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Original research article

Influence of main-panel angle on the hydrodynamic performance of a single-slotted cambered otter-board

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A B S T R A C T

The effect of the main-panel angle of a single-slotted cambered otter-board was investigated using engineering models in a wind tunnel. Three different angles (0°, 6°, and 12°) 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, and the lift−drag ratio C_y/C_x, over a range of angle of attack (0°−70°). These coefficients were used in analyzing the differences in the performance among the three otter-board models. Results showed that the maximum lift coefficient C_y of the otter-board model with a main-panel angle of 0° was highest (1.875 at $\alpha = 25°$). However, when the angle of attack was smaller ($0 < \alpha < 22.5°$), the lift coefficient of the otter-board increased as the angle of the main-panel increased. The maximum C_y/C_x of the otter-board with a main-panel angle of 12° was highest (7.417 at $\alpha = 2.5°$), and the lift−drag ratio increased when the angle of the main-panel increased within the angle of attack at small angles ($0 < \alpha < 12.5°$). A comparative analysis of C_m and C_p showed that the stability of the otter-board with a main-panel angle of 0° is better than those of the other models. Therefore, the comparative analysis of C_m and C_p, shows that a larger angle of the main-panel can reduce the stability of single-slotted otter-board. The findings of this study 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 the spreading of a trawl. The merits of the hydrodynamic performance of otter-boards can be measured using the lift coefficient of the otter-board, the drag coefficient of the otter-board, and the pitching moment coefficient of the otter-board (Mellibovsky, Prat, Notti, & Sala, 2015; Sala, Prat, Antonijuan, & Lucchetti, 2009; Shen, Hu, Kumazawa, Shiode, & Tokai, 2015; Takahashi, Fujimori, Hu, Shen, & Kimura, 2015). Optimizing the structure of otter-boards may improve their hydrodynamic performance and reduce the energy consumption of fishing vessels (Broadhurst, Sterling, & Cullis, 2012, 2015; McHugh, Broadhurst, Sterling, & Millar, 2014, 2015). Extensive studies on the hydrodynamic performance of otter-boards have been conducted in the United States, Europe, Japan, and other countries (e.g., Castro, Marín, Pérez, Pierce, & Punzón, 2012; Fukuda, Fuxiang, Tokai, & Matuda, 2000; Park, Matuda, & Hu, 1996; Sala et al., 2009; Zhuang, Xing, Xu, & Zhang, 2015). In China, researchers have studied the relevant hydrodynamic performance of otter-boards since the early 1980s, which has included the hydrodynamic performance and optimization of different otter-boards with various structure types (e.g., Li et al., 2013; Liu et al., 2015; Wang, Wang, Zhang, Yu, & Xu, 2004a; Xu, Zhang, & Wang, 2010; Zhang, Wang, Wang, Yu, & Xu, 2004).

The development of offshore trawler fleets has increased globally in recent decades, raising the demand for improved otter-board designs. Accordingly, improvements in the hydrodynamic performance of otter-boards has become a major research interest. Some studies have shown that a slit in otter-boards can reduce the resistance and improve the stability of otter-boards. The horizontal spreading force (i.e., lift) produced by this type of otter-board is dependent on the main-panel (Chen & Huang, 2011; Yang, 1996a). The structure of the main-panel affects the hydrodynamic performance of the otter-board directly.

Historically, the study of otter-board hydrodynamic performance has been conducted using engineering models in circulating water channels, commonly referred to as flume tanks. Several decades of research have produced a rich history of information on

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the performance of a wide range of otter-board designs (FAO, 1974; SEAFISH, IFREMER, & DIFTA, 1993). Flume tanks are rare, however, with only a small handful in operation word-wide (see listing in Winger, DeLouche, & Legge, 2006). Wind tunnels, by comparison, are relatively common and can be found at nearly all universities with engineering programs. Recent attempts to evaluate otter-boards in wind tunnels have been conducted in facilities in China (Zhang et al., 2004) and Germany (Mellibovsky et al., 2015) with good success. An assessment by Mellibovsky et al. (2015) determined that wind tunnels offer certain advantages over flume tanks, but both approaches contain inherent assumptions and biases.

The following study investigates the importance of the angle of the main panel within a single-slotted cambered otter-board. We describe an experiment using model otter-boards ($n = 3$ 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 main-panel of otter-boards.

