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Calculating Resistance of Container Ship with Specific Turning Angle using Form Factor Coefficient K

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Abstract

In stability and control of ship, knowledge about ship resistance is very important. In order to control a ship – especially when she changes the course- it is necessary to obtain the resistance value at specific turning angles. In reality, results of ship resistance obtained from doing experiments or simulations using small models have to be adjusted to get the resistance of real ships. This will be more complicated if the ship does not go straight. In this research, the authors try to solve this problem by using form factor k. All the results were obtained using a 170 m long container ship.

Keywords: Ship resistance, form factor, container ship.

1. Introduction

Considering as a highly effective means of sea transportation because of its capability of carrying larger quantity of goods within considerable cost, there is no doubt that ship transport will still play a major role in commercial transportation in the future. One of the key factors to keep the safety of a ship during the voyage is the knowledge about the stability and control of ship. In order to handle the stability and control of ship properly, the input data such as ship resistance, especially resistance at specific turning angles of ship, must be taken into account. However, it is challenging to obtain exactly the total resistance of real ship with specific turning angles. In general, theoretical methods used to calculate resistance of ship are used for the case when ship goes straight. Some commonly used theoretical methods in this case are method of P.V. Oossanen [1], method of G.V. Oortmerssen [2] and method of J.G. Hayes and L.O. Engvall [3]. Experiment to measure total resistance of the real ship can be conducted like the experiment done by C.L. Hoang, Y. Toda, Y. Sanada [4] or H. Kawashima et al. [5]. However, experimenting with a real ship faces a lot of difficulties in both time and cost. In this research, a method to calculate the total resistance of a real ship with specific turning angles is proposed. The proposed method uses form factor *k* which is calculated from total resistance of real ship and model. Total resistance of a real ship with specific turning angle can be obtained later by combining the form factor and resistance of model.

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2. Real ship resistance

2.1 Main dimensions and building model

In order to calculate ship resistance, a container ship with principle particulars shown in Table 1 below is selected.

Table 1. Principle particulars of the ship

Length over all: L_{OA}	180 m
Length between perpendicular: *Lpp*	167 m
Breadth: *B*	27.6 m
Draught: *T*	9 m
Displacement: *D*	28.071 ton
Velocity: *v*	19.4 kt

The 3D-model is built up by using Autoship software. The process of making a model is carried out by following these steps:

- Select a suitable line plane
- Import sections from Autocad into Autoship
- Create and edit surface
- Calculate displacement using Model maker and Autohydro (Modul maker and Autohydro are two modules in Autoship software)
- Compare displacement and refine the surface.

The 3D-model is shown in Figure 1.

2.2 Real ship resistance

Total resistance of ship is calculated using Autopower (a module in Autoship software). The Draught is set at 9m and the velocity of ship is in the range from 15 kt to 23 kt. Figure 2 shows the calculated resistance result vs speed.

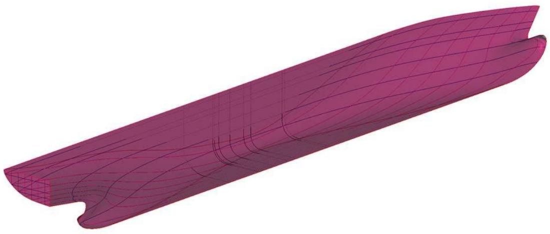


Fig. 1. Ship hull

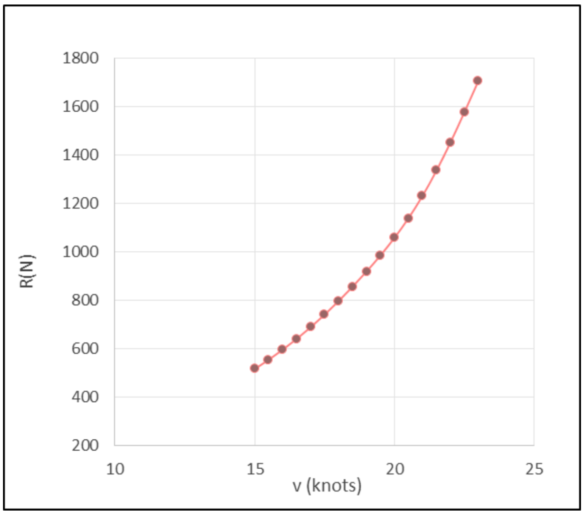


Fig. 2. Resistance vs. speed

Table 2. Resistance of real ship by using Autopower

Resistance of real ship (Autopower)	
V (Kt)	R (KN)
18.00	797.26
18.50	856.66
19.00	919.25
19.50	985.74
20.00	1058.05
20.50	1138.85

The service speed is 19.4 kt. From Table 2, it is easy to obtain resistance of real ship at 19.4 kt by a simple interpolation. The total resistance at service speed is 975.1 KN.

