Numerical study of fairing installed between brackets based on CFD

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Abstract. In view of the low speed and instability of the flow between the two arms of the bracket in front of the propeller, the fairing is installed between the arms of the bracket taking example of compensating duct, in order to speed up the flow between the bracket arms and improve the flow quality. A four-propeller surface ship was studied and an integral mathematic model including hull, appendage and propellers was established. Using a RANS solver, its installation height, angle and airfoil is optimized. Then ship models with fairing and without fairing are calculated. The result shows that fairing improves propeller efficiency behind ship with 1.1% of the outer propeller and 1.6% of the inner propeller, which indicates that fairing helps improve the flow quality.

Keywords. Fairing; propeller efficiency behind ship; four-propeller ship.

1. Introduction

Due to the fact of energy dilemma and poor environment, emission reduction, energy conservation and noise reduction of ships have become the research focus of the whole world. By installing new type of appendage, the uniformity of the wake flow around the stern could be improved and a favorable interference for the propellers could be aroused. In turn, a higher propulsive efficiency could be get. The compensating duct works notably in saving energy, and it has advantages of cheap cost and simple structures. It is widely researched home and abroad.

The compensating duct is a semicircle duct installed before the propellers, which can accelerate the velocity of the flow above the propeller, improve the uniformity of the flow around the stern and the propulsive efficiency of the propellers, and avoid blade tip cavitation erosion to some extent at the same time. In 1984, Germany Pro. Schneekluth.H firstly applied the compensating duct to 74000t "LudolfOldendorff" bulk carrier and worked well. Korkut[1] installed the same type of compensating duct to different boats and conducted contrastive analysis to the effect. The scaling effect to the energy saving effect of compensating duct was researched by Friesch[2]. MARIC[3] conducted 212 resistance tests and 475 self-propulsive tests to 22 ship models which showed that the energy saving effect of compensating duct differed from 5% to 11% due to different ship square coefficients. Wenhao Qian et al.[4] studied the measuring method of appended thrust of the compensating duct. Jieya Li et al. [5-6] verified it’s saving energy and reducing vibration through experiment on compensating duct. Lijian Ou et a l. [7] applied compensating duct in double-tail boat, which showed that compensating duct...
could improve the flow quality. Shaofeng Huang et al. [8] researched the saving energy effect of compensating duct in bulk cargo ship, and proved that the hull efficiency is a reasonable indicator in assessing its saving energy effect.

In this paper, the fairing is installed between the arms of the bracket taking example of compensating duct, in order to speed up the flow between the bracket arms and improve the flow quality. A four-propeller surface ship was studied and an integral mathematic model including hull, appendage and propellers was established. The fairing installation elements were optimized aiming at improving the flow quality and then its energy saving effect was estimated.

2. Mathematic model

2.1. Governing equations

Continuity equation is the concrete pattern of manifestation of mass conservation in the fluid.

\[
\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_i}(\rho u_i) = 0
\]  

(1)

Reynolds-Average Navier-Stokes (URANS) equations are represented as follows:

\[
\frac{\partial}{\partial t} \left( \rho u_i \right) + \frac{\partial}{\partial x_j} \left( \rho u_i u_j \right) = -\frac{\partial P}{\partial x_j} + \frac{\partial}{\partial x_j} \left[ \mu \left( \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) \right] + \frac{\partial}{\partial x_j} \left( -\rho u_i u_j \right) + \rho f_i
\]  

(2)

Where \( \rho \) is the fluid density and \( P \) is the static pressure, \( f_i \) the mass force per unit mass, \( u_i \) and \( u_j \) the velocity components, \( -\rho u_i u_j \) the Reynolds stress representing turbulence effect.

Nowadays, turbulence energy equations and turbulence dissipation equations are basic method to reflect the turbulence characteristic. Added equations are needed to connect the pulse value and the time average in order to solve the increased Reynolds stress in N-S equations, which is called turbulence model. This paper adopted the SST \( k-\omega \) turbulence model, which is developed from the standard \( k-\omega \) turbulence model. This model owns high precision in the fluent simulation because it takes the advantage of the standard \( k-\omega \) turbulence model, combines the cross-diffusion from equation \( \omega \), and takes the spread of turbulent shear stress into consideration.

2.2. Model and scheme

This paper studies a displacement surface ship with bulbous bow. The model is 8.56m at length and draft is 0.303m. There are four same propellers arranged at the stern, which are installed symmetrically. The propellers have five blades and changes in skew and trim. Fig.1 and Fig.2 show that the fairing is installed between brackets.
Fig. 1. Fairing model from front view  

Fig. 2. Fairing model from front side view

Fig.3 shows the factors of the fairing. The length of the fairing, which is 0.033m, is decided by the chord length of bracket cross section. In order to confirm the installation height and angle of the fairing, nine schemes are proposed. Table.1 shows the schemes with same airfoil and different heights and angles.

