Hydrodynamic characteristics of the oval cambered double slotted otter board in bottom trawl fisheries

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Abstract. The otter board is one of the main components of single boat trawl fisheries. An oval cambered double slotted otter board was developed for improving the expansion performance of trawl net in bottom trawl fisheries. A flume model experiment was conducted to measure the lift coefficient ($C_L$), drag coefficient ($C_D$), and lift to drag ratio ($K$) in different angles of attack ($\alpha$). The experimental results are as follows: (1) The $C_L$ and $K$ value show a trend of increasing at the beginning and then decreasing with the increase of angle of attack, the $C_D$ value reflects an upward trend as the angle of attack increases; (2) The D3 otter board (front flow deflector angle at 29°) showed a better hydrodynamic performance. When $\alpha$=30°, the max lift coefficient ($C_{L_{max}}$) was 1.464, in this case $C_{D}=0.554$ and $K=2.643$. When $\alpha=15°$, the max lift to drag ratio ($K_{max}$) was 4.165; $C_{L}=0.633$, and $C_{D}=0.152$. This suggests that the best working scope for the angle of attack is between 15°~30°, in which case, $C_{L}>0.633$ and $K>2.643$. The mean value of the lift coefficient was 1.071 and the mean of the lift to drag ratio was 3.482. Comparative analysis of the hydrodynamic performance of different types of otter boards showed that the D3 otter board both had good expansion performance and efficiency, which can provide a reference basis for further optimization of the bottom trawl otter board.

1. Introduction

Globally, single boat trawling is responsible for nearly 40% of marine fishing [1]. The main equipment used in single trawl fishing vessels is the otter board, and its hydrodynamic performance is an important factor in the efficiency of catching and fishing [1-5]. The otter board both accelerates the settlement of the trawl net and increases the horizontal expansion of the trawl net [2, 3]. The otter board used in distant fishing boat has various structural styles, including vertical cambered, vertical cambered slotted, and vertical cambered V type [2, 3]. The V type otter board and oval cambered otter board are mostly used in near shore single boat trawl fisheries [2, 6]. The hydrodynamic force on the otter board decomposes into the expansion force and water resistance. The expansion force is perpendicular to the flow velocity, which has the effect of increasing the trawl net sweeping area. Water resistance is parallel to the flow of water. The ratio of the expansion force and water resistance is an important parameter for measuring the expansion efficiency of the otter board. The
The hydrodynamic performance of otter board has been studied through two methods: model testing or numerical simulation [6-10]. The model test in a circulating water tank closely approximates the actual working conditions of trawl fishing [5]. Japanese scholars have analyzed the hydrodynamic performance of otter board through the flume model experiment [11-14]. Chinese scholars have focused on analysis of the hydrodynamic performance of the otter board in wind tunnels [1, 15-17], and in recent years have used the flume model experiment [18-21]. Developed countries have sought to improve the hydrodynamic performance of the otter board. Currently, the maximum efficiency of an oval cambered single slotted otter board is 1.25, with a lift coefficient of 0.93, and a drag coefficient of 0.74 [3]. To improve the expansion performance of trawl nets in bottom trawl fisheries, an oval cambered double slotted otter board model experiment is carried out and the effect of the change of the basic parameters (flap angle) on the hydrodynamic performance is studied. The analysis of the hydrodynamic performance of different types of otter boards can provide a reference point for further optimizing the bottom trawl otter board.

2. Materials and methods

2.1. Experimental instruments
The model test was conducted in a circulating water tank at the East China Sea Fisheries Research Institute. The scale of the flume experiment was 180 cm × 50 cm × 50 cm, with a maximum flow rate of 2.5 m·s⁻¹. The experimental device is shown in figure 1. The experimental model was installed in the middle portion of the flume experiment, which connected with the three-component force sensor through the connecting rod. The three-component force sensor fixed on a rotary table used for the machine tool. The model’s angle of attack could be changed by adjusting the rotary table. The measuring instrument was a three-component force sensor LSM-B-500NSA1-P made by Kyowa Co., Ltd., Japan. The measuring range was 500 N. Data was derived from the computer.

