Investigation of the Influence of Blocking Effect on the Aerodynamic and Hydrodynamic Characteristics of a Powered Aircraft Model

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Abstract. This paper investigated the influence of blocking effect on the aerodynamic characteristics of a powered aircraft model by experimental and numerical methods. Firstly, the towing test were carried out in the bottom and front of the trailer. The experimental results showed that the drag and trim of two conditions were different, indicating that the blocking effect was obvious. RANS method, sliding mesh and overset grid were adopted in numerical simulation. The simulation of the wind field in the bottom and front of the trailer were carried out. And the numerical results were compared with the experimental results to verify the accuracy of numerical method adopted in this paper. The results showed that the wind speed in the bottom of the trailer was larger than that in the front of the trailer on average and there was stable speed increment interval when the wind filed simulation was conducted in the front and the bottom of the trailer without model. Then the hydrodynamic performance of the powered aircraft model in infinite domain, in the bottom of the trailer and in front of the trailer were carried out respectively. The aerodynamic downward moment was larger when the model was in the bottom, but the overall aerodynamic lift force of the model was similar under the two conditions. The heave amplitude was also similar under the two conditions, but the trim angle and the total drag was smaller when the model was in the bottom of the trailer.

Keywords: Powered aircraft; RANS; Overset mesh; Blocking effect

1. Introduction

According to the theory of fluid mechanics, the bottom and tank wall limit the flow of water around the ship model which would increase the velocity of the reflow, resulting in a change in viscous drag, called the blocking effect[1]. At present, the research on the blocking effect of the towing tank was mainly focused on the low and medium speed ship, and mainly focused on the blocking effect of water. Sheng Zhenbang pointed out that the shallow water effect and the wall effect of the ship model in the towing tank were usually negligible, and the blocking effect was the main part of the tank boundary effect[2]. The drag of ship model obtained by the towing test conducted in the towing tank was usually greater than the that of the same speed in the infinite domain, where the increase of the drag mainly caused by the tank boundary[3][4]. According to the results of five experiments in the
tank of Zhejiang Ocean University and related theoretical results, Li Guangnian pointed out that the blocking effect can be ignored when the blocking ratio was less than 0.2%[5], indicating that the extent of water blocking effect of the ship model was related to the blocking ratio. At present, the research results on the blocking effect of high-speed surface vehicles were rarely published. And for the towing test of high-speed vehicles such as the aircraft and ground-effect aircraft, the change of wind speed also had a great impact on the test results[6] [7]. In the ideal state, the wind speed in the bottom of the high-speed trailer was equal to the speed of the high-speed trailer, but when the high-speed trailer traveled quickly, the trailer chassis, the tank wall and the water surface limit the air flow and cause the blocking effect, resulting the increase of the wind speed of the air field in that area. Then the aerodynamic characteristics of the aircraft, such as the aerodynamic forces and moments of propellers, elevators and wings were changed, affecting the test result such as drag, heave and pitch of aircraft.

Therefore, this paper took a powered aircraft model as the research object to study the influence of blocking effect on its aerodynamic and hydrodynamic characteristics by experimental and numerical methods. The model towing test was carried out in the two test areas, in the front and bottom of the trailer. The numerical simulation mainly included two parts. Firstly, the wind field simulation of the front and bottom test areas of the trailer were carried out, and the extent of wind field blocking effect in the two areas was studied. And then the simulation when the model in infinite domain, front of and bottom of the trailer were carried out to study the effects of the blocking effect on the aerodynamic and hydrodynamic characteristics of the model.

2. Geometry and Gird

2.1 Geometry
We conducted the experiment and numerical simulation of the powered aircraft mode shown in figure 1. The angles of flaps in this model was 0 degree and the angle of elevators was 16 degree. The size, rotation direction and installation angle of the four six-blade propellers of the aircraft were all the same. When the towing test was carried out in the bottom and front of the trailer, there was no different in the size and other physical conditions except the position of the model. The layout of towing tank was shown in figure 2. And the simulation was carried out in the finite and infinite domain. Two conditions were employed in the finite domain simulation, which were the same as the experiment.

![Figure 1. Geometrical model of surface vehicle.](image1)

![Figure 2. The layout of towing tank.](image2)
the same as the towing tank, while the infinite domain were set as -5.0L to 1.5L in x direction, 0L to 2.5L in y direction and -2.0L to 2.0L in z direction.

