Numerical Study on the Hydrodynamic performance of single hull model of the Seaplane

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Abstract. This paper mainly researched the hydrodynamic performance of seaplane at different conditions. The drag, lift and moment of the single hull model of seaplane at different conditions were compared and analyzed by RANS method. Numerical method in this paper was verified and validated by comparing with experimental results. By analyzing the computed results, the drag increased with the increase of the trim angle, while the moment decreased. When the draft $\leq$ 30mm, the drag, lift and moment changed little. While the draft >30mm, the drag, lift and moment increased obviously with the increase of draft. The drag, lift and moment increased with the increase of velocity, and increasing obviously when the draft >30mm.

1. Introduction

Because amphibious aircraft is affected by hydrodynamic lift, hydrodynamic moment, aerodynamic lift and aerodynamic moment of ship hull in the course of surface movement, the pulling force of engine forms a large downward force moment. Only when the upward force moment acting on the aircraft is equal to the downward force moment caused by propeller, the aircraft can reach the angle of trim to take off from water [1, 2]. One of the most important methods to study the hydrodynamic drag, lift and moment characteristics of hull is to carry out the fixed-state test of a single hull. Fixed-state test of a single hull of a seaplane is the attitude of a completely fixed model. The effects of the trim angle and draft depth of the aircraft on the hydrodynamic drag, lift and moment are obtained by measuring the high-speed taxiing of the aircraft fuselage on the water surface. Based on the single hull moment test [3, 4, 5], many scholars have particularly analyzed the effects of trim angle, draft and speed on the hydrodynamic performance of the fuselage of seaplane, and evaluated the hydrodynamic performance of the seaplane by analyzing the experimental data.

With the rapid development of computer technology and numerical methods, in recent years, there are more and more explorations on the direct numerical calculation of hydrodynamic performance using CFD technology. Liangjun Qiu (2013) analyzed the takeoff process of amphibious aircraft using decoupled hydrodynamic and aerodynamic numerical methods by CFD methods [6]. Based on the analysis of the performance of seaplane in hydrostatic takeoff, Lang Zhang (2018) proposed a new method using multiphase UANS (unsteady RANS) method [7]. Xupeng Duan (2019) studied the air and hydrodynamic performance of seaplane mooring based on CFD method [8].
2. Geometry and Experiment
The single hull model of seaplane was adopted in this paper, the typical features of which were shown in Fig. 1. As shown in Fig. 2, in the single hull model test, the test model was installed under the high-power and high-speed trailer system and connected to the trailer by supporting rod. During installation, the upper end of the balance was fixed with the fixing support, and the lower end was fixed with the angle module and the model installation plane. Adding or reducing 10 mm thick aluminum sheet between the angle module and the model installation plane was needed to regulate the draft of the model.

Figure 1. Feature of single hull model of seaplane.

Figure 2. Layout of experiment.

A trimmed cell mesh employed in the simulation was adopted to solve mesh generating problems of complex surface. The refined meshes was generated in the area around the seaplane to capture the complex flow features appropriately. The size of computational zone was: \(-1.0L \leq x \leq 4.0L, 0L \leq y \leq 1.5L, -1.0L \leq z \leq 1.0L\). Half model was adopted in all simulations, because the model was symmetry, and the symmetry plane had a symmetry condition. The inlet, side, top and bottom boundaries were both selected as velocity-inlet. The outlet were selected as pressure-outlet. Also, the pressure outlet boundary condition was set behind the model since it prevented backflow from occurring. The boundary conditions were shown in Fig. 3 (b).

In this study, all simulations were performed with the RANS solver, and the SST k-ω model was selected as the turbulence model. The free surface was captured by the two-phase Volume of Fluid (VOF) method. The convection term was discretized with a second-order up-wind scheme, and the diffusion term was discretized with a second-order scheme. The average value of wall Y+ adopted in this paper was within 1.

Figure 3. Mesh distributions of seaplane (a) and the applied boundary conditions (b).

