] are shown as below:

$$\frac{\partial \rho}{\partial t} + \frac{\partial (\rho u_i)}{\partial x_i} = 0 \tag{1}$$

$$\frac{\partial(\rho u_i)}{\partial t} + \frac{\partial}{\partial x_j}\left(\rho u_i u_j\right) = -\frac{\partial p}{\partial x_j} + \frac{\partial}{\partial x_j}\left(\mu \frac{\partial u_i}{\partial x_j} - \rho \overline{u_i' u_j'}\right) + S_j \tag{2}$$

In the formula, u_i and u_j means the averaged values of the velocity component (three directions) in time; p means the averaged value of the pressure in time; ρ means the density of fluid; μ means the coefficient of dynamic viscosity; $\rho \overline{u_i' u_j'}$ means the Reynolds stress term; and S_j means the source term, in this artical, the numerical wave beach is the wave damping source term.

2.2. The turbulence model
In this paper, the author analyze a plan of the hull which means of a segregated flow solver by used the finite volume computational method . The formulation is on the basis of pressure and fully coupled. The convective flux terms use second-order upwind spatial discretization, and the diffusion terms use second-order central discretization. The steady-state solution determined by an implicit pseudo time-marching scheme . Preconditioning is used to make this approach suitable for low-speed, isothermal flows [11] (Weiss, 1995). In order to solve the results of discrete linear system at each iteration , the point-implicit (Gauss-Seidel) linear system solver is used with algebraic multigrid acceleration . In this study, the shear stress transport $k-\omega$ model [12] (Menter, 1994) is used to simulate the strong adverse pressure gradient flow field with considering the impact of the shear force exerted by the wall of the model. The free surface is modeled with using the two-phase VOF technique [13] (Hirt, 1981).

2.3. Wave damping
To avoid reflection, at the inlet, outlet, and side boundaries of the tank the author of this paper establish the numerical wave beach. So that waves can be damped by introducing resistance to vertical motion. The method devised by Choi and Yoon [14] adds a resistance term to the equation for w-velocity:

$$S_z^d = \rho\left(f_1 + f_2 |w|\right)\frac{e^{\kappa} - 1}{e^1 - 1} w \tag{3}$$

With

$$\kappa = \left(\frac{x - x_{sd}}{x_{ed} - x_{sd}}\right)^{n_d} \tag{4}$$

In the formula , x_{sd} means the wave damping starting point ; x_{ed} means the wave damping end point; f_1, f_2, and n_d are the parameters of the damping model ; w means vertical velocity .

3. Experiment Model and Equipment

3.1. Experiment model
The experimental ship, whose port and starboard were symmetrical, was a double-propeller vessel with two V-brackets. In this paper, the numerical simulation method introduced in section 4.3 was used to calculated the wake flow fields on the condition of the specific speed . Then , the attack angle of V-bracket of case 1 was determined by the direction of wake-flow velocity vector which were calculated by the simulation. Besides, two additional V-bracket with different attack angle, named as case 2 and case 3, whose attack angles were shown in Figure 1 and Table 1 respectively, were appointed for comparative analysis.

