Research on hull pressure distribution of amphibious landing on water based on RANS method

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Abstract. Aiming at the strength problem of amphibious landing on water, the pressure distribution of ship bottom is studied. RANS multi-phase flow method is used to solve the coupling problem of gas, liquid and solid in the process of amphibious landing on the water surface. Overlapping grid technology is used to simulate the landing under different initial horizontal velocity and vertical velocity. The influence of initial conditions on the motion response of amphibious is analyzed, and the variation law of pressure on each section of ship bottom with time is obtained. This paper analyzes the variation of pressure with time and position, and provides technical reference for the design and application of water loads in the development of amphibious.

1. Introduction

The landing of amphibious on the water surface is essentially a structural impact problem, and it is also a complex physical problem of gas, liquid and solid coupling. When it lands on the water surface normally, it has a high horizontal velocity, which leads to a huge impact load on the bottom of the ship.

In recent years, many scholars use a variety of simulation techniques to study the landing performance of amphibious, and achieved good results. Luo Linyin\(^1\) used LS DYNA simulation platform to analyze the curves of the center of gravity overload and the pressure at the bottom of the ship during landing. Sun Peicheng\(^2\) used MSC. DYTRAN software to simulate the landing impact process of amphibious. Yao Xiaohu\(^3\) used CEL coupled Eulerian Lagrangian algorithm to analyze the dynamic response of amphibious nose entry structure. Zeng Yi\(^4\) used ale fluid structure coupling algorithm to simulate the motion response of amphibious landing on regular waves. Chu Lintang\(^5\) studied the hull landing load by combining ale simulation with model test. Based on LS DYNA software, Ma Zenghui\(^6\) simulated the motion response of amphibious landing in waves, and studied the characteristics of attitude, heave and bottom pressure under the condition of facing waves. Qu Qiulin\(^7\) used the finite volume method to simulate the motion characteristics of naca2929 simplified model in water ditching by using the six-degree-of-freedom model and the whole dynamic grid technology. Zhang Sheng\(^8\) used SPH smoothed particle hydrodynamics method to simulate the forced landing characteristics of small aircraft on waves, and obtained the optimal forced landing state. Yan Ming\(^9\) used LS-DYNA software to simulate and analyze the process of a certain type of forced landing on water.

To sum up, on the one hand, due to the difficulties of theoretical analysis and model test technology, it is especially difficult to obtain the variation law of the whole ship bottom pressure with
time, which makes it difficult for amphibious to apply water load and strength verification test. On the other hand, scholars mainly focus on the change of landing load and attitude of amphibious aircraft. In this paper, RANS method is used to simulate the pressure at the bottom of the ship, and the impact area and change law of aircraft landing pressure are obtained.

2. Numerical method

2.1. Governing equation

The incompressible viscous flow continuity equation and RANS equation are used as the model:

\[ \frac{\partial p}{\partial t} + \frac{\partial (\rho u_i)}{\partial x_i} = 0 \]  

(1)

\[ \frac{\partial (\rho u_i)}{\partial t} + \frac{\partial (\rho u_i u_j)}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j} (\nu \frac{\partial u_i}{\partial x_j} - \rho \bar{u}_i \bar{u}_j) + S_i \]  

(2)

Where: \( u_i, u_j \) mean value of velocity component (\( i, j = 1,2,3 \)); \( \rho \) is the density of the fluid; \( p \) is the mean value under pressure, \( \nu \) is the viscosity coefficient of fluid motion; \( \rho u_i u_j \) is the Reynolds stress term, \( \rho \bar{u}_i \bar{u}_j \) is the average value of Reynolds stress term. The finite volume method is used to discretize the momentum equation, VOF method is used to capture the free surface, SST k-\( \omega \) is selected as the turbulence model.

2.2. Boundary condition

In this paper, a scaled model of an amphibious is selected as the object to simulate the landing performance. The length of the model is L, and the model shape is shown in Figure 1.

