Effect of aspect ratio on hydrodynamic performance of high lift otter board in trawl fisheries

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Abstract. Otter board is one of the main component in the production of single boat trawl fisheries. For improving the expansion performance of trawl net in middle-water trawl fisheries, an improved high lift otter board was developed. A flume model experiment was conducted to measure the lift coefficient (CL), drag coefficient (CD) and lift to drag ratio (K) in different angle of attack (α). The experimental results are as follows: (1) The aspect ratio has significant influence on the max lift coefficient (CLmax), the max lift to drag ratio (Kmax), critical angle of attack (α_0) and lift to drag ratio at α_0 (P<0.01). As the increase of aspect ratio, the CLmax and Kmax value show a trend of increasing at the beginning and then decreasing, Kα_0 value reflects an upward trend, but the α_0 reflects a declining trend; (2) The H2 otter board (aspect ratio was 1.4) showed a better hydrodynamic performance. When α=27.5°, CLmax was 2.535, in this case CD =1.424, K=1.780. When α=10°, Kmax was 3.508, in this case CL =1.660, CD =0.473. Suggest the best working scope of angle of attack is between 15°~30°, in which case, CL>2.053 and K>1.578. The mean value of lift coefficient was 2.356 and the mean of lift to drag ratio was 2.329. Through comparative analysis of the hydrodynamic performance of different types of otter boards, the H2 otter board both had good expansion performance and good expansion efficiency, which can provide a reference basis for further optimization of the bottom trawl otter board.

1 Introduction

Otter board is the main equipment of single trawl fishing vessel and its hydrodynamic performance is an important factor affecting the catch and fishing efficiency [1-5]. The function of otter board is to accelerate the settlement of the trawl net on one hand, and increase the horizontal expansion of the trawl net on the other hand [2,3]. The otter board for distant fishing boat has various structural styles, such as vertical cambered, vertical cambered slotted, vertical cambered V type, and so on [2,3]. The V type otter board and oval cambered otter board are mostly adopted in the near shore single boat trawl fisheries [2,6]. The hydrodynamic force on the otter board decomposed into the expansion force and water resistance. The expansion force is perpendicular to the flow velocity, which effect is increasing the trawl net sweeping area. The water resistance is parallel to the flow of water. The ratio of expansion force and water resistance is an important parameter to measure the expansion efficiency of

otter board. Study on hydrodynamic performance of otter board has two kinds of methods, model test or numerical simulation [6-10]. Model test in circulating water tank is close to the actual working conditions of trawl fishing [5]. The Japanese scholars mainly analyzed the hydrodynamic performance of otter board through the flume model experiment [13-19]. In the early stage, Chinese scholars mainly analyzed the hydrodynamic performance of otter board in the wind tunnel equipment [1,20-22], but through the flume model experiment at recent years [23-27].

The developed countries attach great importance to improvement of hydrodynamic performance of otter board. At present, an improved high lift otter board was developed by Japanese scholars, which the maximum lift coefficient of a kind of oval cambered slotted otter board is 2.48, in this case the drag coefficient is 1.57 and the lift to drag ratio is 1.58 [19]. For improving the expansion performance of trawl net in middle-water trawl fisheries, the model experiment of an improved high lift otter board is carried out and the effect of the change of the aspect ratio on the hydrodynamic performance is studied. The purpose of the comparison of analysis of the hydrodynamic performance of different types of otter boards, which can provide a reference basis for further optimization of the bottom trawl otter board.

2 Materies and methods

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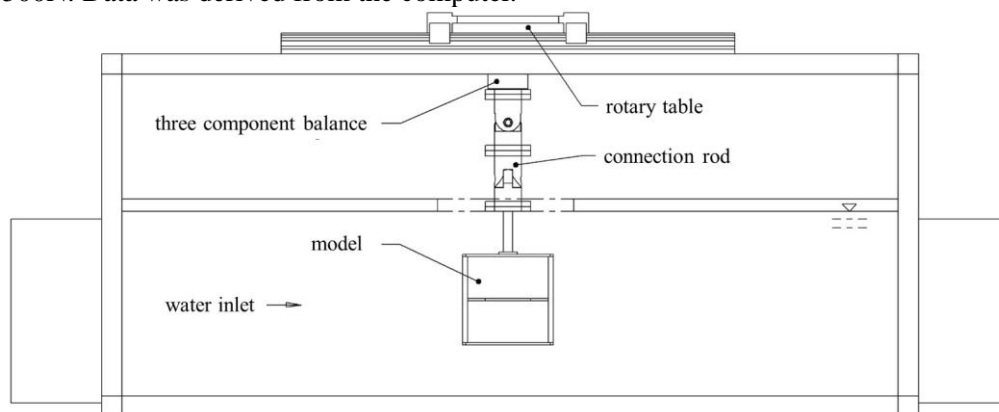