![Figure 3. Mesh distributions of aircraft in the bottom of trailer.](image)

![Figure 4. Mesh distributions of aircraft in the infinite domain.](image)

Because the model and the trailer were both geometrically symmetric, the half model was adopted in the simulation, and the trailer model was simplified that only the trailer chassis was kept. The model and the trailer surface were defined as no-sliding wall boundary. In the infinite domain, inlet, top, side and bottom were set as velocity inlets and the outlet was set as pressure-outlet. The boundary conditions in the finite domain were the same as the finite domain except that the side and bottom should be set as wall. The grid distribution of finite domain and infinite domain was shown in figure 3 and figure 4. Since the model position was the only different of the two simulation in finite domain, so the grid distribution of the model in front of the trailer was set as the example to be shown in figure 3. In this paper, RANS method, SST k – ω turbulence model and two phase volume of fluid (VOF) technology were used in all simulations [8].

3. Experimental methods
In order to verify the blocking effect in the bottom of the trailer, the tests with the model in the front and bottom of the trailer were carried out respectively. It was a routine test to carry out the test in the bottom of trailer, which was shown in Figure 5. There was some description for the test with the model in the front of the trailer because it was the first time to do such a test. The device of the test that in front of the trailer shown in figure 6 mainly included the limiting device, the moving device, the former stretch device and the trailer. In order to extend the model position to the front of the trailer, the trailer should be consolidated with the former stretch device. There were a small pulley, a lifting rod and Barycentric connecting rod in the moving device, which was used to provide the aircraft with the DOF (degree of freedom), such as the translation in the heading direction, heave and pitch. In order to avoid the craft of the model and the tank wall, the limit device was used to limit the yaw movement of the model. The limit function was realized by the navigation bar.

![Figure 5. The experimental device in the bottom of trailer.](image)

![Figure 6. The experimental device in the front of trailer.](image)

4. Results and Discussion

4.1. The experimental results analysis
Figure 7-10 showed the results of the model test. The relative Error was defined as Error(%)=(extension-bottom)/bottom*100%. It's important to note that Δ (displacement) and L (the
length of aircraft) were constant value which was used to normalize the simulation results in this article. Because the research object belonged to the surface high-speed vehicle, the experimental and numerical simulation results under medium and high speed conditions were studied in this paper.

Figure 7-10 showed that the drag when the model was in the bottom of the trailer were significantly greater than that when the model was in the front of the trailer. As can be seen from figure 8, the test results of the model heave in the two conditions were basically consistent, with the error within 2%. As can be seen from figure 9, when the model was in the front of the trailer, the trim angle was larger than that when the model was in the bottom of the trailer, and the error increased with the speed. As can be seen from figure 10, the difference of heave amplitude under the two conditions changed stably with the increase of speed and fluctuated around 0. While the difference of drag and trim angle increased with the increase of speed. When the speed was greater than 10m/s, the tail of the model in the bottom of the trailer started to leave the water, and with the increase of the speed, the trim angle decreased. While the tail of the model in the front of the trailer still did not leave the water, and the trim angle gradually increased. The heave amplitudes of the model under the two test conditions were basically the same. Compared with the model in the front of the trailer, when the model was in the bottom of the trailer, the drag was larger but the trim angle was smaller. Therefore, the experimental results showed that the model test of powered aircraft in the bottom of the trailer was affected by blocking effect obviously. Considering that the simulation object was a powered aircraft model, the influence of blocking effect on the aerodynamic and hydrodynamic characteristics of the model need to be studied further.

4.2. The numerical simulation results analysis

4.2.1 Numerical method verification. Taking the working condition of the model in the bottom of the trailer as an example, the numerical method verification was carried out by comparing the test result with the simulation results. The comparison results of total drag, pitch angle and heave amplitude were shown in figure 11. The drag and attitude results obtained by experiment and simulation were in good agreement, indicating that the simulation method used in this paper was accurate and reasonable.
4.2.2 The blocking effect of the wind in the bottom of trailer. In an ideal state, the wind speed in the bottom of the trailer was equal to the speed of the high speed trailer. However, due to the blocking effect, when the high speed trailer was fast moving in the pool, the wind speed in the bottom of the high speed trailer increased due to the existence of the bottom of the trailer, water surface and tank wall. To research the blocking effect of wind in the bottom of the trailer, the wind field simulation under two conditions was conducted with no model. The simulation result was shown in figure 12 with the test result. The pitot tube and ultrasonic sounder were used in the test. As can be seen from figure 12, the computed and experimental result were in good agreement with each other. The average wind speed in the bottom area of the trailer was 9.1% greater than the trailer speed. While the average wind speed in the front of the trailer was consistent with the trailer speed. The difference between them was less than 1.8%.

