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The Application of Overset Grid in the Analysis of Impact Loads of Amphibious Aircraft during Landing on the Water

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Abstract. In view of the complex three-phase coupling problem of gas, liquid and solid when amphibious aircraft landed on the water surface, based on the finite volume method, the overset grid technology was used to simulate the landing load characteristics of amphibious aircraft; firstly, the overset grid technology was used to establish the landing model of amphibious aircraft, and the load characteristics under different landing conditions were obtained, and compared with the model test results. The results show that, firstly, the larger the sinking speed is, the larger the load is, and the more obvious bounce phenomenon occurs; secondly, the transverse distribution of the bottom pressure gradually increases along the keel to bilge; thirdly, the load characteristics obtained by numerical simulation are basically consistent with the model test. Therefore, the overset grid technology can simulate the landing load characteristics of amphibious aircraft and provide an effective method for the landing load design of amphibious aircraft.

1. Introduction

Amphibious aircraft is one of the important equipment in the emergency rescue system of our country. It can put out fire in the forest or carry out search and rescue at sea. It is a strong guarantee to protect the ecological environment of our country and maintain the maritime Silk Road [1]. According to CCAR 25.519, the landing load of amphibious aircraft shall be designed according to the most severe load conditions that may be encountered in actual operation, and the landing load is the most important input condition for aircraft structure design and strength check. Therefore, the water load is closely related to the safety of the aircraft structure and the weight of the fuselage structure, which affects the overall performance of the aircraft. In the design of amphibious aircraft, reasonable and accurate water load design is a very important task.

With the development of high performance computer, numerical simulation technology has become a powerful means to analyze the landing load characteristics of amphibious aircraft. Ma [2] used ALE method to simulate the wave landing process of amphibious aircraft, and analyzed the load characteristics under different sinking speed and different encounter position. Sun [3] used the general coupling algorithm to simulate the landing process of amphibious flight. The simulation results are in good agreement with the experiments. Zeng [4] used ALE method to simulate the landing response of amphibious aircraft under wave conditions, and analyzed the aircraft attitude, overload and ship bottom pressure under different waves. Yao [5] used the cel method to analyze the time-dependent curves of the ship bottom pressure and vertical velocity of amphibious aircraft under different vertical speeds and attitude angles. Qu [6] uses the finite volume method to solve the RANS equation and K - ε , and uses the global dynamic grid method to simulate the dynamic response of the simplified aircraft model landing on water. Zhang [7] used SPH method to simulate the landing process of the aircraft under the sea waves, and obtained the acceleration and attitude angle curves with time under different working conditions.

In this paper, based on CFD numerical simulation method, using overset grid technology, the impact load of amphibious aircraft during landing on the water surface is simulated, and the load characteristics and motion response under different working conditions are obtained. The influence of sinking speed on the load characteristics is analyzed, and the law of pressure distribution at the bottom of the ship with time is summarized.

2. Overset grid technology

Overset grid technology divides each part of the object into separate grids, and then embeds them into another set of grids. There will be overlaps between the grids. After pre-processing such as digging holes, the grids outside the calculation domain (such as the grid cells located in the surface of the object) will be removed and excluded from the calculation, and the interpolation relationship will be established in the remaining overlapped grid areas. Finally, the data exchange between each set of grids can be carried out in the overlapped grid through the interpolation method. Overset grid technology makes the grid of complex shape easier to generate, and the quality of local grid can be guaranteed. By using the characteristic of overset mesh, the unconstrained six freedom motion of the object can be realized.[8][9]

$$\phi_I = \sum_{i=1}^{n} \omega_i \times \phi_i \tag{1}$$

In this equation, ω_i are the interpolation weighting factors, ϕ_I are the values of the dependent variable. ϕ_i at donor cells N_i ($N_1 \sim N_3$) and subscript $\boldsymbol{i}$ runs over all donor nodes of an interpolation element (denoted by the green triangles in the figure). This way, the algebraic equation for the three neighbor cells from the same mesh and three cells from the overset mesh ($N_4 \sim N_6$). As shown in Figure 1.

