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Experimental Research on Resistance Performance of Gliding-Hydrofoil Craft with a T-Formed Hydrofoil and Shallow V-Shaped Bottom

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Summary

An 11.8m-long gliding-hydrofoil craft with a T-formed hydrofoil and shallow V-shaped bottom is chosen to carry on in this work. Resistance test in towering tank is the main method. Two different installation angle (-1.5° and 0°) of hydrofoil are conducted and the tests were done separately. Relevant results of different resistance performance have been got under the influence of different hydrofoil installation angle.

keywords: hydrofoil, resistance performance, experimental research

Introduction

A new type of hydrofoil craft has been developed with one hydrofoil fixed in the front and one sliding face (V-shaped bottom), which is considered as the combineation of hydrofoil craft and planing craft – gliding-hydrofoil craft[1]. The resistance of this type of craft is 5%∼15% less than that of planing crafts with similar main dimensions in same velocity. 60% of the vessel weight will be lifted by the hydrofoil in the front of the craft and the rest will be mainly afforded by the gliding surface in the service speed (>28kn).

Analysis on main dimensions of the 11.8m-long hydrofoil planing craft and calculation of hydrofoil geometry characteristics

Analysis on main dimensions

Based on the main dimensions of the 5.8m-long hydrofoil craft (with one hydrofoil in the front), the main dimensions are as follows, L_{wl}=5.8m, B=1.6m, d=0.325m, $\Delta = 19.2t$, the 11.8m craft is analyzed.

The design method similar to traditional hydrofoil is adopted, including the first and the second approximate calculation method[2] In fact only the first approximate calculation method is needed as we aim to get the main dimensions of the craft.

As the craft will be designed to take passengers, the area of the cabin is the main factors, which is determined by the following formula:

$$S_c = ksn \qquad (2.1)$$

Where, k-constringency coefficient, k =1.3;
n - the total amount of passengers, n =60;

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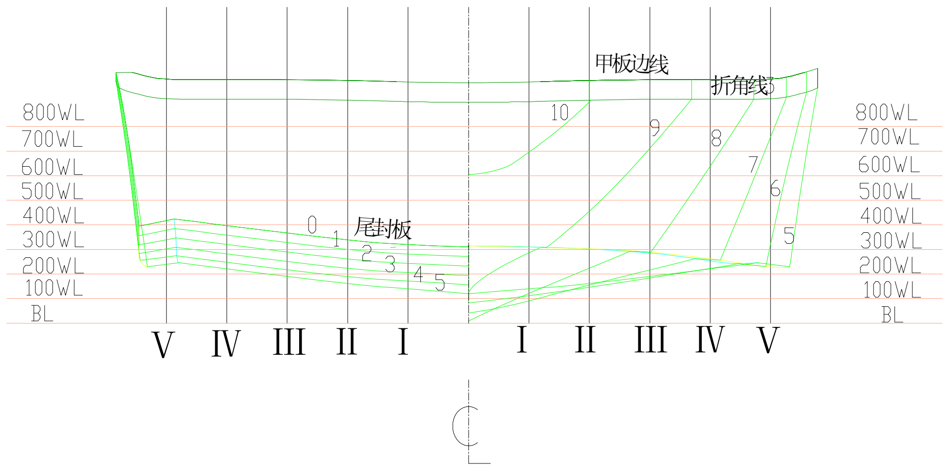

Figure 2.1: Model frame line plan

s - each essential area that passenger should occupy, we choose the average amount of hydrofoil craft, 0.652m^2/person.

According to the 5.8m-long hydrofoil planing craft, main dimensions of the 11.8m-long hydrofoil craft are as follows(Fig 2-1):

$$B = 3.2m, \quad d = 0.5m, \quad L_{wl} = 11.8m, \quad \Delta = 11.46t.$$

Calculation of the hydrofoil geometry characteristics

The hydrofoil of this craft is T-formed foil. The chord length b is calculated first. The aspect ratio of hydrofoil λ is calculated by formula 2.2.

$$\lambda = \frac{300}{V_s}(1 \pm 0.4) \tag{2.2}$$

Service speed $\lambda = 7 \sim 16$. λ is the aspect ratio of hydrofoil, the service speed should be V_s.

$$b = \frac{l}{\lambda}, \quad b = 642 \sim 1686mm \tag{2.3}$$

When the velocity is not high (50~90km/h), load of hydrofoil D can be calculated by formula 2.4.

$$D/S = A'\rho V^2 \tag{2.4}$$

$D/S = 2t/m^2$[2], when the speed is 55km/h. S is the projection area in the horizontal direction of hydrofoil. 60% of the weight is lifted by the hydrofoil fixed in the front, so $D = 8.2t$.

$$S = 5.88m^2 \tag{2.5}$$

$$Z = \frac{\rho V^2}{2} C_Z S \tag{2.6}$$

Z is the lifting force on the hydrofoil. C_Z is the lift coefficient.

$$C_z = \frac{k_\varphi \frac{\partial C_z}{\partial \alpha} (\alpha + \alpha_0 - \Delta\alpha_0)}{1 + \frac{\partial C_z}{\partial \alpha} \bullet \frac{k_\varphi}{\pi\lambda} (1+\tau)\,\xi \left(\frac{\bar{h}}{\lambda}\right)} \tag{2.7}$$

$$\frac{\partial C_z}{\partial \alpha} = 5.5, \alpha_0 = 1.74\bar{f} \tag{2.8}$$

$\alpha_0$is the 0-lift angle.

$$\Delta\alpha_0 = \frac{\bar{c}}{2}\left(\frac{1}{k_\varphi} - 1\right) \tag{2.9}$$

$\Delta\alpha_0$ is the value which occurs as the result of free surface[3].

