Study of board bending degree on hydrodynamic performances of a single-layer cambered otter-board

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Abstract. The effect of board bending degree on hydrodynamic performances of a single-layer cambered otter-board was investigated using engineering models in a wind tunnel. Three different bending degree boards 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 three otter-board models. Results showed that the bending of the board(No. 2, No. 3) increased the water resistance of the otter-board, and improved the lift coefficient of the otter-board in the small angle of attack (0°< α ≤20 °) ; the maximum lift coefficients C_y of otter-board model (No. 1) was higher (1.680, α = 25°). the maximum lift - drag ratios of models (No. 1, No. 2 and No. 3) are 6.822 (α = 7.5 °), 6.533 (α = 2.5 °) and 6.384 (α = 5.0°), which showed that the board bending reduces the lift-to-drag ratio of the otter-board.The stability of the No. 3 model was better than those two models (No. 1, No. 2) in most range of attack angle, but No. 1 otter-board model had a better stability in roll of otter-board. The findings of this study can offer useful reference data for the structural optimization of otter-boards for trawling.

1 Introduction

The merits of the hydrodynamic performance of otter-board what is the important part of fishing gear for spreading the trawl mouth can be measured on the basis of the lift coefficient of the otter-board, the drag coefficient of the otter-board, the pitching moment coefficient, and the center of pressure coefficient of the otter-board [1]. Optimizing the structure of otter-boards may improve the hydrodynamic performance of the otter-board [2-13]. 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. The following study investigates the importance of the board bending degree within the otter-board. We describe an experiment using otter-board models (n=3 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 board bending degree of otter-boards.

2 Material and Methods

2.1 Design and manufacture of otter-board model

The otter-boards evaluated in this study were single-layer curved structures with differrent board bending degree (figure 1), which was achieved by a folded joint of several boards. This structure design was simplified in order to meet objectives and requirements of the study.

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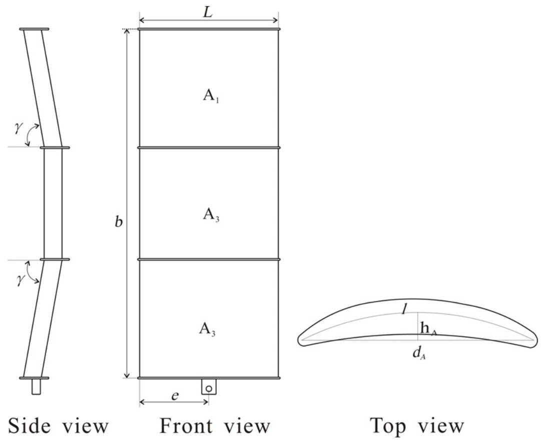

Fig. 1. Structure and parameters of otter-board

Note: L: chord; b: span; e: distance between fulcrum and the front end of model; $A_{1\text{-}n}$: main-panel; γ: bending angle of board; l: arc length of main-panel; h_A: distance from the vertex of the arc to the arc chord; d_A: length of arc chord.

Each of models had an aspect ratio of 2.5, and were identical in many structural parameters and dimensions (table 1). The curvature of the main-panel was 0.12(δ_A) and was consistent in all models. The parameters that varied between the models was the number of boards($A_{1\text{-}n}$) and the bending angle between boards. The models were made of steel with painted surfaces (figure 2).

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

No.	**1**	**2**	**3**
***L*/m**	0.249	0.258	0.258
***b*/m**	0.628	0.637	0.643
λ	2.5	2.5	2.5
***S*/m²**	0.156	0.164	0.166
***e*/m**	0.140	0.129	0.129
γ	-	80°	80°
l	0.260	0.260	0.260
δ_A	0.12	0.12	0.12

Note: *L*: chord; *b*: span; *λ* (*b/L*): aspect ratio; *S* (*L·b*): surface area; *e*: distance between fulcrum and the front end of model; *γ*: bending angle of board; *l*: arc length of main-panel; δ_A(h_A/ d_A) : curvature of main-panel.

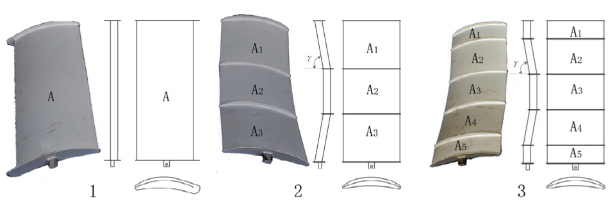

Fig. 2. Three otter-board models evaluated in this study.

Note: $A_{1\text{-}n}$: main-panel; *γ*: bending angle of board

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) × 3 m (width) × 2.5 m (height). The cross-sectional area was 7.18 m^2. 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 compromising 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.

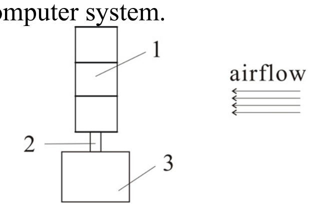

Fig. 3. Installation instruction of otter-board model in wind tunnel.

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 ° -70 ° when the wind speed reaches 28m / s (room temperature 20 ℃), 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 Z-axis direction, and the pitch moment is provided by the M_y of balance along the Z-axis direction.

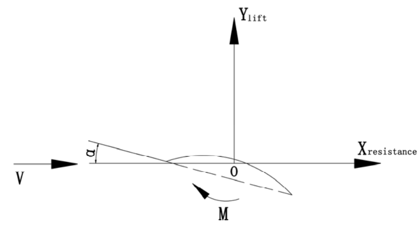

Fig. 4. Parameter definition diagram of test model in wind tunnel.