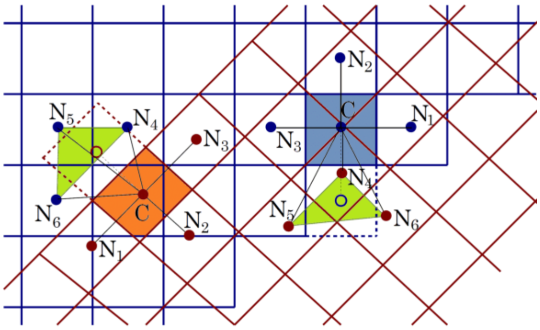

Figure 1. Diagram of overset grid

3. Geometric and model test

3.1 Geometric

Amphibious aircraft includes fuselage, wing, flap, vertical tail, flat tail, elevator and wing pontoon. When it lands on the water surface, the flap has a certain deflection angle, which makes the lift coefficient increase and the horizontal speed decrease when the aircraft lands on the water. At the same time, the elevator has a certain deflection angle, which provides a certain amount of lift moment for the aircraft, and avoids the aircraft's head burying under the action of hydrodynamic moment. The geometry of amphibious aircraft is shown in Figure 2 below:

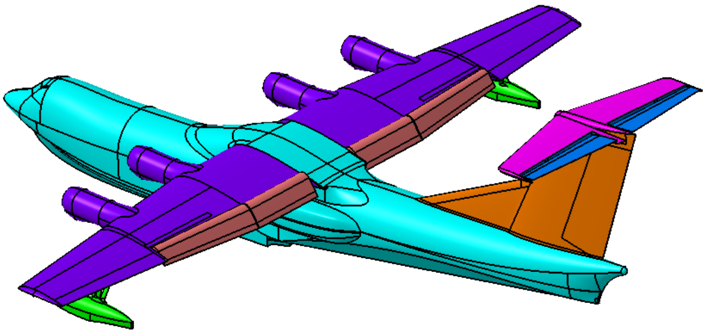

Figure 2. The geometry of amphibious aircraft

3.2 Model test

According to Fu rude's similarity criteria, the scale-up model of amphibious aircraft is designed, the model landing test device is developed, and the landing test is carried out in the high-speed towing pool, as shown in Figure 3:

Before the test, adjust the initial height and attitude angle of the model, and fix it with front and rear, left and right struts. During the test, the high-speed trailer is used to accelerate the model to a certain horizontal speed. When the speed is stable, the model will be released. Under the action of gravity and aerodynamic lift, the model will impact the water surface after falling freely, and the acceleration and bottom pressure during the impact process will be tested.

Figure 3. Test of amphibious model

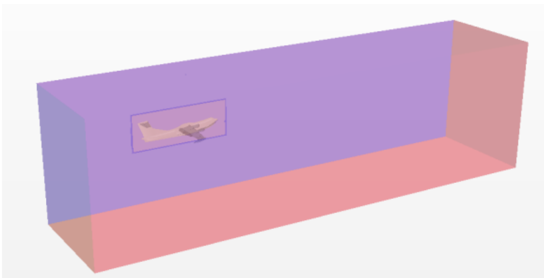

Figure 4. Computational domain

4. Mesh generation and boundary conditions

4.1 Mesh generation

The length of the aircraft is L. the entrance of the calculation area is 4L from the head of the aircraft, the exit is 1.5L from the tail of the aircraft, and the top and bottom are 1L from the aircraft respectively. In order to save computing resources, half of the basin is taken for calculation The trim grid is adopted. The hull surface grid size is 8 ‰ of the aircraft length. The wing and tail are locally encrypted. The grid size is 2 ‰ of the aircraft length. The free surface is locally encrypted, and the total mesh is 6.5 million. The distribution diagram of calculation domain is shown in Figure 4. The multi-phase flow model and VOF model are used to capture the free surface. SST k-omega turbulence model is used in the turbulence model, and the first-order upwind discrete scheme is adopted.

After the calculation domain is established, grid generation is carried out. In mesh generation, all kinds of meshes use cut volume mesh. According to the calculation domain grid, it is divided into background grid and overset grid. The overset grid is divided into three layers as a whole, namely, the surrounding part, the transition part and the outermost part of the aircraft. The outermost grid overlaps the background grid, and the size of this part of the grid is consistent.

4.2 Boundary condition

First of all, the background grid area, the inlet is set as the speed inlet, the outlet is set as the pressure outlet, and the rest, except for the symmetry plane, are all set as the speed inlet. Secondly, the overlapped grid area, the fluid area and the hull surface are set as overlapped grids, and the motion rules of the overlapped grid area are defined as DFBI rotation and translation. Finally, the interface between the background grid area and the overset grid area is calculated.

In DFBI, an aircraft is defined as a 6-DOF body, and its centroid is set. At the same time, set the initial value of the aircraft, such as the moment of inertia, initial speed. In this paper, the initial horizontal velocity of aircraft is defined as 15.7m/s. The time step of the solver is 0.025 s, and the maximum number of iterations is 5.