![Figure 1. Schematic diagram of circulating water tank with test model.](image)

2.2. Experimental models
Three series models were produced using the different front flow deflector angles of oval cambered double slotted otter boards, as shown in table 1. The model scale was 1:20 and the wall thickness was 3 mm (figure 2). The top of the experimental model was connected with a support through a M4 threaded hole. The screen model is made of photosensitive resin composite material. The process parameters were as follows, model precision: ±0.1 mm, detail resolution: 0.4 mm, minimum wall thickness: 1 mm, print layer thickness: 0.1 mm. The model used a method of stereo light curing (3D print technology) derived from a computerized model, which has the advantage of high strength and
resistance to deformation. Compared with the traditional method (manufacturing from stainless steel), the 3D print model has the advantages of high precision, a short manufacturing cycle, low cost, and suitability for highly complex modeling. It also has the advantages of higher accuracy and better surface finish than the fused deposition modeling method.

![Experimental otter board (a) and diagram of its cross section (b).](image)

Figure 2. Experimental otter board (a) and diagram of its cross section (b).

| No. | Front flow deflector angle β | Parameters | Chord length b (cm) | Aspect ratio λ | Flow area (m²) |
|-----|------------------------------|------------|---------------------|---------------|---------------|
| D1  | 23°                          | Middle flow deflector | 26                | 0.8           | 0.048         |
| D2  | 26°                          | angle 26°; Back flow |                    |               |               |
| D3  | 29°                          | deflector angle 11° |                    |               |               |

### 2.3. Experimental conditions

The factors and levels are shown in Table 2. The interval is 2.5° between 15°～40°, and 5° between 0°～15° and 40°～60°. The experimental flow velocity range is 0.6～1.0 m·s⁻¹ with an interval of 0.1 m·s⁻¹.

| Factor                          | Level |
|--------------------------------|-------|
| Angle of attack α              | 0°, 5°, 10°, 15°, 17.5°, 20°, 22.5°, 25°, 27.5°, 30°, 32.5°, 35°, 37.5°, 40°, 50° |
| Flow velocity (m·s⁻¹)          | 0.6, 0.7, 0.8, 0.9, 1.0 |

### 2.4. Data processing

The aspect ratio (λ) is defined as the ratio of the span length l and chord length b. The results of the resistance \( F_x \) and \( F_y \) were recorded using a three-component balance. The drag coefficient \( C_D \), lift coefficient \( C_L \) and lift to drag ratio \( K \) were calculated after pole interference correction. The calculation equations follow:

\[
C_D = \frac{F_x}{0.5 \rho V^2 S} \tag{1}
\]

\[
C_L = \frac{F_y}{0.5 \rho V^2 S} \tag{2}
\]
\[ K = \frac{C_L}{C_D} \]  \hspace{1cm} (3) \\
\[ Re = \frac{Vb}{\nu} \]  \hspace{1cm} (4)

In the equations, \( \rho \) stands for fluid density; \( V \) stands for flow velocity (m·s\(^{-1}\)); \( S \) stands for area (m\(^2\)); \( Re \) stands for Reynolds number; \( \nu \) stands for fluid kinematic viscosity (m\(^2\)·s\(^{-1}\)); \( b \) stands for the characteristic length, which is seen as the chord length.

In the experiment, when the flow velocity is higher than a specific value, the lift coefficient (or the drag coefficient) remained unchanged, which is considered to be an automatic model area. The lift coefficient (or the drag coefficient) under a different angle of attack is defined as the average value in the automatic model area. The lift coefficient and drag coefficient discussed in this study are both the average value in the automatic model area.

3. Results and analysis

3.1. Automatic model area

As shown in figures 3-5, when the Reynolds number is higher than \( 2.08 \times 10^5 \), the lift coefficient or the drag coefficient value remain stable. We considered the lift coefficient (or the drag coefficient) in an automatic model area. The average value of the lift coefficient at the Reynolds number between \( 2.08 \times 10^5 \sim 2.60 \times 10^5 \) was considered to be the lift coefficient for this angle of attack.

![Figure 3](image_url)

Figure 3. The relationship between lift coefficient, drag coefficient, and Reynolds number of the D1 model.
Figure 4. The relationship between lift coefficient, drag coefficient, and Reynolds number of the D2 model.

Figure 5. The relationship between lift coefficient, drag coefficient, and Reynolds number of the D3 model.

3.2. Hydrodynamic performance
The results of the lift coefficient, drag coefficient, and lift drag ratio under different angles of attack are shown in figure 6. The results of hydrodynamic performance of the otter board, show that the $C_L$ and $K$ value of the otter board show a trend of increasing at the beginning and then decreasing with the increase of the angle of attack. The $C_D$ value reflects an upward trend with the increase in the angle of attack.
Figure 6. Hydrodynamic performance of the otter board at different angles of attack.