(a)Vertical view of V-brackets

(b)Case 1   (c)Case 2   (d)Case 3
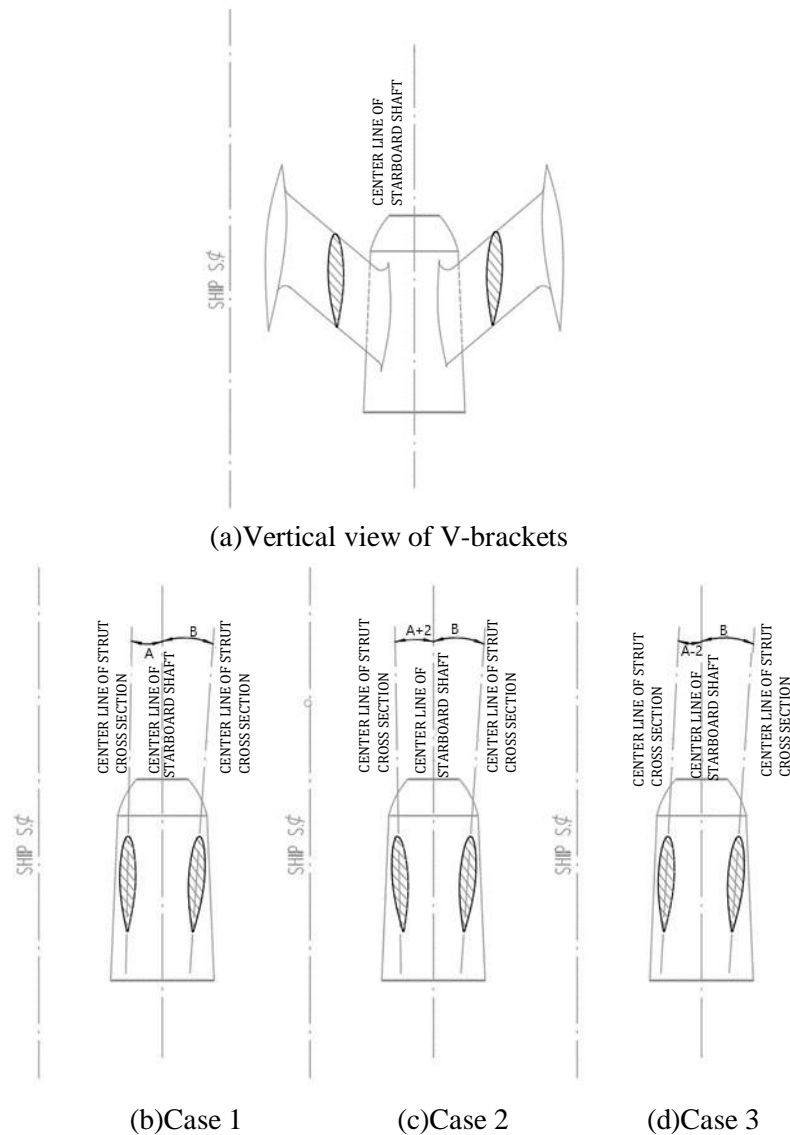
Figure 1. Different angle attack of V-bracket

Table 1. Different angle attack of V-bracket

Number of model tests	Parameters of V-brackets	
	Inner arm*	Outer arm**
Case1	A	B
Case2	A+2	B
Case3	A-2	B

*The arm closed to the central longitudinal section;
**The arm away from the central longitudinal section.

3-dimension plans of experiment models with different attack angle were drawn on the basis of lines plans, and then models shown as Figure 2, were printed by way of 3D printing technology.
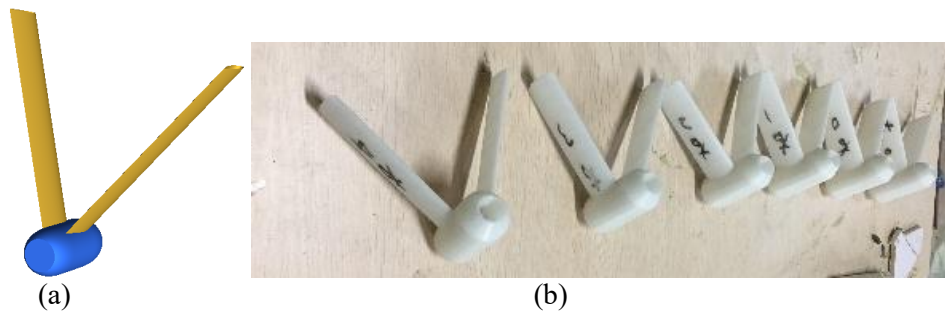
Figure 2. Experimental models of different attack angle

3.2. Experimental equipments

The model experiments were conducted in the Harbin Engineering University ship models towing-tank laboratory. The specific laboratory equipment(shown as Figure 3) were as described below:

Towing tank: it is 108 meters long , 7 meters wide, × 3.5 meters deep ;

Trailer: the maximum speed is greater than 6.5 m/s;

accuracy is about 0.1%;

maximum average acceleration= a+>0.09g;

maximum average deceleration= a->0.09g;

Type of the four DOF motion recorder is made in Japan, which name is GEL-421-1; the measurement range is about $F \leq 200$ N; the measurable heave is ±200 mm; the surging =is ±400 mm; the roll angle is $\pm50°$; the pitch angle is $\pm50°$; the accuracy is 0.1%;

Type of the data acquisition and analysis processing system: DH-5922; the range is ±20 mv~±20 v; channel number is 8; accuracy is 16 bit D/A;

Figure 3. Experiment equipments

4. Analysis and simulation of wake-flow field

The orientation and distribution of streamline around the V-bracket under the condition of the ship economic speed were determined by the means of numerical calculation.