5. Results and discussion

5.1 Calculation condition

When amphibious aircraft land on the water surface, it usually keeps a small sinking speed close to the water surface. In this paper, five different sinking speeds are selected as calculation conditions. As shown in the following table 1:

Table1. Calculation conditions

Condition	Attitude /°	Horizontal velocity /m/s	Sinking velocity / m/s
1			0.2
2			0.4
3	6	15.7	0.6
4			0.8
5			1.0

When the calculation time is set to 0.8s, the complete landing process of amphibious aircraft is obtained. The vertical acceleration, vertical velocity, attitude angle, bottom pressure and horizontal velocity time history curve of the aircraft are monitored, and the load characteristics, motion response and ship bottom pressure under different sinking speeds are analysed . As shown in Figure 5, the free surface of the amphibious aircraft landing at different times.

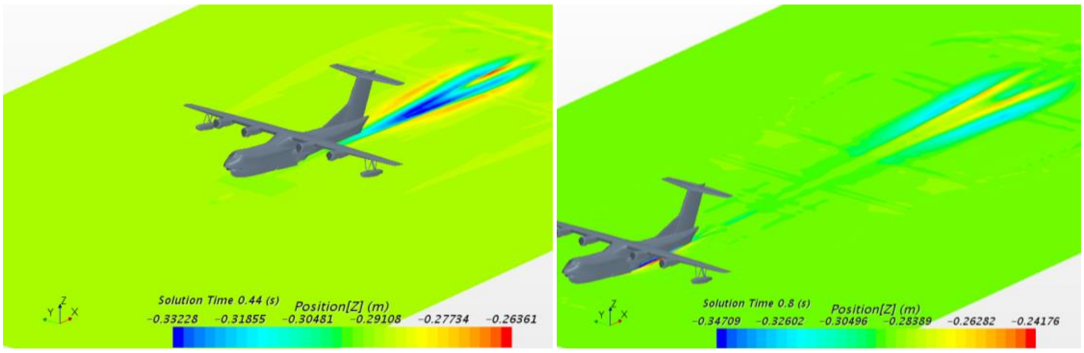

Figure 5. Free surface of amphibious aircraft landing

5.2 Load characteristics

The simulation results are compared with the model test, as shown in Figure 6, the vertical acceleration time history curve, showing good consistency, indicating the accuracy of numerical simulation.

Figure 6 shows that the larger the initial sinking speed is, the more obvious the vertical acceleration increases, and the earlier the peak occurs. In a short time, the peak acceleration of the aircraft is up to 2.15g. It can be seen that the landing process of amphibious aircraft is short and the load is very large.

A one-way coupling relationship is established between the fluid area and the structural area to transfer the bottom pressure to the structural area, extract the bottom pressure of each analysis step, select a cross section before the fault step, and analyze the pressure distribution law at different times.

