Effect of bevel angle of three-layer parallel plate on hydrodynamic performances of otter-board

Lei WANG, Lu Min WANG, Yu ZHANG, Ai Zhong ZHOU, Yong Li LIU, Wen Wen YU, Xun ZHANG^a

Key Laboratory of Oceanic and Polar Fisheries, Ministry of Agriculture; East China Sea Fisheries Research Institute, Chinese Academy of Fishery Sciences, Shanghai 200090, China

Abstract. The effect of bevel angle of three-layer parallel plate of otter-board on hydrodynamic performances is investigated by model wind tunnel test. Four otter-board models are designed with four different bevel angles (8° , 10° , 12° and 14°), and tested under the wind speed 28 m/s in wind tunnel. Model experiment is conducted to obtain the drag coefficients C_x , the lift coefficient C_y , the pitch moment coefficient C_m , the center of pressure coefficient C_p and calculated the lift-drag ratio C_y/C_x . The result shows that the maximum lift coefficient and the maximum lift-drag ratio of the otter-board model with a bevel angle 12 degree is higher, there is 2.598 ($\alpha=65^\circ$) and 2.607 ($\alpha=37.5^\circ$); For comparison in stability of otter-board, the stability of the otter-board model with the bevel angle 8 degree is better by the comparative analysis of C_m and C_p , the absolute value of C_m is 0.174 and the minimum variation coefficient of C_p is 4.37%. The results can offer reference for the structural optimization design of trawl otter-board.

1 Introduction

Trawl doors is an important member of fishing gear for spread of trawl. The merits of otter-board hydrodynamic performance can be measured by the lift coefficient of the trawl door, the drag coefficient of the trawl door and pitching moment coefficient of the trawl door [1]. By optimizing the structure of otter-board may improve hydrodynamic performance of the otter-board, and reducing the energy consumption of fishing vessels [2-3]. Currently, extensive studies on otter-board hydrodynamic performance had been conducted in the US, Japan, Norway and other countries [4-9]; In China, researchers have studied the relevant hydrodynamic performance of otter-board early since 1980s, and the series of optimization studies on otter-board structure is still necessary [10-15]. With the development of offshore fishing, higher requirements on the otter-board design is put forward, hydrodynamic performance improvement of otter-board will be the focus of future research. This article is part of the series of tests, which analyze the hydrodynamic performance of otter-board with the bevel angle of three-layer parallel plate changing.

2 2 Material and Methods

2.1 Design and manufacture of otter-board model

Test model of otter-board with three parallel plates is designed in different bevel angle of the three parallel plates.

Ensuring the premise of other parameters in common, the design of model structure has been simplified based on the test objectives and requirements, while, only the bevel angle of three parallel plates changes. The structure and parameters of the model are illustrated in figure 1.

Figure 1 Structure and parameters of otter-board

Note: L : chord; b : span; e : distance between fulcrum and front end of model; A, B, C: parallel plate; γ : bevel angle; β : angle of front plate; d_1 : horizontal distance between A and B; d_2 : horizontal distance between B and C; d_3 : projected length of C.

For four otter-board test models, the aspect ratio is fixed at 1.0, model's area is 0.250m², the corresponding distance between plate A-B-C and each projected length of plate C are same, when the bevel angle of three parallel plates changes four angle (8, 10, 12 and 14), the curvature of the plate C is 12%, the specific parameters in table 1, four otter-board models are numbered 1, 2, 3, 4 respectively. Models are made of steel with painted

^a Corresponding author: zhangxun007@hotmail.com

surfaces (figure 2).

