

Effect of deflector curvature on hydrodynamic performances of a double-slotted cambered otter-board

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Abstract. The effect of deflector curvature on hydrodynamic performances of a double-slotted cambered otter-board was investigated using engineering models in a wind tunnel. Four different curvature (0.06, 0.09, 0.12 and 0.15) were evaluated at a wind speed of 28 m/s. Parameters measured included: drag coefficient C_x , lift coefficient C_y , pitch moment coefficient C_m , center of pressure coefficient C_p , over a range of angle of attack (0° to 70°). These coefficients were used in analyzing the differences in the performance among the four otter-board models. Results showed that the maximum lift coefficient C_y of the otter-board model with the curvature (0.06) of two deflectors was highest (2.020 at $\alpha=55^\circ$). The maximum C_y/C_x of the otter-board with the curvature (0.12) of two deflectors was highest (3.655 at $\alpha=22.5^\circ$). A comparative analysis of C_m and C_p showed that the stability of otter-board model with the curvature (0.12) of two deflectors is better in pitch, and the stability of otter-board model with the curvature (0.06) of two deflectors is better in roll. The findings of this study can offer useful reference data for the structural optimization of otter-boards for trawling.

1 Introduction

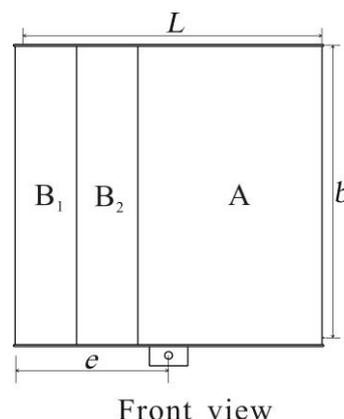
Otter-boards are an important part of fishing gear for spreading the trawl mouth. The merits of the hydrodynamic performance of otter-boards can be measured on the basis of the lift coefficient of the otter-board, the drag coefficient of the otter-board, and the pitching moment coefficient of the otter-board [1]. Optimizing the structure of otter-boards may improve the hydrodynamic performance of the otter-board [2-3]. Extensive studies on the hydrodynamic performance of otter-boards have been conducted in the United States, Japan, Norway, and other countries [4-8]. In China, researchers have studied the relevant hydrodynamic performance of otter-boards since the early 1980s, including the hydrodynamic performance and optimization of different otter-boards with various structure types [9-13]. Improvements in the hydrodynamic performance of otter-boards has become a major research interest as the development of offshore trawler fleets increasing globally in recent decades. Some studies have shown that the slit in otter-boards can reduce the resistance and improve the stability of otter-boards [14-19]. The following study investigates the importance of the curvature of the deflector within the otter-board. We describe an experiment using otter-board models ($n=4$ designs) in a wind tunnel in which we measured various hydrodynamic coefficients for a range of angles of attack. The results are relevant as a

reference for the study of the structural parameters of the deflector curvature of otter-boards.

2 Material and Methods

2.1 Design and manufacture of otter-board model

The otter-boards evaluated in this study were double-slotted curved structures comprising two deflectors and a main-panel (figure 1). This structure design was based on the used bottom trawl otter-board currently, and was simplified in order to meet objectives and requirements of the study. Only the curvature of two deflectors was modified.



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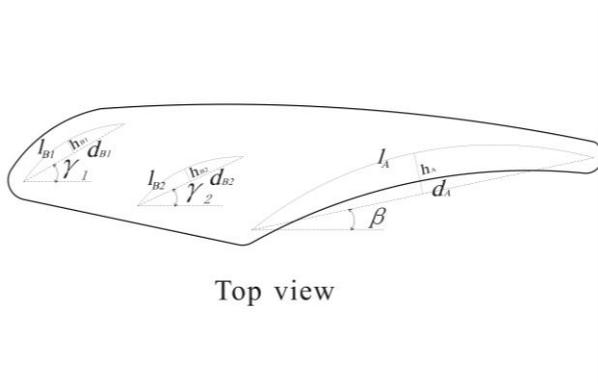


Fig. 1. Structure and parameters of otter-board

Note: L : chord; b : span; e : distance between fulcrum and the front end of model; B_1, B_2 : deflector; A : main-panel; γ_1, γ_2 : angle of deflector; β : angle of main-panel; l_{B1}, l_{B2} : arc length of deflector; l_A : arc length of main-panel; h_{B1}, h_{B2}, h_A : distance from the vertex of the arc to the arc chord; d_{B1}, d_{B2}, d_A : length of arc chord.

Each of models had an aspect ratio of 1.0, surface area of 0.25 m², and were identical in many structural parameters and dimensions (table 1). The curvature of the main-panel was 12% and was consistent in all models. The only parameter that varied between the models was the curvature of two deflectors (δ_{B1}, δ_{B2}). The models are made of steel with painted surfaces (figure 2).

Table 1. Descriptive characteristics of the four model otter boards evaluated in this study.