For otter board D1, at the critical angle of attack $\alpha=50^\circ$, the max lift coefficient ($C_{L_{max}}$) is 1.746. In this case $C_D=1.422$ and $K=1.228$. When the working scope of the angle of attack is between $15^\circ$–$30^\circ$, $C_L>0.597$ and $K>1.027$. The mean value of the lift coefficient was 1.027 and the mean of lift to drag ratio was 3.464. When $\alpha=17.5^\circ$, the max lift to drag ratio ($K_{max}$) is 3.997, in this case $C_L=0.720$, $C_D=0.180$.

For otter board D2, at the critical angle of attack $\alpha=50^\circ$, $C_{L_{max}}=1.761$, in this case $C_D=1.521$ and $K=1.157$. When the working scope of the angle of attack is between $15^\circ$–$30^\circ$, $C_L>0.671$, and $K>2.284$. The mean value of the lift coefficient was 1.114 and the mean of lift to drag ratio was 2.827. When $\alpha=20^\circ$, the max lift to drag ratio ($K_{max}$) is 3.101, in this case $C_L=0.988$ and $C_D=0.319$.

For otter board D3, at the critical angle of attack $\alpha=50^\circ$, $C_{L_{max}}=1.809$, in this case $C_D=1.413$ and $K=1.281$. When the working scope of the angle of attack is between $15^\circ$–$30^\circ$, $C_L>0.633$, and $K>2.643$. The mean value of the lift coefficient was 1.071 and the mean of lift to drag ratio was 3.482. When $\alpha=15^\circ$, $K_{max}=4.165$, and in this case $C_L=0.633$, $C_D=0.152$.

When the scope of angle of attack is between $0^\circ$–$30^\circ$, the $C_L$ value shows a trend of first rising then declining with the increase of the angle of the front flow deflector. When the scope of the angle of attack is between $32.5^\circ$–$50^\circ$, the $C_L$ value shows an uptrend with the increase of the angle of the front flow deflector. For the D3 otter board, when the working scope of the angle of attack is between $15^\circ$–$30^\circ$, the numerical range of $C_L$ is 0.633–1.464 and the numerical range of $K$ is 2.643–4.165. In this case, the lift coefficient value of D2 is higher than the D1 and D3 otter boards. However, the lift to drag ratio of the D2 otter board is far below the other otter boards because its drag coefficient is the highest. The lift coefficient of the D3 otter board is higher than the D1 otter board, which supported the conclusion that the D3 otter board has a better hydrodynamic performance, although its lift to drag ratio is slightly lower than the D1 otter board. For otter board D3, at the working angle of attack $\alpha=30^\circ$, $C_{L_{max}}=1.464$, $C_D=0.554$, and $K=2.643$. When $\alpha=15^\circ$, $K_{max}=4.165$, $C_L=0.633$, and $C_D=0.152$. This suggests that the best working scope of the angle of attack is between $15^\circ$–$30^\circ$, in which case, $C_L>0.633$ and $K>2.643$. The mean value of the lift coefficient was 1.071 and the mean of the lift to drag ratio was 3.482.

4. Discussion

The lift coefficient and lift to drag ratio of the otter board at different front flow deflector angles were compared and analyzed. The analysis showed that the D3 otter board had a better hydrodynamic performance than the other models. In the angle of attack between $15^\circ$–$30^\circ$, the lift coefficient of the D3 otter board was higher than the D1 otter board, which supported the conclusion that the D3 otter board had a better hydrodynamic performance, although its lift to drag ratio was slightly lower than the D1 otter board. In this working scope of the angle of attack, the numerical range of $C_L$ of the D3 otter board was 0.633–1.464 and the numerical range of $K$ was 2.643–4.165.