Table 1 Introductions for dimension and structure parameters of four otter-board models

No.	L/m	b/m	λ	S/m^2	e/m	$d_1=d_2/m$	d_3/m	$\gamma=\beta$	δ
1	0.50	0.50	1.0	0.250	0.25	0.15	0.20	8°	0.12
2	0.50	0.50	1.0	0.250	0.25	0.15	0.20	10°	0.12
3	0.50	0.50	1.0	0.250	0.25	0.15	0.20	12°	0.12
4	0.50	0.50	1.0	0.250	0.25	0.15	0.20	14°	0.12

Note: b : span; L : chord; $\lambda = b/L$, aspect ratio; $S = L \cdot b$; e : distance between fulcrum and front end of model; d_1 : horizontal distance between A and B; d_2 : horizontal distance between B and

C; d_3 : projected length of C; γ : bevel angle; β : angle of plate C; δ : curvature of plate C.

Figure 2 Four otter-board models and top view of design

Note: A, B, C: parallel plate.

2.2 Test facility

Wind tunnel for this test is Nanjing University of Aeronautics and Astronautics NH-2 wind tunnel, the tunnel is closed reflux wind tunnel with double string test section, this experiment is carried out in a small test section, the main technical performance of the small test section: 6 m (length) $\times$ 3 m (width) $\times$ 2.5 m (height), import cross-sectional area 7.18 m², the maximum wind speed is 90m / s, the minimum steady wind speed is 5 m / s.

The dynamometer test uses six-component mechanical tower - Balances to measure, test model installation is shown in figure 3.

Test data acquisition and processing system used is made up by the pre-amplifier and four networked computer system.

Figure 3 Installation instruction of otter-board model in wind tunnel

Note: 1.otter-board model 2.model connection 3.six-component force balance

2.3 Test method

2.3.1 Parameter definition of test model

Test models need to be installed on the wind tunnel in

six-component balance mechanical base according to the order, angle of attack of model rotates by the 0° -70° when the wind speed reaches 28m / s (room temperature 20 °C),wherein the angle of attack in the range 0° -50°, 2.5° intervals to record a measurement data point, after the attack angle 50°, each measurement interval of 5° to record data points, there are 25 sets of data totally, including the drag coefficient C_x , the lift coefficient C_y , the pitch moment coefficient C_m and the center of pressure coefficient C_p .

The relevant parameters of models in the wind tunnel test section are defined as shown in figure 4. In figure 4, O is torque reference point, which is the punch of the model at the bottom. During the test, the resistance of the model is provided by the force of balance along the X-axis direction, the lift is provided by the force of balance along the Y-axis direction, and the pitch moment is provided by the M_y of balance along the Z-axis direction.

Figure 4 Parameter definition diagram of test model in wind tunnel

For this test, Wind speed $V=28m/s$, when the Reynolds number $Re=VL/\nu=0.93 \times 10^6$ (coefficient of viscosity $\nu=15 \times 10^6 m^2 \cdot s^{-1}$) [10].

2.3.2 Parameter definition of test measurement

Three components: lift Y , drag X , pitching moment M (around the fulcrum), while the distance from the center of pressure to the front-end otter-board $d=e-(M/N)$ [12], (N is the normal force).

Lift coefficient $C_y = \frac{Y}{\rho V^2 S/2}$ [3]; drag coefficient $C_x = \frac{X}{\rho V^2 S/2}$; pitch moment coefficient $C_m = \frac{M}{\rho V^2 SL/2}$; center of pressure coefficient $C_p = \frac{d}{L}$.

Air density $\rho=1.225 \text{ kg/m}^3$ in above formula; S is otter-board area (m^2); L is the otter-board chord length (m).

All the experimental data have been carried out the stent disturbance correction which is completed by the method of taking out light pole directly.

3 Results and Discussion

3.1 Drag coefficient and lift coefficient

Data from the experiment includes the drag coefficient C_x , the lift coefficient C_y , the pitch moment coefficient C_m and the center of pressure coefficient C_p . C_y / C_x is the lift-drag ratio, which is an important factor to determine the merits of otter-board hydrodynamic performance. Otter-board with excellent hydrodynamic properties will get higher lift-drag ratio and better stability, what can be analyzed by comparing the pitching moment coefficient C_m stencil and the center of pressure coefficient C_p [1-3]. The test data is divided and made $C_x-\alpha$, $C_y-\alpha$ and $C_y / C_x-\alpha$ graph shown in figure 5 for analyzing the differences of hydrodynamic properties of four otter-board models clearly.