![Figure 1 Shape of amphibious model](image1)

The calculation domain and boundary conditions of amphibious are shown in Figure 2. Due to the symmetry of the aircraft, in order to reduce the computing resources and time, the right half of the computing domain is selected. The aircraft motion adopts DFBI motion specification, releases the longitudinal and vertical displacement and pitch rotation freedom of the aircraft, and sets the initial speed. The grid of computational domain and free surface are shown in Figure 3.

![Figure 2 Computational domain and boundary conditions](image2)
2.3. Mesh
In CFD, in order to capture the flow characteristics near the wall, grid nodes need to be arranged in the boundary layer. The calculation formula of the node height of the first layer grid in the boundary layer is as follows:

\[ Y^+ = 0.172 \text{Re}^{0.9} \left( \frac{\Delta y}{L} \right) \]  

In the above formula: Re is the Reynolds number, L is the model length, Δy is the height of the first layer grid node in the boundary layer, generally Y+ value is 50 ~ 100.

3. Result analysis

3.1 Calculation condition
The different calculation condition as follow:

| Condition | Weight/kg | Initial attitude/° | Horizontal speed m/s | Vertical velocity m/s |
|-----------|-----------|--------------------|-----------------------|-----------------------|
| 1         | 49.8      | 5.0                | 14.0                  | 0.4                   |
| 2         |           |                    | 15.0                  | 0.4                   |
| 3         |           |                    | 15.7                  | 0.2                   |
| 4         |           |                    |                       | 0.4                   |
| 5         |           |                    |                       | 0.6                   |
| 6         |           |                    |                       | 0.8                   |
| 7         |           |                    | 16.6                  | 0.4                   |

3.2 Motion analysis
The motion under different initial conditions are compared, as shown in Figure 4 and Figure 5.

Figure. 4 Time curve of motion response under different initial vertical velocity
It can be seen from the vertical acceleration curve in Figure 4 that the greater the initial vertical velocity, the greater the load generated by landing, and the shorter the time to reach the maximum load. The maximum load may appear in the second landing. It can be seen from Figure 5 that the larger the initial horizontal velocity, the larger the aerodynamic lift, and the smaller the landing load under the same initial vertical velocity. It can be seen from the vertical displacement and velocity curve in Figure 4 that the greater the initial vertical velocity is, the greater the draught is after landing. Under the impact of the water surface, it will leave the water quickly, and the greater the landing load is, the greater the distance from the water surface.

3.3 Hull bottom pressure analysis
In order to maintain the stability of landing, amphibious mainly choose the step landing instead of the bow or stern landing. Therefore, this paper mainly analyzes the pressure distribution in the front area of the step, and the action area is shown in Figure 6. The longitudinal section line, transverse section line are shown below pressure when the initial vertical velocity is 0.4 m/s, as shown in Figure 7 ~ Figure 11.
Figure 8 Pressure distribution along the bottom at 3rd and 4th longitudinal sections

Figure 9 The 1st and 2nd cross sections are laterally distributed along the bottom

Figure 10 Transverse distribution along the bottom when the 3rd and 4th cross sections
Figure 11 The pressure distribution of ship bottom at different time when the initial horizontal velocity is 15.7m/s (pressure unit: Pa)

4. Conclusion

Through the numerical simulation of landing of amphibious under different conditions, we can see the following conclusion:

1) The larger the initial vertical velocity is, the larger the landing load will be. The second and third landing will usually occur. The maximum load may occur in the second landing. The larger the initial horizontal velocity is, the greater the aerodynamic lift of the wing will be, and the smaller the landing load will be;

2) After landing, the amphibious has a severe impact on the water surface, and the draft increases rapidly. The stagnation point of the water surface contacting with the bottom of the ship forms a large pressure peak, and the stagnation point moves rapidly to the bow, and the stagnation point in the bilge has a large pressure. When the aircraft reaches the maximum impact load, the pressure peak is concentrated in the bilge area of the bottom of the ship, The larger the peak pressure of bilge, the larger the peak area.

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