Figure 1 Model test conditions of otter board

2.2 Experimental models
According to the different aspect ratio of an improved high lift otter boards, 4 series models were produced (as is shown in Figure 2). Model scale is 1:20 and the wall thickness is 3mm. The top of the experimental model is connected with the support through a M4 threaded hole. The screen model is made of photosensitive resin composite material, and the process parameters is as follows, model precision: ±0.1mm, detail resolution: 0.4mm, minimum wall thickness: 1mm, print layer thickness: 0.1mm. The model is a method of stereo light curing method (3D print technology) from a computerized model, which has the advantage of high strength, not easy to deformation. Comparing with the traditional method (made by stainless steel), the 3D print model has the advantages of high precision, short manufacturing cycle, low cost, and is suitable for high complexity of the model. It also

has the advantages of higher accuracy and better surface finish than fused deposition modeling method.
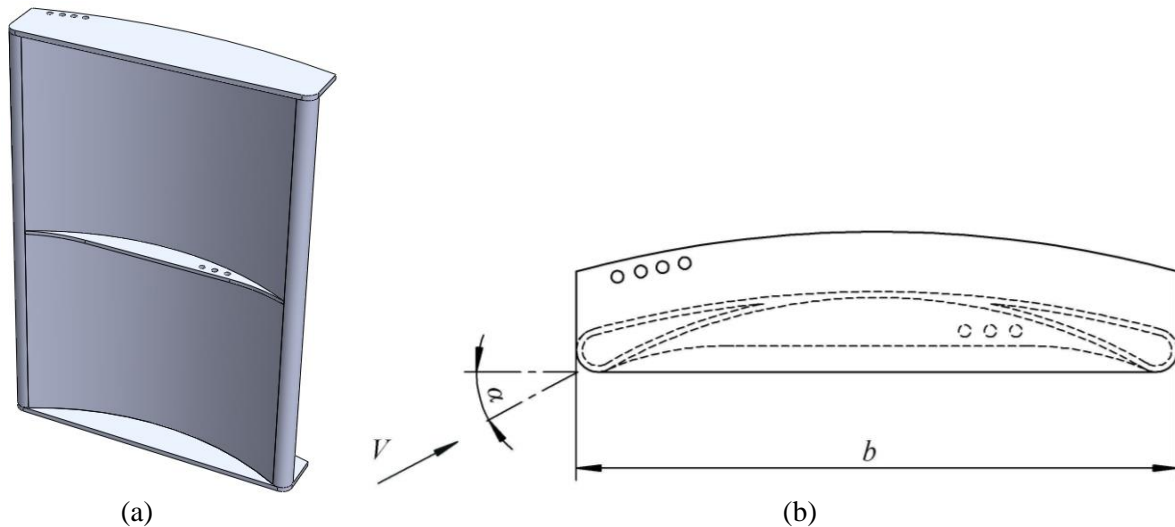

(a)   (b)

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

Table 1 Specification of model otter board

No.	Parameters	Chord length l [cm]	Aspect ratio λ	Flow area [m^2]
H1	Maximum relative camber of		1.2	0.012
H2	inner arc 12.5%;	10	1.4	0.014
H3	Maximum relative camber of		1.6	0.016
H4	outside arc 6%		1.8	0.018

2.3 Experimental conditions

The specific factors and levels are shown in table 1 and table 2. The interval is 2.5° between 15°~40°, but 5° between 0°~15° and 40°~60°. The experimental flow velocity range is 0.6~1.0 m·s^{-1} with the interval of 0.1 m·s^{-1}.