No.	1	2	3	4
L/m	0.5	0.5	0.5	0.5
b/m	0.5	0.5	0.5	0.5
λ	1	1	1	1
S/m^2	0.25	0.25	0.25	0.25
e/m	0.25	0.25	0.25	0.25
γ_1	30°	30°	30°	30°
γ_2	25°	25°	25°	25°
β	6°	6°	6°	6°
l_{B1}	0.127	0.127	0.127	0.127
l_{B2}	0.12	0.12	0.12	0.12
l_A	0.313	0.313	0.313	0.313
δ_{B1}	0.06	0.09	0.12	0.15
δ_{B2}	0.06	0.09	0.12	0.15
δ_A	0.12	0.12	0.12	0.12

Note: L : chord; b : span; λ (b/L): aspect ratio; S ($L \cdot b$): surface area; e : distance between fulcrum and the front end of model; γ_1, γ_2 : angle of deflector; β : angle of main-panel; l_{B1}, l_{B2} : arc length of deflector; l_A : arc length of main-panel; δ_{B1} (h_{B1}/d_{B1}), δ_{B2} (h_{B2}/d_{B2}): curvature of deflector; δ_A (h_A/d_A): curvature of main-panel.

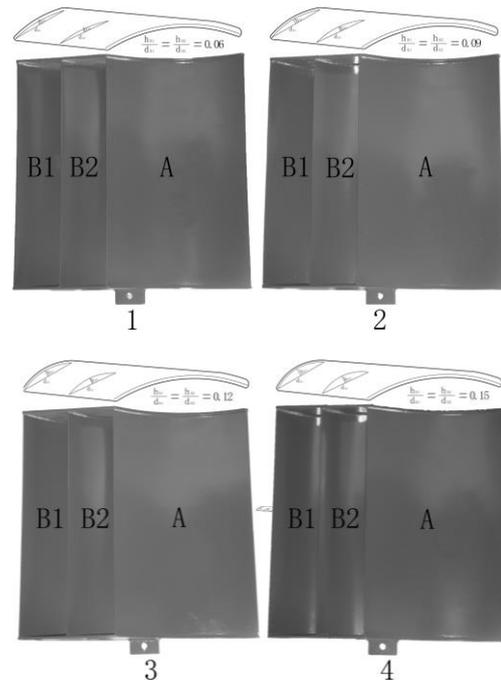


Fig. 2. Four otter-board models evaluated in this study.
 Note: A: main-panel; B_1, B_2 : deflector.

2.2 Test facility

The wind tunnel used for this experiment was the NH-2 wind tunnel located at Nanjing University of Aeronautics and Astronautics, China. The tunnel is a closed reflux wind tunnel with a double-string test section. The experiment was conducted in a small test section. Dimensions of the test section were 6 m (length) \times 3 m (width) \times 2.5 m (height). The cross-sectional area was 7.18 m². The minimum and maximum wind speeds of the tunnel were 5 m/s and 90 m/s, respectively. Figure 3 illustrates the experimental setup inside the wind tunnel. The otter-board models were attached to a dynamometer comprising a six-component mechanical tower-balance to measure forces in all directions. The data acquisition and processing system used is composed of a pre-amplifier and a four-networked computer system.

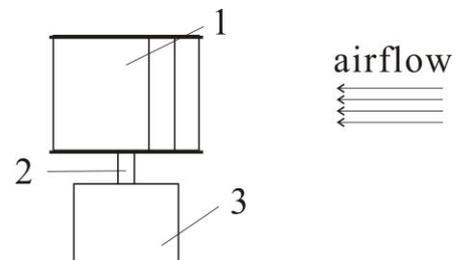


Fig. 3. Installation instruction of otter-board model in wind tunnel.

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 model 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 $0^\circ - 70^\circ$ when the wind speed reaches 28 m/s (room temperature 20°C), wherein the angle of attack in the range $0^\circ - 50^\circ$, 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 Z-axis direction, and the pitch moment is provided by the M_y of balance along the Z-axis direction.

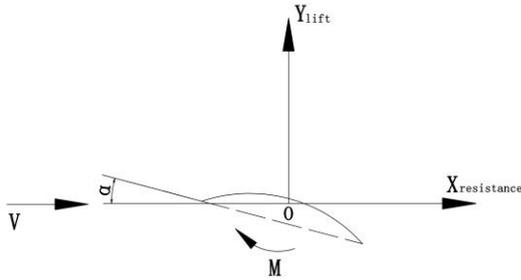


Fig. 4. Parameter definition diagram of test model in wind tunnel.

For this test, Wind speed $V=28\text{m/s}$, when the Reynolds number $R_e=VL/v=0.93\times 10^6$ (coefficient of viscosity $v=15\times 10^6\text{ m}^2\cdot\text{s}^{-1}$) [14].

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 $d=e\cdot(M/N)$ [16], (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 included 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 lift-drag ratio was computed (C_y / C_x), which is an important factor for determining the merits of the hydrodynamic performance of otter-boards. An otter-board with excellent hydrodynamic properties can achieve higher lift-drag ratio and improved stability; such performance can be analyzed by comparing the pitching moment coefficient C_m stencil and the center of pressure coefficient C_p . The test data were divided into groups, yielding $C_x-\alpha$, $C_y-\alpha$ and $C_y / C_x-\alpha$ graphs shown in figure 5. These graphs are used for analyzing the differences in the hydrodynamic properties of the four otter-board models.