| Number | Height | Angle | Length/m | Aioli     | Note                                      |
|--------|--------|-------|----------|-----------|-------------------------------------------|
| X1     | 10     | 0.033 | 65       | 1 -410    |                                           |
| X2     | 1.05D  | 15    | 0.033    | 65(1) -410|                                           |
| X3     | 20     | 0.033 | 65(1) -410|           |                                           |
| Y1     | 10     | 0.033 | 65(1) -410|           | The front fairing and the back fairing in all schemes are the same.|
| Y2     | 1.1D   | 15    | 0.033    | 65(1) -410|                                           |
| Y3     | 20     | 0.033 | 65(1) -410|           |                                           |
| Z1     | 10     | 0.033 | 65(1) -410|           |                                           |
| Z2     | 1.15D  | 15    | 0.033    | 65(1) -410|                                           |
| Z3     | 20     | 0.033 | 65(1) -410|           |                                           |

2.3. Mesh generation and boundary conditions
As the computational model is symmetrical, only starboard is considered in modeling and simulating. In order to eliminate the influence of the computational boundary on the simulated flow, the boundary of the computational flow field is set at a distance long enough away from the computational model. The inflow boundary, at a distance of one total model length upstream from the bow of the model, is
imposed with the velocity-inlet boundary condition. The outflow boundary, at a distance twice the total model length downstream from the stern of the model, is imposed with the undisturbed pressure-outlet boundary condition. The outer boundary, at a distance of one total model length from the central axes of the model, is imposed with the undisturbed velocity boundary condition. The surface of the model is set as in no-slip boundary condition.

Due to the complexity of the model and the repeatability of the schemes, a multi-block grid consisting of four blocks is used, which is showed in Fig.4. Interface is used to connect each block. Block 1 includes the front bracket and its mesh is generated by structured grid. Block 2 includes the back bracket and its mesh is generated by structured grid. Block 3 includes the deadwood immediately and its mesh is generated by unstructured grid. The hull’s mesh is generated by structured grid. The number of the mesh of block 1 and block 2 is 1.05 million, of block 3 is 4.3 million and the rest is 5.7 million. Fig.5 shows the mesh model.

![Figure 4. Blocks of the model](image)

![Figure 5. Stern mesh and fairing mesh](image)

The fluid control equation and the turbulence equation are numerically solved by the finite volume method. The convection term is discretized by a second order upwind scheme, the diffusion term is discretized by the central difference scheme, the temporal term is discretized by a second order implicit scheme, and the pressure-velocity coupling equation is solved by the PISO method. The discretized algebraic equations are solved by the Gauss-Seidel iteration method.

3. Numerical computation

3.1. Optimization of height and angle
Nominal flow at the propeller of different schemes is obtained to determine preferred fairing installation height and angle. In order to show the improvement of flow quality accurately, uneven coefficient of each scheme is presented in table.2. Uneven coefficient comparison of all schemes is presented in fig.6.
### Table 2. Uneven coefficient in different schemes

| r/R  | 0.4 | 0.6 | 0.8 | 1.0 | 0.4 | 0.6 | 0.8 | 1.0 |
|------|-----|-----|-----|-----|-----|-----|-----|-----|
| Original | 0.4202 | 0.404 | 0.3715 | 0.3253 | 0.4196 | 0.3604 | 0.3322 | 0.3386 |
| X1   | 0.4484 | 0.3987 | 0.3349 | 0.3257 | 0.4074 | 0.3421 | 0.3322 | 0.3833 |
| X2   | 0.4422 | 0.3856 | 0.3176 | 0.3166 | 0.4046 | 0.3359 | 0.3302 | 0.3672 |
| X3   | 0.4341 | 0.3645 | 0.3057 | 0.3025 | 0.3983 | 0.3252 | 0.3232 | 0.3731 |
| Y1   | 0.4415 | 0.3988 | 0.3366 | 0.3083 | 0.4083 | 0.3423 | 0.334 | 0.3538 |
| Y2   | 0.4383 | 0.3873 | 0.3187 | 0.3052 | 0.4054 | 0.338 | 0.3354 | 0.365 |
| Y3   | 0.4328 | 0.3683 | 0.3053 | 0.3014 | 0.3979 | 0.3236 | 0.3201 | 0.3593 |
| Z1   | 0.4515 | 0.4007 | 0.3348 | 0.3063 | 0.4119 | 0.3442 | 0.3331 | 0.3483 |
| Z2   | 0.4395 | 0.3914 | 0.3166 | 0.3032 | 0.4043 | 0.3367 | 0.3295 | 0.3474 |
| Z3   | 0.4379 | 0.3732 | 0.3005 | 0.3024 | 0.3841 | 0.3272 | 0.3249 | 0.3545 |

**Figure 6.** Comparison of uneven coefficient on the propeller plane

Fig. 6 shows that uneven coefficient on the outer propeller plane of each scheme is smaller than the original scheme’s at r/R<0.8, bigger at blade tip. Comprehensive comparison of uneven coefficient on the outer propeller plane at different radius figures out that uneven coefficient reduction of scheme Z2 at r/R=0.4, 0.6, 0.8 is 3.62%, 6.56%, 0.83% respectively, and at blade tip the increase is 2.59%, which is the best among all schemes. Uneven coefficient on the inner propeller plane of each scheme is smaller than the original scheme’s at all radius except at blade root. Scheme Y3’s uneven coefficient reduction at r/R=0.6, 0.8, 1.0 is 8.83%, 17.81%, 7.37% respectively and increase at r/R=0.4 is 3.00%, which is the best among all schemes.