Table 2 Experimental conditions

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 span length l and chord length b. The results of the resistance F_x and F_y was recorded by the three-component balance. The drag coefficient C_D, lift coefficient C_L and lift to drag ratio K was calculated after the pole interference correction. The calculation equations are as follows,

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

$$C_L = \frac{F_y}{0.5 \rho V^2 S} \tag{2}$$

$$K = \frac{C_{\mathrm{L}}}{C_{\mathrm{D}}} \tag{3}$$

$$Re = \frac{Vb}{\upsilon} \tag{4}$$

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

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

3 Results and analysis

3.1 Automatic model area

As shown in Figure 3-Figure 6, when the Reynolds number is higher than 0.8×10^5, the lift coefficient or the drag coefficient value keeps stable. We considered the lift coefficient (or the drag coefficient) was in an automatic model area. The average value of the lift coefficient at the Reynolds number between 0.8×10^5-1.0×10^5 was considered as the lift coefficient for this angle of attack.
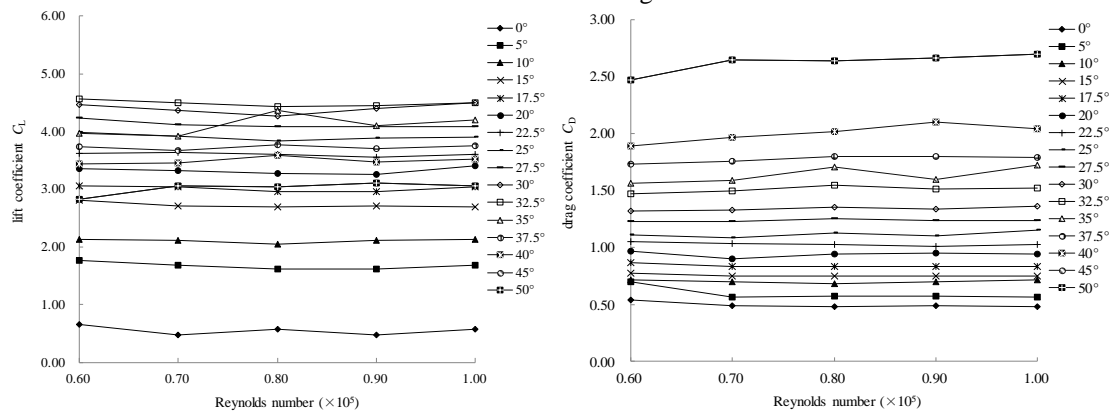

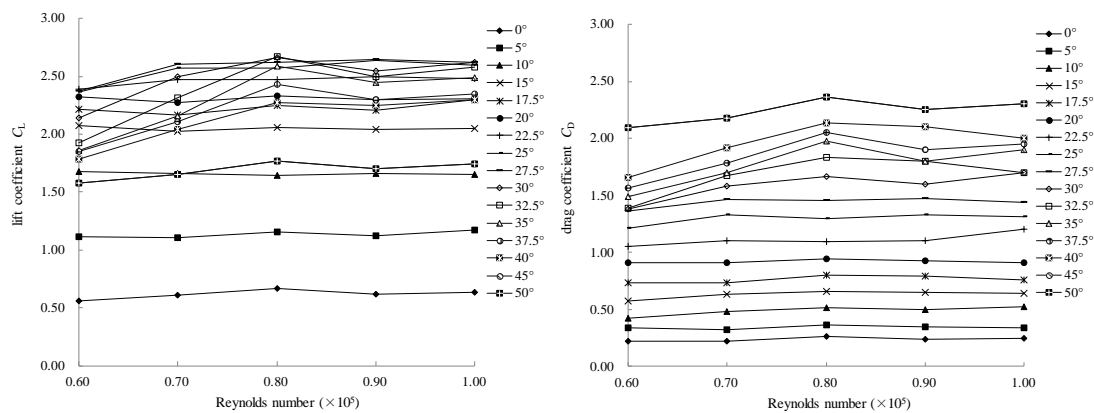Figure 3 The relationship between lift coefficient, drag coefficient and Reynolds number of H1 model