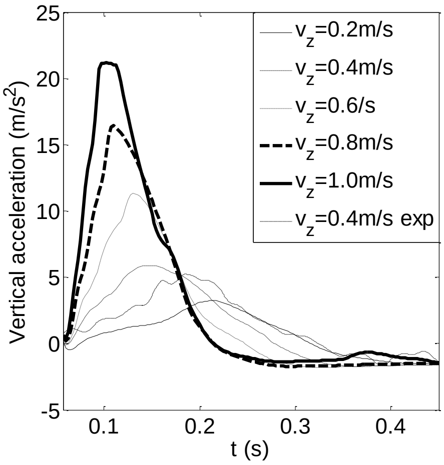

Figure 6. Time history curve of vertical acceleration

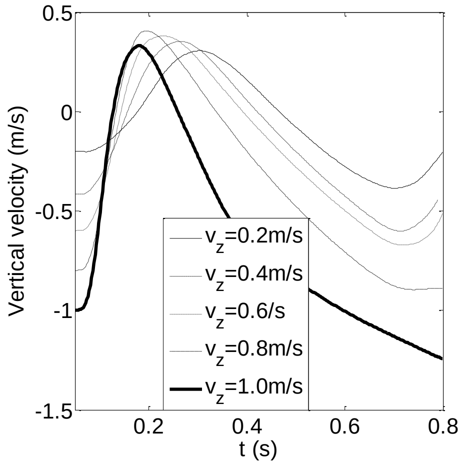

Figure 7. Time history curve of vertical velocity

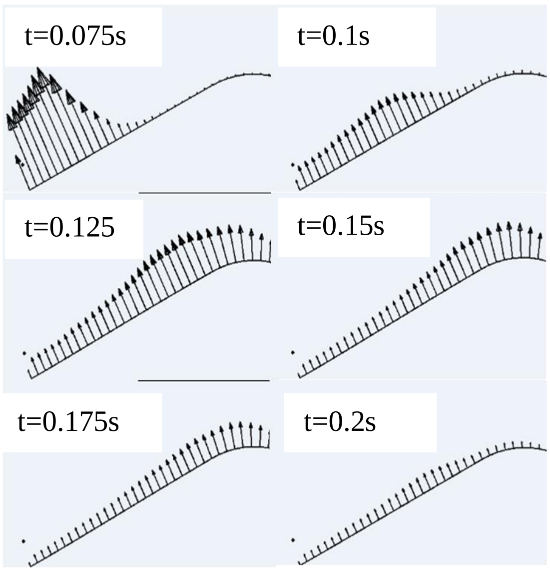

Figure 8. Pressure distribution at different times of 80mm cross section before fault terrace with V_Z = 0.6m/s

5.3 Motion response and pressure

Figure 7 shows the vertical velocity variation law under different sinking speeds. It can be seen that the larger the initial sinking speed is, the greater the impact load of water is, and the faster the vertical velocity decreases. Figure 7 shows that the smaller the initial sinking speed is, the earlier the plane hits the water again. Due to the impact force of water, the aircraft produces upward speed. Under the impact load and aerodynamic lift, the aircraft leaves the water surface and glides close to the water surface. Then under the action of aerodynamic lift and gravity, the aircraft strikes the water surface again and receives upward impact load, but it is not as large as the first impact load.

Figure 8 shows that when amphibious aircraft is connected to the water, there is a large pressure near the keel. As the aircraft lands on the water surface, the peak pressure transfers to bilge until the acceleration begins to decrease. When the acceleration is maximum, the peak pressure of bilge is 2-3 times of that of keel. Comparing Figure 6 and Figure 8, it can be seen that the resultant force of the pressure distribution is consistent with the time corresponding to the peak acceleration.

Figure 9 shows the curve of horizontal velocity changing with time. The larger the initial sinking velocity is, the greater the wetting depth is, the greater the water resistance is, and the faster the horizontal velocity decreases. Figure 10 shows the curve of attitude angle changing with time. After the plane hits the water surface, the attitude angle gradually increases.

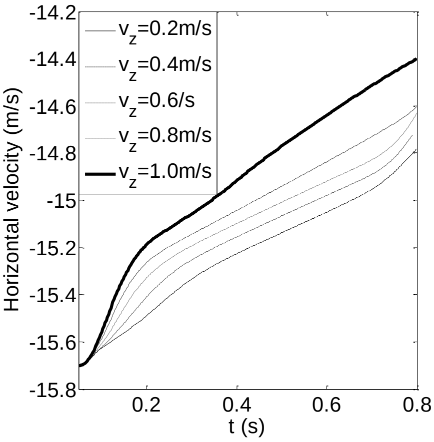

Figure 9. Time history curve of horizontal speed

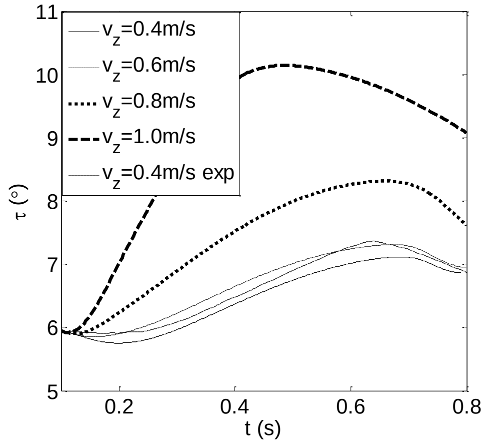

Figure10. Time history curve of attitude

6. Conclusions

Using the overset grid technology, the process of amphibious aircraft landing on the water surface at different sinking speeds is simulated, and the results are compared with the model test results, and the following conclusions are obtained:

1) The numerical simulation results are in good agreement with the test results, which shows the accuracy of the numerical simulation results;

2) When the amphibious plane lands on the water surface, the larger the initial sinking speed is, the greater the load it is subjected to, and the more obvious bounce phenomenon occurs.

3) In the process of landing, the transverse distribution of ship bottom impact pressure gradually increases from keel to bilge, but bilge is not completely immersed in the water.

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