Installation elements are obtained from above, which is showed in table 3.

### Table 3. Installation elements of fairing

|                | height | angle/° |
|----------------|--------|---------|
| Front fairing  | 1.15D  | 15      |
| Back fairing   | 1.1D   | 20      |

3.2. Optimization of airfoil

In this part, several airfoils such as NACA2410, 4412, 4415, 63(1) -410, 63(1) -412, 63(2) -615, 65(1) -206, 63-206 are researched to choose the best airfoil. Table 4 shows the uneven coefficient of each scheme on the propeller plane. Uneven coefficient comparison of all schemes is presented in fig. 7.

### Table 4. Uneven coefficient in different schemes
The inner propeller | The outer propeller
---|---|---|---|---|---|---|---|---|---|---|---|---|---
| r/R | 0.4 | 0.6 | 0.8 | 1 | 0.4 | 0.6 | 0.8 | 1 |
| Original | 0.4202 | 0.404 | 0.3715 | 0.3253 | 0.4196 | 0.3604 | 0.3322 | 0.3386 |
| 2410 | 0.4409 | 0.3674 | 0.3161 | 0.3191 | 0.4326 | 0.3882 | 0.3706 | 0.3706 |
| 4412 | 0.4482 | 0.3762 | 0.3195 | 0.3181 | 0.4324 | 0.387 | 0.3877 | 0.4194 |
| 4415 | 0.4515 | 0.3831 | 0.3216 | 0.317 | 0.4331 | 0.3832 | 0.3753 | 0.409 |
| 63(1)-410 | 0.447 | 0.3743 | 0.3184 | 0.3199 | 0.4378 | 0.391 | 0.3917 | 0.414 |
| 63(1)-412 | 0.446 | 0.3724 | 0.3161 | 0.3204 | 0.434 | 0.388 | 0.3794 | 0.3961 |
| 63(2)-615 | 0.447 | 0.3752 | 0.3183 | 0.3183 | 0.4325 | 0.3878 | 0.3866 | 0.4268 |
| 65(1)-206 | 0.4392 | 0.3601 | 0.3133 | 0.3192 | 0.4405 | 0.3955 | 0.3881 | 0.4005 |
| 63-206 | 0.4323 | 0.3542 | 0.2977 | 0.3079 | 0.4089 | 0.3384 | 0.3335 | 0.3369 |

**Figure 7.** Comparison of uneven coefficient on the propeller plane

Fig. 7 shows that uneven coefficient on the outer propeller plane of each scheme is bigger than the original’s except the scheme 63-206. Uneven coefficient on the inner propeller plane of each scheme is smaller than the original scheme’s at all radius except at blade root. Among all schemes, uneven coefficient of scheme 63-206 is the smallest. Comprehensively, airfoil NACA63-206 is the best scheme. Uneven coefficient on the outer propeller plane reduces by 2.54%, 6.08% at r/R=0.4, 0.6, while stays unchanged at r/R=0.8, 1.0. Uneven coefficient reduction on the inner propeller plane at r/R=0.6, 0.8, 1.0 is 12.33%, 19.86%, 5.36% respectively and increase at r/R=0.4 is 2.9%.

3.3. Efficiency evaluation

In this part, a multi-block grid is used including five blocks. Block 1 and block 3 cover the brackets, including 1,100,000 structured grids. Block 2 and block 4 cover the rotating area, including 500,000 unstructured grids. Block 5 covers the dead wood, including 4,300,000 unstructured grids. The rotating area includes 700,000 unstructured grids, while the other area includes 5,700,000 structured grids. Fig.8 shows the block dividing. Table5 shows the comparison of the hydrodynamic coefficient.
Figure 8. Blocks of the model

Table 5. Result comparison

| Comparison of computational result | hydrodynamic coefficient | the outer propeller | the inner propeller |
|-----------------------------------|--------------------------|---------------------|--------------------|
|                                   | Kt | 10Kq | η | Kt | 10Kq | η |
| original scheme                   | 0.1835 | 0.3898 | 0.6307 | 0.209 | 0.4423 | 0.633 |
| fairing scheme                    | 0.1807 | 0.3797 | 0.6374 | 0.2101 | 0.4377 | 0.6431 |
| increase percentage/%            |               | 1.0678 |               | 1.5946 |

We can see from above that efficiency of the outer propeller and the inner propeller increases by 1.1% and 1.6% respectively after installing the fairing, which verifies the effect of improving the stern flow.

4. Conclusion
The research above tells us the installation elements of the fairing. The length of the fairing is 0.033m and the airfoil is NACA63-206. The height of the outer fairing and the inner fairing is 1.15D and 1.1D respectively, and the angle is 15° and 20° respectively. The fairing can improve the flow around the propeller and the efficiency is improved.

However, this paper just takes the flow and the efficiency into account, neglecting the resistance which is a negative effect of installing fairing. So next work should pay more attention to the comprehensive evaluation of the fairing.

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