Figure 4 The relationship between lift coefficient, drag coefficient and Reynolds number of H2 model
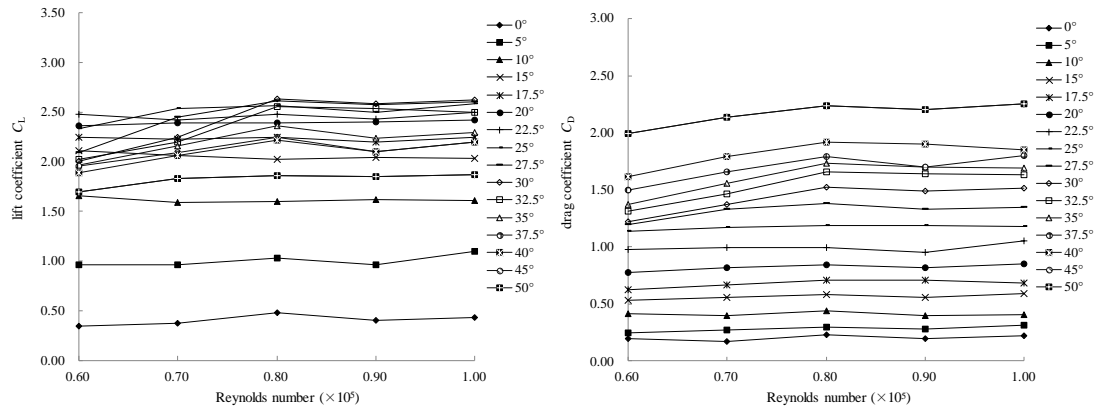
Figure 5 The relationship between lift coefficient, drag coefficient and Reynolds number of H3 model
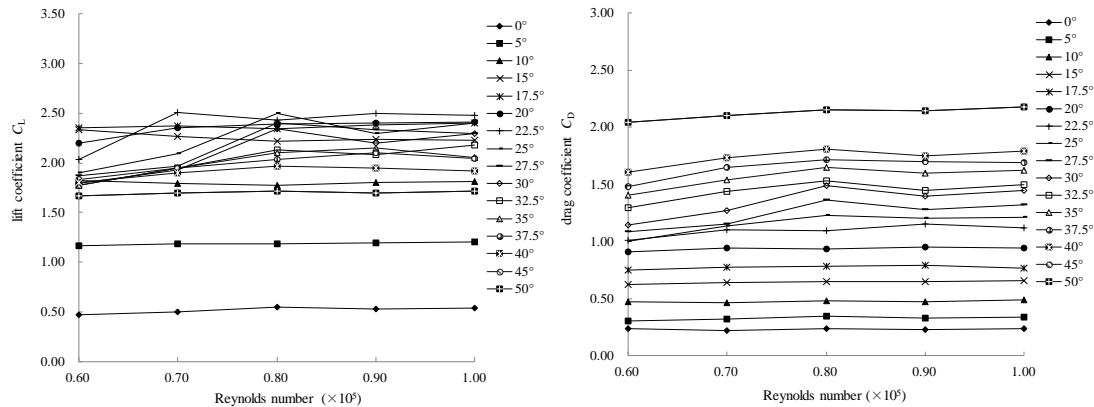

Figure 6 The relationship between lift coefficient, drag coefficient and Reynolds number of H4 model

3.2 Hydrodynamic performance

The results of lift coefficient, drag coefficient and lift drag ratio under different angle of attack are shown in Fig.7. From the results of hydrodynamic performance of the otter board, we can find out the C_L and K value of otter board shows 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 with the increase of angle of attack.