4.1. Geometry model

Before the numerical calculation, it is necessary to establish the model of the object which is consistent with the actual situation, and the model of the flow field which is coincide with the motion status of the object. The geometric model is established using software ICEM in this calculation. The ship geometric model is shown in Figure 4.
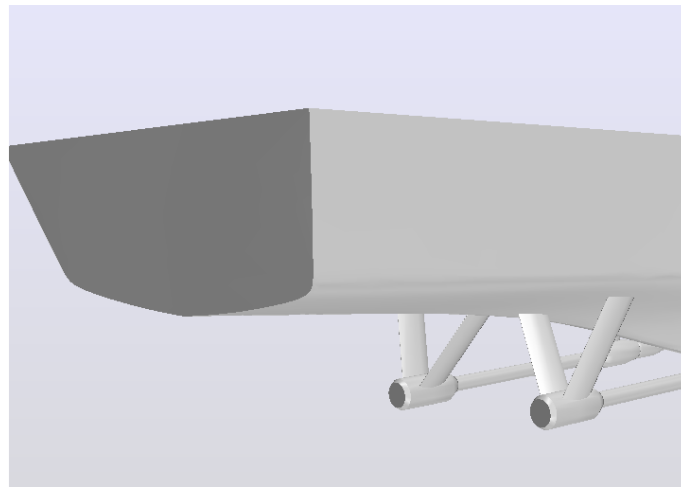
Figure 4. Geometry model

4.2. Meshing and Calculation Parameter Setting

The calculate domain was chosen as a cuboid. The length of ship is LWL, the domain is -2 LWL <X<1.0 LWL, -1.0 LWL <Y<1.0 LWL, -1.0 LWL <Z<0.5 LWL , the condition of the boundary can be list in the Figure 5. All trimmed meshes were generated by software which shown as Figure 6. Generally, the model-scale Y+ is usually recommended at 60 ,we try to keep it aroud 60,accordingly, the first layer of grids thickness should set in 0.8~1mm (see Castro A M et al). In addition, when computational grids are divided, the bow and stern of the hull where wake field varies dramatically should give more grids.

The turbulence model is SST model (see Menter 1994). Under the help of second order unwind, the governing equations can be discretized by finite volume method. VOF method and Simplec method are used to trace the free surface.and couple iteration pressure-velocity.
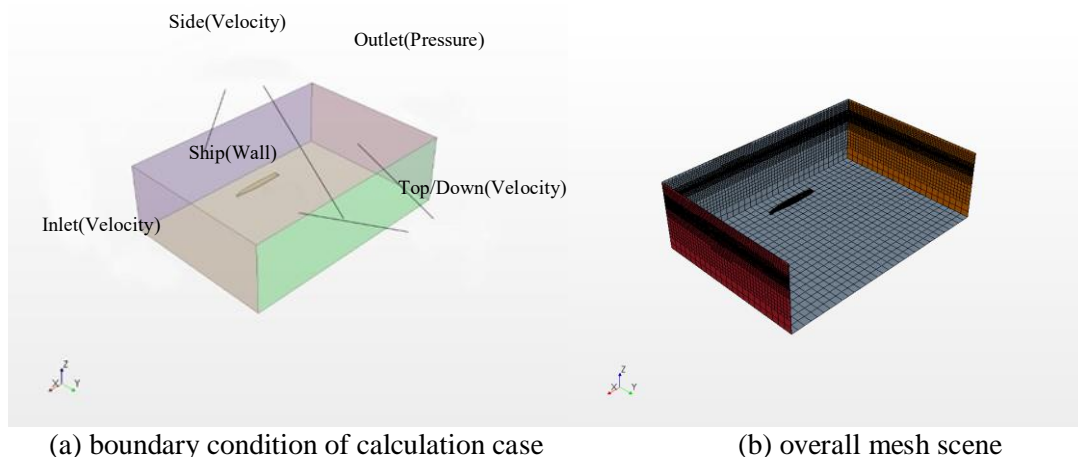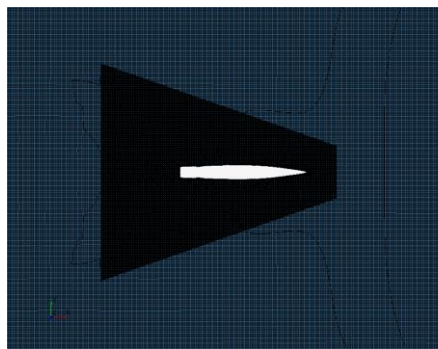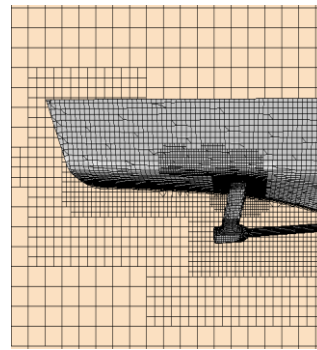