For this test, Wind speed *V*=28m/s, when the Reynolds number $R_e=VL/\upsilon=0.93\times10^6$ (coefficient of viscosity $\upsilon=15\times10^6$ m^2·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-(M/N)* [15], (*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 ρ=1.225 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 and the center of pressure coefficient C_p. The test data were divided into groups, yielding C_x-α, and C_y-α graphs shown in figure 5. These graphs are used for analyzing the differences in the hydrodynamic properties of the three otter-board models.

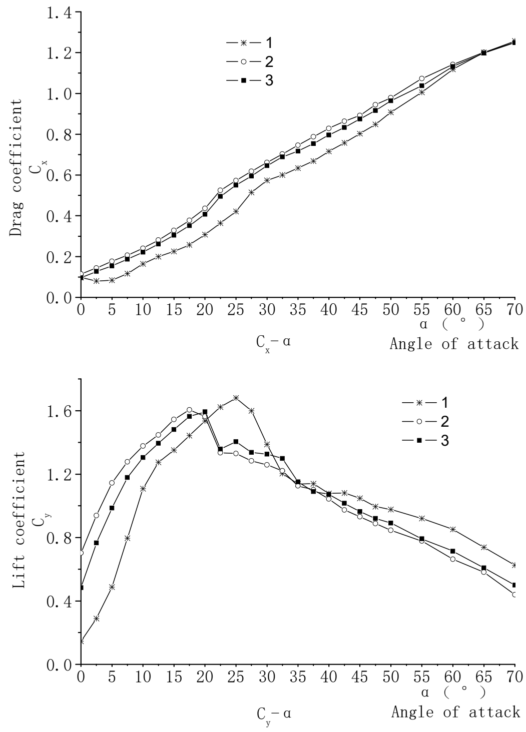

Fig. 5. Drag coefficient and lift coefficient of three otter-board models across a range of angle of attack.

In figure 5, C_x-α and C_y-α graphs show the variation curve of the drag and lift coefficient of the three models while the angle of attack α changes. Compared to a non-angular otter-board(No. 1), the bending of the board(No. 2, No. 3) increases the water resistance of the otter-board. However, in the small angle of attack (0° <α≤ 20 °), the board bending can increase the lift coefficient of the otter-board. The maximum lift coefficients C_y of No. 1 otter-board model is higher (1.680, α = 25°).

3.2 Lift-drag ratio

In figure 6, the maximum lift–drag ratios of No. 1, No. 2 and No. 3 models are 6.822 (α = 7.5 °), 6.533 (α = 2.5 °) and 6.384 (α = 5.0°), respectively. It can be seen that the board bending reduces the lift-to-drag ratio of the otter-board, although it has a relatively high lift-to-drag ratio in the small angle of attack.

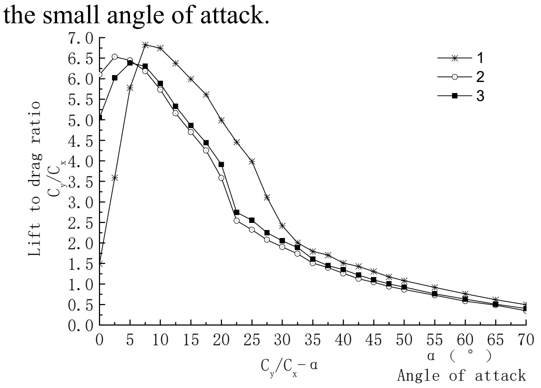

Fig. 6. Lift-drag ratio of three otter-board models across a range of angle of attack.

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 C_m tending to 0 represents the more excellent stability of otter-board.

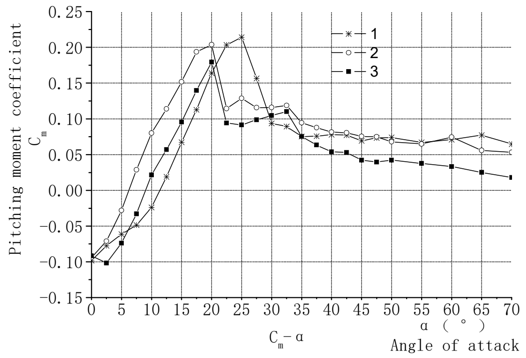

Fig. 7. Pitching moment coefficient of three otter-board models across a range of angle of attack.

With the change of the angle of attack, the C_m of the three models are different. As figure 7 illustrated, the stability of the No. 3 model is better than that of the No. 2 model (10° ≤α<70°), and the best in the 3 models (35° ≤α<70°).

Table 2. Parameters of three otter-board models for C_p analysis.

No.	Angle corresponding to the maximum lift –drag ratio α	Variable coefficient of C_p
1	7.5°	8.3%
2	2.5°	9.5%
3	5.0°	9.0%

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 [16-17]. The calculated data are shown in table 2. The minimum variation coefficient of C_p is 8.3%; 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 board bending degree has a point for equilibrating the hydrodynamic performances of otter-board. No.2 and No.3 otter-boards with the bending board have the higher lift coefficient at the angle of attack (0° <α≤ 20 °), and No. 1 otter-board model has the higher maximum lift coefficients (1.680, α = 25°). Stability analyzing by the data of C_m and C_p, the board bending will improve the pichting stability of the otter-board during certain attack angle, 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.

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