2.3 Verifying the results

In order to verify the results which was calculated by using Autopower, the real ship resistance was recalculated using Holtrop-Mennen method [6]. In this method, the total resistance can be subdivided as in equation (1):

$$R = R_F(1+k) + R_{APP} + R_W + R_B + R_{TR} + R_A \qquad (1)$$

Where:

R_F: frictional resistance

R_{APP}: resistance of appendages

R_W: wave making and wave breaking resistance

R_B: additional pressure resistance of bulbous bow near the water surface

R_{TR}: additional pressure resistance of immersed transom stern

R_A: model-ship correlation resistance

$1+k$: form factor describing the viscous resistance of the hull form in relation to R_F

The calculation process is done according to the instructions of Holtrop and Mennen. The principle particulars of the investigated ship were previously shown in Table 1. Service speed is 19.4 kt. The result of real ship resistance is shown in Table 3. Here, additional pressure resistance of immersed transom stern R_{TR}=0 because the draught is below the lowest point of transom. On the other hand, the transom area, in this case, is equal to 0. As shown in Table 3, the total resistance of the real ship is 927.91 KN. This result is a little bit lower than the total result calculated using Autopower (975.1 KN). However, the difference between the two results is acceptable (about 4.8%). It can be said that these two results agree quite well with each other. So, the total resistance calculated by using Autopower is reliable and will be used for further calculation to find the form factor k in section 4 of this paper.

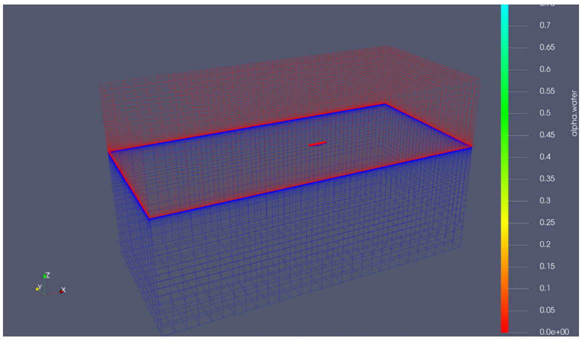
Table 3. Resistance of real ship by using Holtrop-Mennen method

Resistance of real ship (Holtrop-Mennen)	
R_F	430.13 (KN)
R_{APP}	8.12 (KN)
R_W	169.75 (KN)
R_B	110.98 (KN)
R_{TR}	0 (KN)
R_A	118.29 (KN)
R	927.91 (KN)

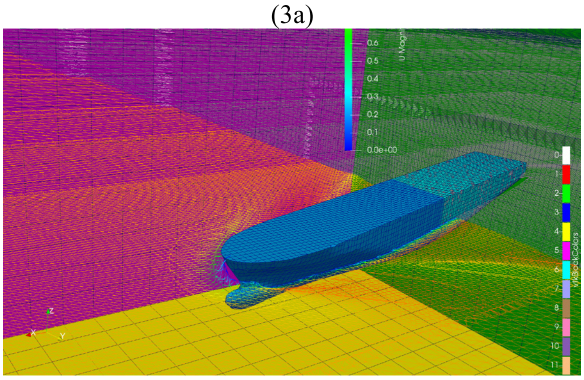
3. Resistance of container ship model

3.1 Dimension of model and meshing

Figure 3a and 3b show the model and the domain which were used for simulation. The model was scale with the ratio 1/100 (Length, Breadth and Draught). The Length overall, Breadth and Draught of the model are 1.8 m, 0.276m and 0.09m, respectively. The velocity of the model was calculated from the Froude similarity. After calculation, the velocity of the model is 1m/s. The simulation was carried out by using the open-source interDyMFoam two phase solver of OpenFOAM. The interDyMFoam solver uses the volume of Fluid Algorithm to calculate the free surface between liquid phase and air phase. The interDyMFoam has been verified by many publishes such as P.V Sang [7], D. Q. Vu [8], V. Q. Do et al. [9]. Meshing was carried out in snappyHexMesh. The domain size is 28.7m long, 20.6m wide and 16.7 m high. The total number of cells is 3,842,300. Computation time for one case is about 480 minutes



(3a)



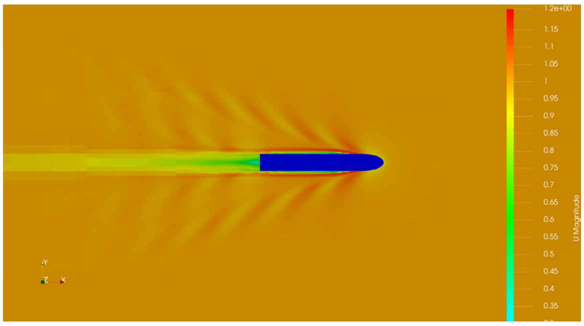
(3b)

Fig. 3. Hull mesh

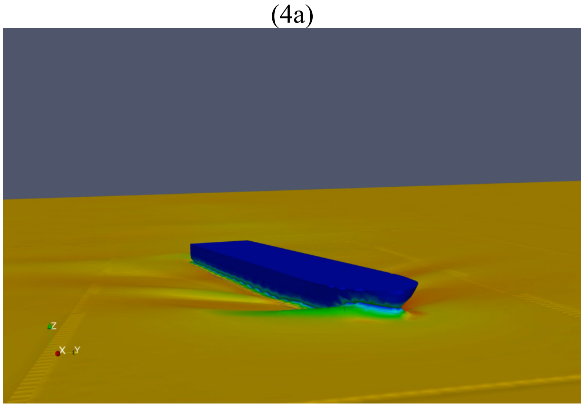
3.2 Simulation results

As mentioned earlier, the velocity of model is 1m/s, and turning angles of the ship are 0º, 5° and 10°. Figures 4a, 4b and 4c show the distribution of pressure around the ship hull with the view from the top, the side and the bow of the model, respectively.