The key factor in achieving highly efficient bottom trawl fishing is the reasonable selection of the otter board using performance and operation characteristics [1,3,5]. Table 3 shows comparisons of the hydrodynamic performance of several commonly used offshore trawl otter boards. The rectangular flat and oval flat slotted otter boards have a simple construction, and are less affected by working conditions. However, the expansion performance of the rectangular flat and oval flat slotted otter board is poor, and the maximum lift coefficient is less than 1.0 [2]. The hydrodynamic performance of the oval cambered single slotted otter board is better than the rectangular flat and oval flat slotted otter board [2,3]. The lift coefficient of the V type otter board is higher than the plat otter board, but the lift to drag ratio is lower than other types of otter boards, which means that the expansion efficiency is poor [6]. The lift characteristics of the vertical cambered otter board showed a large improvement over the flat otter board. The maximum lift to drag ratio of the vertical cambered otter board is 4.67, which is higher than the other types of flat otter boards [2]. However, with the increase in the aspect ratio, the
stability performance of vertical cambered otter board was lower than in the other types of otter boards. After adding the leading-edge slot, the expansion performance is improved, but the expansion efficiency decreased as the drag efficient increased. The maximum lift to drag ratio of the oval cambered double slotted otter board (proposed in this study) and the vertical cambered otter board are over 4.0, which means the expansion efficiency is significantly higher than found in other types of otter boards. The maximum lift coefficient of the oval cambered double slotted otter board is 1.464, which is the maximum value in several commonly used types. The maximum lift to drag ratio at $\alpha_0$ is also the highest value for several types, which suggests that the D3 otter board has good expansion performance and efficiency.

The critical angle of attack of the lift coefficient increases with the increase of the flow deflector angle. This is because when the main panel has reached the critical angle, the diversion wing has not yet reached the critical angle of attack, which provides a part of the lift [1]. The mechanism of the change of the flow deflector is discussed below. The proportion of the "funnel shape" structure of the inlet and outlet changed with the change of the flow of the deflector angle. Vortex flow at the back of the main plates drifts backward along the flow through, causing reduction of the otter board. When other structural parameters are constant, adjusting the flow deflector angle can optimize the hydrodynamic performance of the otter board. Recently, a design optimization approach for otter boards using computational fluid dynamics models showed that when the front flow deflector angle increased from 20° to 24°, the lift coefficient remained constant but the lift to drag ratio increased by 12% [22]. The configuration of the location of flow deflector is also an important factor affecting the hydrodynamic performance of the otter board, with the exception of the angle parameter. This study is limited because the lift force and drag force of the 3 parameter variations of the front flow deflector angle are measured. In future research, we can increase the testing of the gradient of the flow deflector angle. Analysis of the influence of deflector flaps structure parameters on the hydrodynamic performance of the otter board could be conducted using the computer simulation method, from the angle of the flow field effect.

### Table 3. Hydrodynamic performance comparison among different types of otter boards.

| Types                  | Working angle of attack $\alpha_0$ | Maximum lift coefficient $C_{L_{\text{max}}}$ | Maximum lift to drag ratio at $\alpha_0$ $K_{\alpha_0}$ | Maximum lift to drag ratio $K_{\text{max}}$ |
|------------------------|-----------------------------------|----------------------------------------------|------------------------------------------------------|------------------------------------------|
| Rectangular flat [2]   | 40°                               | 0.82                                         | 1.14                                                 | 2.23                                     |
| V type [6]             | 20°                               | 1.08                                         | 0.85                                                 | 1.86                                     |
| Oval flat slotted [2]  | 35°                               | 0.86                                         | 1.36                                                 | 2.35                                     |
| Oval cambered single slotted [2-3] | 35°                               | 0.93                                         | 1.25                                                 | 2.10                                     |
| Vertical cambered [2]  | 30°                               | 1.44                                         | 2.21                                                 | 4.67                                     |
| This study D3          | 30°                               | 1.46                                         | 2.64                                                 | 4.17                                     |

### 5. Conclusion

Using the model experiment method, this study analyzed the hydrodynamic properties of a new type oval cambered double slotted otter board. Results show that the D3 otter board (with a front flow deflector angle of 29°) had a better hydrodynamic performance than the other tested boards. When $\alpha=15^\circ$, the max lift to drag ratio ($K_{\alpha_0}$) was 4.165, $C_{L_{\text{max}}}$ =0.633, and $C_D$ =0.152. The experimental results show that the best working scope of angle of attack is between 15°~30°, in which case, $C_{L_0}$>$0.633$ and $K>$2.643. When $\alpha=30^\circ$, the max lift coefficient ($C_{L_{\text{max}}}$) was 1.464, $C_D$ =0.554, and $K=2.643$. The mean value of the lift coefficient was 1.071 and the mean of lift to drag ratio was 3.482. Comparative
analysis of the hydrodynamic performance of different types of otter boards showed that the D3 otter board had both good expansion performance and good expansion efficiency.

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