The wind direction of each measuring point was parallel to the incoming wind direction, and the error of angle was less than 2.0%, which was less than the error of measurement and equipment installation. It could be seen that the side wall and water surface did not affect the wind field. But the wind speed was increased. Therefore, the wind field in the bottom of the trailer had obvious blocking effect, while the wind field in the front of the trailer had no blocking effect.

4.2.3 the influence of blocking effect on the model. Figure 13 and figure 14 showed the simulation results of drag and attitude when the model was in the front, bottom of the trailer and infinite domain. The simulation result showed that the relative error of the drag, pitch angle and heave was small between the condition of infinite domain and the front of the trailer, and the overall error was within 3%. The average wind speed in the front of trailer area was the same as the speed of trailer, indicating that there was not blocking effect in the front of the trailer. When the simulation was carried out in the bottom and front of the trailer, there was no different in the size of model and other physical conditions except the position of the model. The relative error between the condition of infinite domain and the bottom of the trailer was obvious and consistent with the experimental result. Considering the average wind speed in the bottom of the trailer 9.1% larger than the trailer speed, we can conclude that the influence of the blocking effect in the bottom of the trailer was dominate when conducting a towing test.
To study the effect of blocking effect on the aerodynamic characteristics of the model appendage, the aerodynamic lift and longitudinal moments on the propeller, wing + flap and tail + elevator under the two calculated conditions were shown in figure 15 and figure 16. In these figure, lift was positive when \( z \) was greater than 0 and moment was positive when there was trim by bow. These figure showed that the aerodynamic lift and upward moment of flat tail + elevator and wings + flap in the bottom of the trailer were significantly greater than that in the front of the trailer due to the average in the bottom of the trailer was 9.5% larger than that in the front of the trailer. Analyzed the simulation of propeller. On the one hand, the heave amplitude was very close under two condition. It explained by that the influence of the larger downward pull of propeller when it was in the bottom of trailer counteracted the influence of the greater wind speed. On the other hand, the downward moment when the propeller in the bottom of the trailer was greater than that in the front of the trailer and the difference with the increment of the downward moment was significantly greater than the increment of the upward moment of the flat tail + elevator and the wing + flap under the same condition. Therefore, the trim angle of the model in the bottom of the trailer was less than that in the front of the trailer. In summary, affected by the blocking effect of the wind in the bottom of the trailer, the lifting force in \( z \) direction of the powered aircraft model was similar and the downward moment was larger when the model was in the bottom of the trailer compared with that in front of the trailer, which explained that the heave amplitude of the model in two conditions was similar and the trim angle of model in the bottom of trailer was smaller. Thus the drag of the model in the bottom of trailer was smaller.

![Figure 15. Computed aerodynamic lift of different parts.](image15.png)

![Figure 16. Computed aerodynamic moment of different parts.](image16.png)

![Figure 17. Attitudes of model and distribution of free surface at the speed of 11m/s.](image17.png)

Figure 17 showed the comparing between the attitudes of model in the bottom and front of the trailer and distribution of free surface at the speed of 11m/s, where the black grid area was the trailer and the pool wall. As shown in the figure, comparing with the model in the front of the trailer, model,
the trim angle and height of the wave system around model was smaller. Wave energy was provided by the body, so the wave amplitude small means less drag. From the height of the fault terrace, the heave of model in the two conditions were similar.

5. Conclusion
In this paper, the effect of blocking effect on the aerodynamic characteristics of a powered aircraft model was studied by experiment and numerical simulation. The following conclusions can be drawn from the above work:

1) The results of the test in the front and bottom of the trailer show that the drag and the trim angle were smaller when the model was in the bottom of the trailer, but the heave amplitude under the two conditions was similar.

2) The speed of the wind field in the bottom of the trailer was 9.1% higher than that in the front of the trailer on average, indicating that there was obvious blocking effect. While the wind speed in the front part of the trailer was consistent with the theoretical value which meant that there was not blocking effect.

3) The computed results of the model in the infinite domain and the front of the trailer were similar indicating that the blocking effect of water on the model can be negligible. The total drag and the trim angle of the model were significantly different when the model was in the front and the bottom of the trailer respectively, indicating that the blocking effect of the wind on the aerodynamic characteristics of the model was obvious.

4) By analyzing the aerodynamic components of each control surface of the model, compared with the model in the front of the trailer, there were similar aerodynamic lift force but larger downward moment when model in the bottom of the trailer. Therefore the heave amplitude was similar, the trim angle decreased, which meant the windward area of the ship was smaller and then the drag decreased.

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