(a) boundary condition of calculation case   (b) overall mesh scene

Figure 5. Geometry model

(a) mesh scene of ship bow stern   (b) refinement mesh scene of Kelvin wave

Figure 6. Model meshing

4.3. Hydrodynamic performance analysis

The calculation results are shown in Figure 7.The result of numerical calculation shows that:

(1) The directions of streamline at the stern have the tends of turning towards to the central longitudinal section, and the distributions of the streamline are different on different cross sections.

(2) The change of the streamline angles at the position, where the V-bracket will be set, has a small range, and the deflection angle becomes bigger when the draft goes deeper. The deflection angle of inner arm is in a range of A-1°~A+1°, and B-1°~B+1° of outer arm. Figure 7. shows the distribution of the stern streamline and the change of deflection angle with draft.
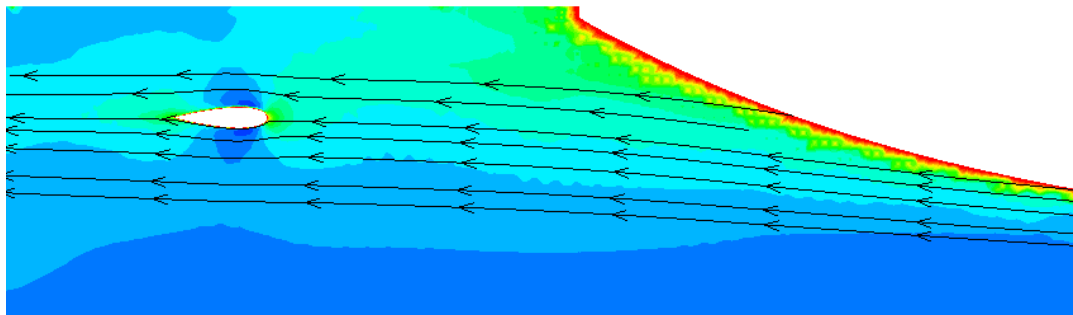
Figure 7. Streamline at the stern

5. Model Experiment

The model experiments were conducted in the Harbin Engineering University ship models towing-tank laboratory. To determine the influence of the different V-bracket to the ship resistance, the ship resistance experiments were conducted using one model ship. The schemes of experiments are shown in Table 2.

Table 2. The model tests

Number of model tests	Parameters of V-brackets	
	Inner arm	Outer arm
Without V-bracket Model	—	—
Case1	A	B
Case 2	A+2	B
Case 3	A-2	B

First of all, the stationary resistance of model ship without V-brackets at economic speed is measured, then the resistances of model ship with different V-brackets were investigated. The experimental results are shown in Table 3.

Table 3. The resistance of model ship

Number of model tests	Parameters of V-brackets		The resistance in economic speed	Percentage increase
	Inner arm	Outer arm		
Without V-bracket Model	—	—	20.45N	—
Case1	A	B	20.90N	2.2%
Case 2	A+2	B	21.08N	3.1%
Case 3	A-2	B	22.23N	8.7%

Comparing the results, which are shown in Table 3, mounting V-bracket results in a 2.2 to 8.7 percent increase of resistance ,and there are great differences in resistance increase when use different V-bracket attack angle. Obviously, using the V-bracket of case 1, in which the attack angle follows direction of flow velocity vector, the V-bracket can achieve the lowest resistance increase and highest energy saving.

6. Conclusions

Research on effect of resistance reduction was developed through methods of CFD simulation and model experiments on V-bracket, and the conclusion below are proved.

1. Verified by model experiments, the resistance of the V-bracket makes 2.2%-8.7% contributes to the total resistance on the condition of the ship economic speed.

2. The angle of streamline at the stern turns towards the central longitudinal section, and the distribution of the streamline changes with the variety of cross sections.

3. V-bracket installed along the streamline provide a better effect of resistance reduction than other attack angles.

4. In order to insure good effect of resistance reduction, the wake-flow field should be uniform because of the same attack angle of V-bracket at different drafts.

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