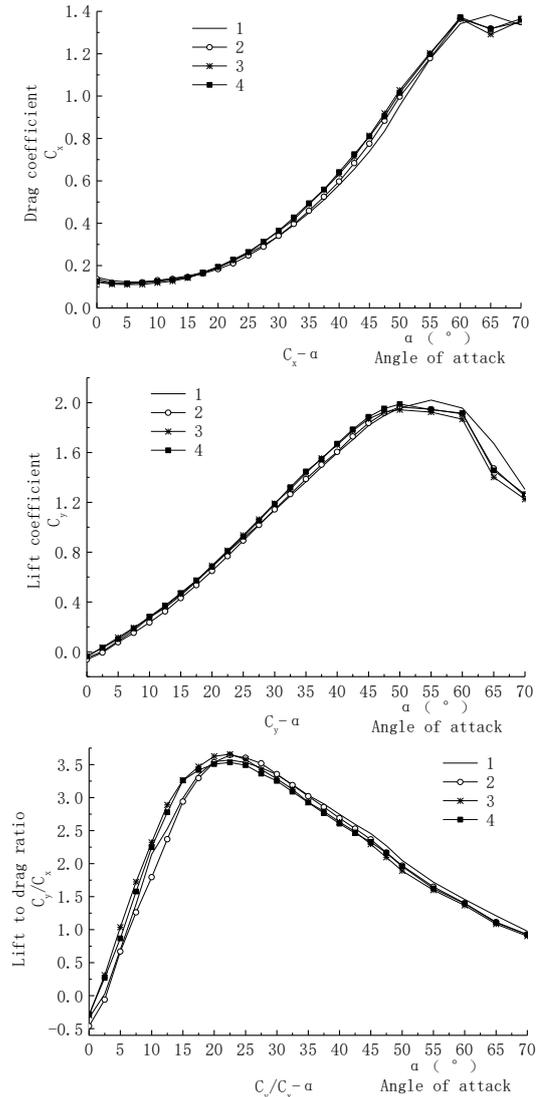


Fig. 5. Hydrodynamic properties of four otter-board models across a range of angle of attack.

In figure 5, $C_x-\alpha$ and $C_y-\alpha$ graphs show the variation curve of the drag and lift coefficient of the four models while the angle of attack α changes. The maximum lift coefficients C_y of No. 1, No. 2, No. 3, and No. 4 otter-board models were 2.020 ($\alpha = 55^\circ$), 1.965 ($\alpha = 50^\circ$), 1.942 ($\alpha = 50^\circ$), and 1.988 ($\alpha = 50^\circ$), respectively. It shows that the maximum lift coefficient of No.1 model with the deflector curvature 0.06 is largest.

3.2 Lift-drag ratio

In figure 5, the maximum lift–drag ratios of No.3 model with the deflector curvature 0.12, there is 3.655 ($\alpha = 22.5^\circ$). The maximum lift–drag ratios of No. 1, No. 2 and No. 4 models are 3.571 ($\alpha = 22.5^\circ$), 3.644 ($\alpha = 22.5^\circ$) and 3.534 ($\alpha = 22.5^\circ$), respectively. The higher or lower curvature of deflectors may result in a lower maximum lift–drag ratio.

3.3 Stability of otter-board

Pitching moment can be divided into upper and lower pitching moments, which are usually distinguished by positive and negative values, Positive means the otter-board tilts backward, and negative means tilts forward. 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. 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, the angle of attack corresponding to the maximum lift–drag ratio C_y/C_x is selected [20]. The corresponding absolute value of C_m is shown in table 2. The absolute value of C_m of No. 3 model is 0.144, so hence, the stability of No. 3 otter-board model is better in pitch.

Table 2. Parameters of four otter-board models for stability analysis.

No.	Angle corresponding to the maximum lift–drag ratio α	$ C_m $	Variable coefficient of C_p
1	22.5°	0.183	6.83%
2	22.5°	0.163	7.85%
3	22.5°	0.144	8.13%
4	22.5°	0.160	7.81%

The stability in roll of otter-board can be measured according to the center of pressure coefficient C_p ; and the way of comparison is analyzing the coefficient of variation in C_p within the range of angle approximately 5° of the angle of attack corresponding to the maximum lift–drag ratio; a smaller coefficient results in the improved stability [21]. The calculated data are shown in table 2. The minimum variation coefficient of C_p is 6.83%; this value also means that the stability of No. 1 otter-board model is better in roll of otter-board.

4 Conclusion

Test analysis shows that the curvature of two deflectors has a point for equilibrating the hydrodynamic performances of otter-board. No.3 otter-board with the deflector curvature of 0.12 has the higher maximum lift–drag ratio at the angle of attack 22.5° , and at this angle of attack, the lift coefficient (0.813) is also higher than the

other three models. In the meanwhile, the stability of No.3 otter-board model in pitch is also better comparatively, and the stability of No.1 otter-board model in roll is better. The data and conclusions of this study can provide a reference for the design of otter-board.

Acknowledgements

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