2. Materials and methods

2.1. Design and manufacture of otter-board models

The otter-boards evaluated in this study were single-slit curved structures comprising a deflector and a main-panel (Fig. 1). This simplified design was selected to meet the objectives and requirements of the study. Only the angle of the main-panel was modified.

Three different model otter-boards were evaluated. Each of models had an aspect ratio of 2.5, a surface area of 0.156 m^2, and were identical in many structural parameters and dimensions (Table 1). The curvature of the deflector and main panels was 12% and was consistent in all models. The only parameter that varied between the models was the angle of the main panel (β) which was set as 0°, 6°, and 12°. The models are made of steel with painted surfaces (Fig. 2).

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

No.	L (m)	B (m)	λ	S (m^2)	e (m)	l_A (m)	l_B (m)	γ(°)	β (°)
1	0.250	0.625	2.5	0.156	0.130	0.065	0.195	25	0
2	0.250	0.625	2.5	0.156	0.130	0.065	0.195	25	6
3	0.250	0.625	2.5	0.156	0.130	0.065	0.195	25	12

Note: S = surface area (L·b); λ = aspect ratio (b/L).

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. Fig. 3 illustrates the experimental setup inside the wind tunnel. The model otter-boards were attached to a dynamometer compromising a six-component mechanical tower-balance to measure forces in all directions (Table 2). The data acquisition and processing system used is composed of a pre-amplifier and a four-networked computer system.

2.3. Test method

2.3.1. Parameter definition of the test model

The angle of attack of the model otter-board was rotated between 0° and 70°. Intervals of 2.5° were used for the range of 0°–50°, followed by intervals of 5° for the range of 50° to 70°. This

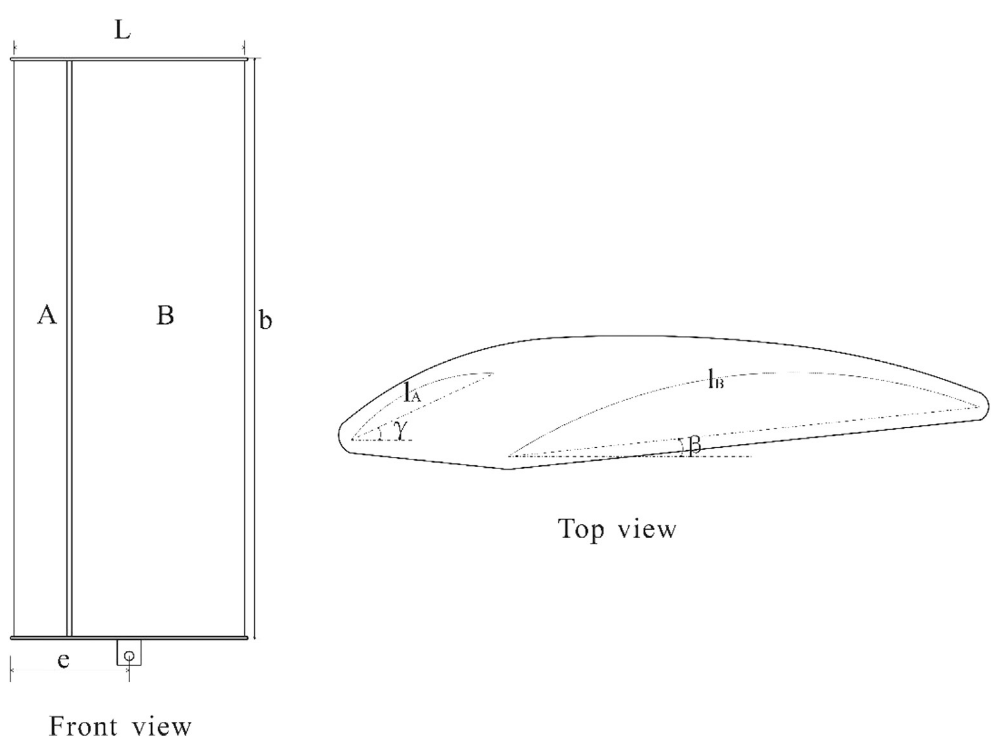

Fig. 1. Structure and parameters of single-slotted cambered otter-board. L: wing chord length; b: wing span length; e: distance between fulcrum and the front end of model; A: deflector; B: main-panel; γ: angle of deflector; β: angle of main-panel; l_A: length of deflector; l_B: length of main-panel.