The Grout number is influenced by the form of hydrofoil (formula 2.10).

$$\begin{aligned} \tau\left(\frac{\bar{h}}{\lambda}\right) &= 0.85 + \frac{0.16}{\sqrt{\bar{h}/\lambda}} \\ \bar{h} &= \frac{640}{500} = 1.28 \\ \bar{c} &= 0.06 \\ k_\varphi &= 0.952 \\ \alpha &= \frac{1.5}{180} \times 3.14 = 0.0262, \Delta\alpha_0 = 0.0015 \\ b &= 0.06,\ \text{then}\ Z = 9.2t \end{aligned} \tag{2.10}$$

The experiment and analysis

Testing procedure

Summary

Two experiments are carried on with two installation angles of the hydrofoil (-1.5°, 0°). The resistance and trimming angle are recorded separately and analyzed together[4].

The experiment was carried on in the towering tank in our university ($100m \times 6m \times 2m$).

Choices of the velocity of the garage

The scale between the model and real ship is 1:10. Follow the formula $Fr_{\Delta m} = Fr_{\Delta s}$ and the service speed of real ship has been taken into account[8]. The velocity of the garage is chosen as follows:

At the point $Vs = 50$km/h (service speed), $Vs = 55$km/h and the maximum speed of the garage;

At the point $Fr = 0.3$ and $Fr = 0.5$;

Between the points Fr =0.3 and Fr =0.5, three points of velocity are picked up.

Finally ten points of velocity are chosen:

0.6, 1.3, 2.1, 2.7, 3.7, 4.1, 4.4, 4.6, 4.8; the unit is the m/s.

Resistance test in calm water

Several problems occurred in the test.

(1)Water overflowed inside the model; (2) Water splash was serious; (3) Much water swarmed into the model when it stopped; (4) Navigation pole collided with the navigate shelves when the velocity increased to a certain value.

Planks have been added on the deck so that the first two problems were solved. The model was lifted when it stopped (problem 3). New navigate shelves were designed and produced (problem 4). Resistance test continued until the data was recorded correctly.

The trimming angle and resistance

Here the trimming angle and resistance are shown in Fig.3-1∼3-4 and Table 3-1. The x-axis is the velocity, m/s. The y-axis is the trimming angle, °.

Table 3.1: Resistance at different velocity

velocity of the model (m/s)	velocity of the real ship (km/h)	f1(N) -1.5° installation angle	f2(N) -0° installation angle
0.6	6.83	0.2	0.53
1.3	14.80	2.87	7.84
2.1	23.90	8.11	13.71
2.7	30.73	9.3	11.36
3.7	42.12	13.78	15.2
4.1	46.67	14.66	16.22
4.4	50.09	13.32	16.76
4.6	52.36	19.63	23.17
4.8	54.64	18.06	17.78

The x-axis is the velocity, m/s. The y-axis is the resistance, g.

Analysis

(1) As the velocity increases, the trimming angle rises to its maximum value. For

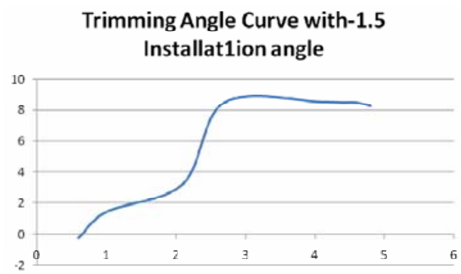

Figure 3.1: Trimming angle curve at -1.5° installation angle

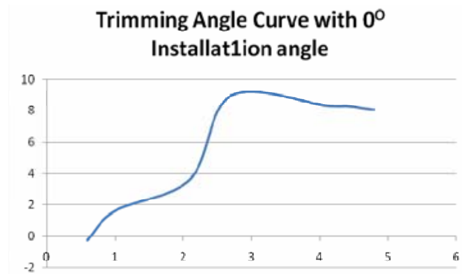

Figure 3.2: Trimming angle curve at 0° installation angle

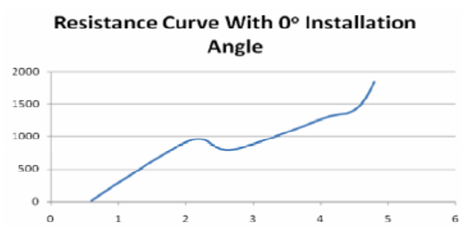

Figure 3.3: Resistance curve at 0° installation angle

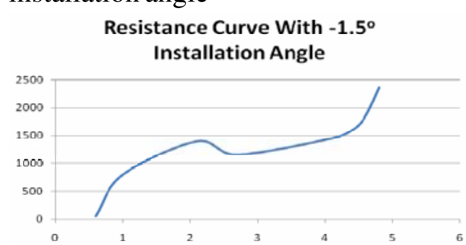

Figure 3.4: Resistance curve at -1.5° installation angle

the -1.5° installation angle of hydrofoil the maximum angle is 8.531°, and the 0° installation angle, 8.923°. If the velocity continues increasing, the trimming angle decreases to less than 1°.