For otter board H1, at the critical angle of attack $\alpha=30°$, the max lift coefficient (C_{Lmax}) is 2.365, in this case $C_D=1.446$, $K=1.635$. When the working scope of angle of attack is between 15°~30°, $C_L>1.699$ and $K>1.635$. The mean value of lift coefficient was 2.078 and the mean of lift to drag ratio was 2.238. When $\alpha=15°$, the max lift to drag ratio (K_{max}) is 2.767, in this case $C_L=1.699$, $C_D=0.614$. For otter board H2, at the critical angle of attack $\alpha=27.5°$, $C_{Lmax}=2.535$, in this case $C_D=1.424$, $K=1.780$. When the working scope of angle of attack is between 15°~30°, $C_L>2.053$ and $K>1.578$. The mean value of lift coefficient was 2.356 and the mean of lift to drag ratio was 2.329. When $\alpha=10°$, the max lift to drag ratio (K_{max}) is 3.508, in this case $C_L=1.660$, $C_D=0.473$. For otter board H3, at the critical angle of attack $\alpha=25°$, $C_{Lmax}=2.478$, in this case $C_D=1.166$, $K=2.125$. When the working scope of angle of attack is between 15°~30°, $C_L>2.068$ and $K>1.671$. The mean value of lift coefficient was 2.330 and the mean of lift to drag ratio was 2.591. When $\alpha=10°$, $K_{max}=3.893$, in this case $C_L=1.615$, $C_D=0.415$. For otter board H4, at the critical angle of attack $\alpha=17.5°$, $C_{Lmax}=2.359$, in this case $C_D=0.769$, $K=3.066$. When the working scope of angle of attack is between 15°~30°, $C_L>2.020$ and $K>1.554$. The mean value of lift coefficient was 2.219 and the mean of lift to drag ratio was 2.356. When $\alpha=10°$, $K_{max}=3.802$, in this case $C_L=1.799$, $C_D=0.473$.
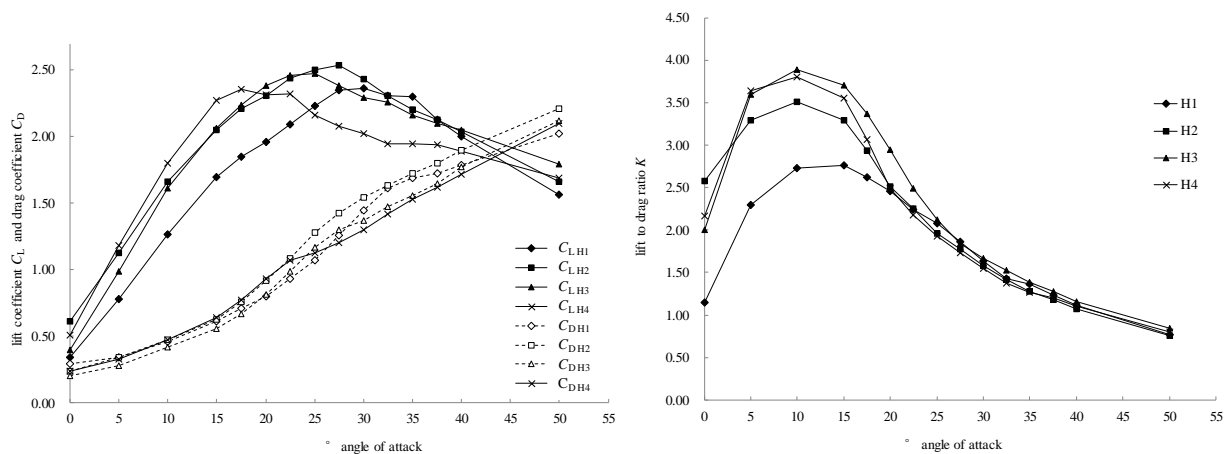
Figure 7 Hydrodynamic performance of the otter board at different angle of attack

In conclusion, the C_{Lmax} and K_{max} value shows a trend of rise first followed by a decline with the increase of the aspect ratio. The $K_{\alpha 0}$ value shows an uptrend with the increase of the aspect ratio. The α_0 value shows an downward trend with the increase of the aspect ratio. For H2 otter board, when the working scope of angle of attack is between 15°~30°, the numerical range of C_L is 2.053~2.535 and the numerical range of K is 1.578~3.292. In this case, the lift coefficient value of H2 is higher than other otter boards (when α is between 25°~30°). But the lift to drag ratio of H2 otter board is between the other otter boards. The lift coefficient of H2 otter board is higher than H1 otter board, which supported the conclusion that the H2 otter board has a better hydrodynamic performance, although its lift to drag ratio is slightly lower than H3 and H4 otter board. For otter board H2, at the critical angle of attack α=27.5°, C_{Lmax}=2.535, in this case C_D =1.424, K=1.780. When α=10°, the max lift to drag ratio (K_{max}) is 3.508, in this case C_L=1.660, C_D =0.473. Suggest the best working scope of angle of attack is between 15°~30°, in which case, C_L>2.053 and K>1.578. The mean value of lift coefficient was 2.356 and the mean of lift to drag ratio was 2.329.