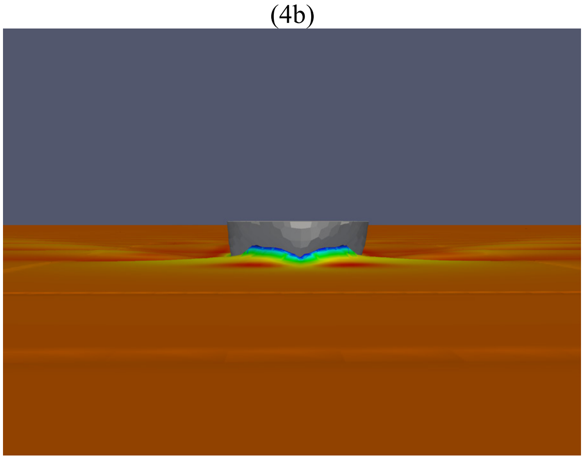
Table 4 shows the total resistance of the model with specific turning angles. As shown in the table, when the ship goes straight, the total resistance is 1.76N. The values of total resistance increased significantly when the ship changes the course. The total resistance of the model reached 2.24 N and 4.4N as the ship turns 5° and 10°, respectively.



(4a)



(4b)



(4c)

Fig. 4. Pressure distribution around the ship hull

4. Resistance of real ship with specific turning angles prediction

4.1 Calculating form factor

The purpose of this research is to propose a method to predict the total resistance of a real ship with specific turning angles. In order to get the total resistance of the model with specific turning angles, researchers can do simulation like the results shown in table 4. Researchers can also do experiments to obtain total resistance for this case. However, for a real ship, it is very complicated to perform the same action as for the model. Issues include the complexity of techniques, the high expense, and time-consuming experiments. In this research, a method to determine total resistance of ship with specific turning angles is proposed. Form factor *k* plays very important role in calculation process.

Table 4. Resistance of model

Resistance results of the model (Rm)	
Turning angles	Value
0 degree	1.76 N
5 degrees	2.24 N
10 degrees	4.4 N

The total resistance coefficient of real ship can be calculated according to the instructions of the International Towing Tank Conference (ITTC) [10].

$$C_{TS} = (1+k)C_{FS} + C_R + \Delta C_F + C_{AA} \qquad (2)$$

where:

k: form factor

C_{FS}: frictional coefficient of the ship. C_{FS} can be obtained by using ITTC1957 formula [11]

$$C_F = \frac{0.075}{(\lg \mathrm{Re} - 2)^2} \qquad (3)$$

Re: Reynolds number

C_R: residual resistance coefficient

ΔC_F: roughness allowance. ΔC_F can be obtained by using equation (4)

$$\Delta C_F = \left[105\left(\frac{ks}{L_{wl}}\right)^{\frac{1}{3}} - 0.64\right]10^{-3} \qquad (4)$$

The roughness k_S can be taken as 150.10^{-6} m.

L_{wl} is the length of water line at draught

C_{AA}: air resistance coefficient. The value of C_{AA} can be obtained by using equation (5)

$$C_{AA} = 0.001\frac{A_T}{S} \qquad (5)$$

where:

A_T is transverse projected area of ship above the water line and S is wetted surface

C_R is calculated from the total and frictional coefficients of the model.

The real ship resistance can be predicted with the assumption that residual resistance coefficient and form factor are the same for real ship and model.

Table 5. Calculation of form factor *k*

Calculation of form factor	
C_{TS}	0.0033
C_{FS}	0.00147
C_{Tm}	0.006
C_{Fm}	0.0044
ΔC_F	0.00037
C_{AA}	0.00712
k	0.294

Table 5 shows the result of form factor *k* which is obtained from equation (2). The subscript s and m represent for real ship and model, respectively. As shown in the table, the form factor *k* is 0.294.

4.2 Real ship resistance prediction

The value of form factor will be used to calculate the total resistance of real ship with the assumption that form factor *k* is kept the same for both model and real ship. Total resistance of ship is obtained after getting total resistance coefficient which is shown in equation (2) by simple relationship between total resistance and total resistance coefficient. Predicted results of total resistance of real ship can be seen in table 6.

Table 6. Total resistance of real ship

Angle (degree)	0	5	10
R_m (N)	1.756	2.244	4.400
R_S (KN)	975	1,462	3,617

5. Conclusion

In this research, a method to calculate the total resistance of real ship with specific turning angle using form factor *k* is proposed. The predicted method can be used with an assumption that residual resistance coefficient and form factor for real ship and for the model are the same. With these assumptions, total resistance of real ship can be obtained from simulation results of model.

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