The lift of hydrofoil in the front of the craft increases as the velocity gets faster[10]. So the trimming angle increases until a certain velocity, when the lift grows less than the force on the shallow V-shaped gliding surface. Then the trimming angle decreases.

(2) The resistance increases as the velocity increases until a certain minimum point (the valley point of the curve).

Analysis of rapidity

Calculations of the wetted area

Analysis of the rapidity is the main analysis of the efficiency power for the real ship. The recommended methods (by ITTC) are adopted. The coefficients of resistance should be calculated by following steps:

1. Measure the trimming angle;
2. Find the length of wetted lines at different frame;

3. Calculate the wetted area using integral methods.

4. Calculate the coefficients of resistance ;

5. Calculate effective power of the real ship.

The trimming angle is measured by note the sea gauge fore and aft.

The length of wetted lines are measured on the model frame line plan after the points of intersection (the waterline with different framelines) have been found. Then the wetted area is calculated using integral methods.

Efficiency power of real ship

Methods recommend by ITTC are used in the calculations of efficiency power of real ship. Here the curves of power are given directly for the complete calculations are too large to write in this paper.

The x-axis is the velocity of real ship, *kn*. The y-axis is the efficiency power, *kw*.

Curve of Navy coefficient

Navy coefficient (*Cm*, Fig. 4-3 ∼ Fig. 4-4) shows the rapidity of crafts. The greater its value is the higher speed to get while for applying the same power. To high speed craft, the navy coefficient formula is as follows[11]:

$$C_m = \frac{\Delta V^2}{P_E/\eta} \tag{4.11}$$

P_E is the efficiency power under different installation angles of hydrofoil. η is the efficiency of propulsion systems.

The x-axis is the velocity of real ship, *kn*. The y-axis is the Navy coefficient.

Conclusions

(1) The resistance of the model is increasing at the beginning with the increase of the speed under different installation angle of hydrofoil (-1.5° , 0^o) in the experiment till up to a certain maximum point. Then the resistance decreases to a certain minimum point and continues increasing after clicking through the point.

(2) The trimming angle increases as the velocity increases till up to a maximum point and then decreases back to a certain angle f the velocity continues increasing.

(3) The bigger installation angles of hydrofoil are, the bigger maximum of the trimming angles are and the earlier the maximum trimming angles appear.

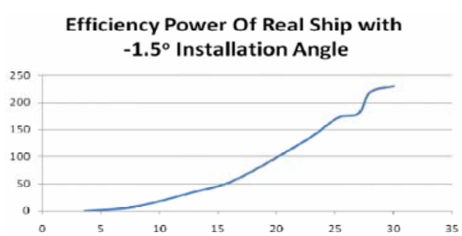

Figure 4.1: Efficiency power of real ship with -1.5° installation angle of hydrofoil

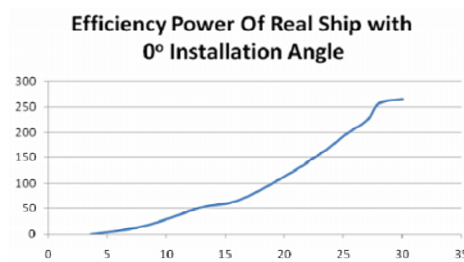

Figure 4.2: Efficiency power of real ship with 0° installation angle of hydrofoil

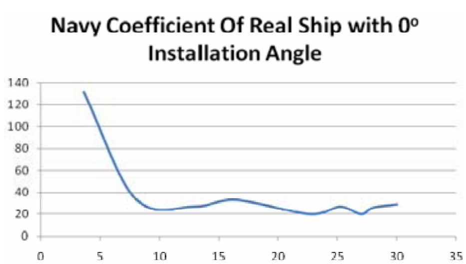

Figure 4.3: Navy coefficient of real ship with 0° installation angle of hydrofoil

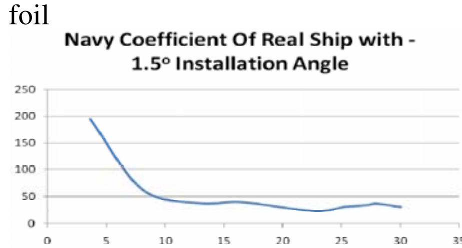

Figure 4.4: Navy coefficient of real ship with -1.5° installation angle of hydrofoil

(4) The navy coefficient changes little as the velocity rises to a certain point, which means the rapidity will not change

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