Figure 5 The changing curve comparison of $C_x(a)$, $C_y(b)$ and $C_y/C_x(c)$ along with the angle of attack α

In figure 5, graph $C_x-\alpha$ and $C_y-\alpha$ show the variation curve of drag coefficient C_x and lift coefficient of four models while the angle of attack α changed. The relationship between C_x and α is proportional, No.1 otter-board model with the bevel angle of 8° has the higher drag coefficient. The maximum lift coefficient C_y of No. 3 model is higher, there is 2.598 ($\alpha=65^\circ$), and the maximum lift coefficient of No. 1 and No. 2 otter-board model are 2.583 ($\alpha=60^\circ$) and 2.527 ($\alpha=65^\circ$), the maximum lift coefficient C_y of No. 4 model is the lowest, there is 2.519 ($\alpha=65^\circ$).

3.2 Lift-drag ratio

The lift-drag ratio can be more intuitive to analysis the hydrodynamic performance of otter-board, and the otter-board with higher lift-drag ratio gets the better operational efficiency. In figure 5, the curve $C_y / C_x-\alpha$ indicates that the

lift-drag ratio C_y / C_x of No. 1 otter-board model with the bevel angle of 8° is higher at the angle of attack $\alpha < 27.5^\circ$, and the maximum lift-drag ratio is 2.411 ($\alpha=37.5^\circ$), the maximum lift-drag ratio of No. 2 and No. 4 model is 2.564 ($\alpha=37.5^\circ$) and 2.555 ($\alpha=40^\circ$), respectively; however, the maximum lift-drag ratio C_y / C_x of No. 3 otter-board model with the bevel angle of 12° is higher than the other three models, there is 2.607 ($\alpha=37.5^\circ$).

3.3 Stability of otter-board

Pitching moment, also known as longitudinal moment, what is the component along the horizontal axis of the moment of force that is generated by the aerodynamic acting on the otter-board to the center of gravity of model, and the pitching moment coefficient C_m is usually converted for analysis and comparison instead. Pitching moment can be divided into upper and lower pitching

moment, what are usually distinguished by positive and negative, its absolute value represents the level of pitching moment, and the pitching moment coefficient tending to 0 represents the more excellent stability of otter-board generally, in practice, comparing the absolute value C_m corresponding to the operation angle of attack of otter-board may determine the stability level of otter-board. For comparison, it is assumed to select the angle of attack corresponding to the maximum lift-drag ratio C_y/C_x [16], when the absolute value of C_m corresponded is shown in table 2. The absolute value of C_m of No.1 model is 0.174, so the stability of No.1 otter-board model is better.

Table 2 Parameters of four otter-board for stability analysis

No.	Angle corresponding to the maximum lift – drag ratio α	$ C_m $	Variable coefficient of C_p
1	37.5°	0.174	4.37%
2	37.5°	0.194	4.70%
3	37.5°	0.183	5.17%
4	40°	0.191	4.99%

The stability of otter-board can be measured by the center of pressure coefficient C_p , and it is generally compared by analyzing the coefficient of variation of C_p within the range of angle around 5 ° of the angle of attack corresponding to the maximum lift-drag ratio, the smaller the coefficient, the better the stencil stability [17]. Data Calculated is shown in table 2, the minimum variation coefficient of C_p is 4.37%, and it also means the stability of No.1 otter-board model is better.

4 Conclusion

The test study concludes that designing the bevel angle of otter-board plates appropriately can improve the lift coefficient of the otter-board. When the bevel angel of three parallel plates of otter-board is designed in 8°or 12°, the otter-board has the higher maximum lift coefficient. It is also needed to pay attention to adjust the lift -drag ratio and stability of the otter-board, test shows that the maximum lift-drag ratio of otter-board model with the bevel angle of 12°is higher than the other three models, and the stability of the otter-board model with the bevel angle of 8°is better. Data and conclusions of this study can provide a reference for the design of otter-board.

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