3. Results and discussion
The hydrodynamic moments of single ship hull of seaplane at different trim angles, drafts (distance between the lowest point at step-fault and water surface) and different velocities were calculated by RANS method. The effects of trim angle, draft and speed on the moment of the seaplane were analyzed. In this paper, lift was positive in vertical upward direction, drag was positive in horizontal backward direction, and moment was positive in aircraft head-up. The dimensionless drag, lift and moment coefficients were defined as follow: \(C_d = F_d/\Delta\), \(C_l = F_l/\Delta\) and \(C_m = M/(\Delta L^2)\), where \(F_d, F_l, \Delta, L\) were drag, lift, displacement and length of the model.
3.1. Validation and verification

The results of dimensionless drag and lift coefficients observed from numerical simulations and experiments were shown in Fig. 4 and Fig. 5. In all, the computed results were close to the experimental data, which confirmed the applicability and rationality of grid distributions and turbulence model adopted in this paper.

3.2. Influence of velocity, trim angle and draft on drag

Fig. 6 showed the curve of dimensionless drag coefficient varying with trim angle at different velocities when draft was 50 mm. When the velocity and draft were constant, the dimensionless drag coefficient showed a fluctuating growth trend with the increase of trim angle. The law of resistance curve fluctuation of different velocities was similar. There were two drag peaks, and the drag peak with lower amplitude corresponded to the trim angle of 5°, while the drag peak with higher amplitude corresponded to the trim angle of 7°. The amplitude increased with the increase of velocity, when 6.5 m/s ≤ V ≤ 9 m/s, the amplitude increased from 0.045 to 0.058; when 9 m/s ≤ V ≤ 12 m/s, the amplitude increased from 0.058 to 0.10. Fig. 7 showed the curve of dimensionless drag coefficient varying with the draft at different trim angles when the velocity was 10 m/s. When the trim angle and velocity were constant, the dimensionless drag coefficient decreased with the increase of draft when draft ≤ 30 mm, and increased obviously with the increase of draft when draft > 30 mm.

![Figure 4. Comparison of $C_d$ generated by experiment and CFD.](image1)

![Figure 5. Comparison of $C_l$ generated by experiment and CFD.](image2)

![Figure 6. $C_d$ with trim at draft=50mm.](image3)

![Figure 7. $C_d$ with draft at Velocity =10m/s.](image4)
Fig. 8 showed the curve of dimensionless drag coefficients varying with velocity at different draft when the trim angle was 4°. When $V \leq 10\text{m/s}$, the dimensionless drag coefficient increased slowly, and when $V > 10\text{m/s}$, the dimensionless drag coefficient increased obviously. When $\text{Draft} \leq 30\text{ mm}$, the dimensionless drag coefficient changed slightly, while when $\text{Draft} > 30\text{ mm}$, the dimensionless drag coefficient increased obviously. Because when the draft was less than 30 mm, only the draft of step-fault was needed, and drag changed slightly, when the draft reached 30 mm or more, the bilge line of forebody began to touch the water, and the contact area between the model and water increased rapidly, which caused the drag to increase significantly.

Figure 8. $C_d$ with velocity at trim=4°.

3.3. Influence of velocity, trim angle and draft on lift

Fig. 9 showed the curve of dimensionless lift coefficient varying with trim angle at different velocities when the draft was 50mm. When $6.5\text{m/s} \leq \text{Velocity} \leq 8\text{m/s}$, with the increase of trim angle, the dimensionless lift coefficient increased and extremum occurred at angle 5, the fluctuation of which was relatively small. When $9\text{m/s} \leq \text{Velocity} \leq 12\text{m/s}$, the dimensionless lift coefficient increased significantly with the increase of pitch angle. Fig. 10 showed the variation of dimensionless lift coefficient varying with draft at different trim angles when the velocity was 10 m/s. When $\text{Draft} \leq 30\text{ mm}$, the dimensionless lift coefficients changed smoothly, for $3^\circ \leq \text{Trim} \leq 5^\circ$, the dimensionless lift coefficients decreased with the increase of draft, but for $5^\circ < \text{Trim} \leq 8^\circ$, the dimensionless drag coefficients increased with the increase of draft. When $\text{Draft} > 30\text{ mm}$, dimensionless lift coefficients increased significantly with the increase of draft, and the range increased with the increase of draft. When $\text{Draft}=30$, Trim=5°, the afterbody of the model began to contact the water surface, so the dimensionless lift coefficient began to increase significantly.