Table 3 The main hydrodynamic performance parameters of otter board

No.	Critical angle of attack α_0	Maximum lift coefficient C_{Lmax}	Maximum lift to drag ratio at α_0 $K_{\alpha 0}$	Maximum lift to drag ratio K_{max}
H1	30	2.365	1.635	2.767
H2	27.5	2.535	1.780	3.508
H3	25	2.478	2.125	3.893
H4	17.5	2.359	3.066	3.802

4 Discussion

According to the experimental results, the lift coefficient and lift to drag ratio of the otter board in different angle of front flow deflector compared and analyzed. Based on the analysis results, the H2 otter board considered to have a better hydrodynamic performance among the four types of models. In this case, the lift coefficient value of H2 is higher than other otter boards (when α is between 25°~30°). But the lift to drag ratio of H2 otter board is between the other otter boards. The lift coefficient of H2 otter board is higher than H1 otter board, which supported the conclusion that the H2 otter board has a better hydrodynamic performance, although its lift to drag ratio is slightly lower than H3 and H4 otter board. In this working scope of angle of attack between 15°~30°, the numerical range of C_L of H2 otter board is 2.053~2.535 and the numerical range of K is 1.578~3.292.

With the development of middle-water trawl fishery, the key factor to achieve high efficiency fishing is the reasonable selection according to performance and operation characteristics of otter board [1,3,5]. As shown in the table 3, we compared the hydrodynamic performance of several

commonly used offshore trawl otter board. The rectangular flat and oval flat slotted otter board have a simple construction, which are less affected by the working condition. But the expansion performance of the rectangular flat and oval flat slotted otter board is poor, which the maximum lift coefficient is less than 1.0 [2]. The hydrodynamic performance of oval cambered slotted otter board is better than the rectangular flat and oval flat slotted otter board [2,3]. The lift coefficient of V type otter board is higher than plat otter board, but the lift to drag ratio is lower than other types otter board, which considered the expansion efficiency is poor [6]. The lift characteristics of vertical cambered otter board had a very big improvement compared with the flat otter board. The maximum lift to drag ratio of vertical cambered otter board is 4.67, which is higher than other types of flat otter board [2]. But with the increase of aspect ratio, the stability performance of vertical cambered otter board is lower than other types otter board. After adding the leading-edge slot, the expansion performance is improved, but the expansion efficiency decreased as the drag efficient increasing. The maximum lift coefficient of the improved high lift otter board (this study) is over 2.5, which means the expansion performance is significantly higher than other types. The maximum lift to drag ratio of the improved high lift otter board is 3.508, which is only lower than the vertical cambered otter board. The maximum lift to drag ratio at α_0 is also the higher value of several types (only lower than the vertical cambered otter board), which suggested the H2 otter board has good performance of expansion performance but also good expansion efficiency.

The critical angle of attack of lift coefficient decreases with the increase of the aspect ratio. This is because the wing tip vortex strength becomes weaker with the increase of aspect ratio [3]. The mechanism of the change of the aspect ratio is discussed. When other structural parameters are constant, adjust the aspect ratio can optimize the hydrodynamic performance of the otter board. The configuration of the place of flow deflector is also an important factor affecting the hydrodynamic performance of the otter board except the aspect ratio. The limitations of this study is that only the lift force and drag force of 4 parameter variation of the aspect ratio are measured. In the future, we can increase the testing of the gradient of the aspect ratio. From the angle of flow field effect, analysis of the influence of other structure parameters on the hydrodynamic performance of the otter board through computer simulation method.

Table 4 Hydrodynamic performance comparison among different types of otter board

Types	Working angle of attack α_0	Maximum lift coefficient C_{Lmax}	Maximum lift to drag ratio at α_0 $K_{\alpha 0}$	Maximum lift to drag ratio K_{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 slotted[2,3]	35°	0.93	1.25	2.10
Vertical cambered[2]	30°	1.44	2.21	4.67
This study H2	27.5°	2.54	1.78	3.51

5 Conclusion

By using the method of model experiment, this study analyzed the hydrodynamic properties of one kind of improved high lift otter board. Results show that the H2 otter board (aspect ratio was 1.4) showed a better hydrodynamic performance. When α=10°, the max lift to drag ratio (K_{max}) was 3.508, in this case C_L =1.660, C_D =0.473. According to the experimental results, it is recommended that the best working scope of angle of attack is between 15°~30°, in which case, C_L>2.053 and K>1.578. When α=27.5°, the max lift coefficient (C_{Lmax}) was 2.535, in this case C_D =1.424, K=1.780. The mean value of lift coefficient was 2.356 and the mean of lift to drag ratio was 2.329. Through comparative analysis of the hydrodynamic performance of different types of otter boards, the H2 otter board both had good expansion performance and good expansion efficiency.

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