Figure 10. $C_l$ with draft at Velocity =10m/s.

Figure 11. $C_l$ with velocity at trim=4
Fig. 11 showed the variation of dimensionless lift coefficient varying with draft at different velocities when the trim angle is 4°. When Draft≤30mm, the dimensionless drag coefficients of different velocities were similar which increased slightly with the increase of velocity. When 30mm<Draft≤60mm, the dimensionless lift coefficient increased obviously.

3.4. Influence of velocity, trim angle and lift on moment

Fig. 12 showed the curve of dimensionless moment coefficients varying with trim angle at different velocities when draft was 50 mm. When 3°≤Trim≤6°, moment decreased slightly, while when 6°≤Trim≤8°, moment decreased obviously, and large downward force moment appeared. Fig. 13 showed the variation of dimensionless moment coefficients varying with draft at different velocities when the velocity was 10 m/s. When the trim angle and velocity were constant, the dimensionless moment coefficient increased with the increase of draft, especially when the draft reached 30 mm or more, the increase of the moment was obvious. With the increase of draft, the difference of moment coefficients with different trim angles decreased obviously.

Fig. 14 showed the curve of dimensionless moment coefficients varying with draft at different velocities when the trim angle is 4°. When Draft≤30mm, the dimensionless moment coefficients of different velocities were similar, and increased slightly with the increase of velocities. When 30mm<draft≤60mm, the dimensionless moment coefficient increased obviously.

The Computed free surface of single model (Draft=50mm, Trim=4°) of air tanker at the speed of 8m/s, 10 and 12 m/s were shown in Fig 15, respectively. From the computed results, with the increase of velocity, the computed Kelvin angle decreased, the highest zone of the wave system and the wave amplitude increased, which was in good agreement with the experimental results.
The accuracy of the calculation of the single hull moment were verified by comparing with the results of the free towing test of the single hull model. The principle of test was shown in Fig. 16. In the test, the weight was used to exert downward force moment on the model. When the trailer steadily ran at a certain velocity, the model would eventually remain in a certain state (the trim angle and the draft were constant). In this state, the hydrodynamic moment of the hull was equal to the weight of the weights multiplied by the distance between the center of gravity and the action line of the downward force moment. The hydrodynamic force and moment obtained by this method had higher reliability. The moment, which was calculated in the same state as that in test, was fitted by the least square method, as shown in Table 1. By comparing the results of two methods with different velocities, the error was less than 3.8%, which showed that the calculation method had high accuracy and reliability.

![Figure 16. Schematic diagram of towing test.](image)

### Table 1. The moments generated from towing test and CFD

| Conditions                        | Towing test | CFD  | Errors (%) |
|-----------------------------------|-------------|------|------------|
| Trim=6.70 °, Draft=42.8 mm, Velocity=8m/s; | 0.0157      | 0.0161 | -2.56      |
| Trim=5.81 °, Draft=38.6 mm, Velocity=10m/s; | 0.0294      | 0.0283 | 3.64       |
| Trim=4.82 °, Draft=31.6 mm, Velocity=12m/s; | 0.0123      | 0.0128 | -3.78      |

### 4. Conclusion

From the results of these works, the following conclusions could be derived:

The results of moment test and the free towing test of single hull model of seaplane were in good agreement with computed results, which verified the accuracy and rationality of the computed results and methods adopted in this paper.

When the draft and speed were constant, the drag increased with the increase of the trim angle, in which there were two resistance peaks. The lift increased with the increase of the trim angle, and the rate of which increased with the increase of the speed. The moment decreased with the increase of the trim angle, and the rate of which increased with the increase of the speed, even the downward force moment appeared.

When the trim angle and velocity were constant, when the draft ≤30mm, the drag, the lift and moment showed small change. While the draft >30mm, the resistance, lift and moment increased obviously with the increase of draft. This was because that the draft line of the precursor began to draft, and the contact area between the model and the water increased rapidly, which led to the significant increase in hydrodynamic force and moment when the draft >30.

When the trim angle and draft were constant, the resistance, lift and moment increased with the increase of velocity, and increase was obvious when the draft >30mm.

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