Numerical Simulation Method for Wave Surface Landing of Seaplane

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Abstract: A seaplane is an aircraft that takes off and land on the water. The water surface is divided into a static surface and a wave surface. The numerical simulation technology of seaplane landing on wave surface is carried out. The accuracy of the simulation method of static water is verified by the comparison of simulation and experiment. The numerical wave generation is realized based on the pseudo-physical method, and the wave surface landing simulation is realized by combining the numerical simulation method with the numerical wave-making method. It is found that the pseudo-physical wave-making method can realize numerical wave-making and the precision is adjustable; then the water-water simulation of the wave surface is realized.

1. Introduction

Amphibious aircraft are aircrafts that can take off and land on both water and land. Their uses include transportation, water search and rescue, forest fire fighting, tourism and so on. They can also be used for maritime reconnaissance, patrol and anti-submarine missions. The amphibious aircraft will be impacted by the water surface during the surface landing, and the water impact load is one of the main load conditions of the amphibious aircraft. The initial analysis of the amphibious aircraft landing problem relies on engineering estimation methods and model tests. In recent years, with the development of computer hardware and numerical simulation software, numerical simulation has made great progress in solving large-scale engineering problems. There are more and more numerical simulation studies on water impact.

StreckWall et al [1] established the hydrostatic surface model of the aircraft in two programs Ditch and Comet respectively and obtained the change of the movement posture during landing on water. Nathalie [2] used the FE, SPH and FE-SPH hybrid methods to establish the water-entry model of an aircraft and studied the damage of the aircraft during the ditching and the influence of structure energy absorption on dynamic response. Zeng Yi et al [3] carried out numerical simulation calculations for the response of amphibious aircraft landing on wave-water and analyzed the load characteristics. Ma Zenghui et al [4] carried out numerical analysis on the seakeeping resistance of amphibious aircraft landing on the wave and analyzed the influence of wave height and wavelength on the seakeeping resistance. Yang Rong et al [5] used the fluid-solid coupling technique to analyze the overload of the center of gravity of the aircraft and the pressure response of the bottom of the hull. Qiu [6] uses CFD technology to calculate the aerodynamic and hydrodynamic forces of the amphibious aircraft during take-off by decoupling. The information is exchanged at each time step, and the resistance calculation
results have better accuracy. R. Ortiz [7] used the SPH method to simulate the landing of the aircraft on the water and analyzed the structural deformation and damage under the action of the ditching load.

At present, the research on the simulation of amphibious aircraft landing on the wave is still in the method exploration stage, and it can't meet the need to solve engineering problems. The research on this problem is divided into three steps, and the simulation method of the hydrostatic surface is first verified. Then numerical simulation of the wave environment is achieved. Finally, the simulation method of aircraft landing on wave is formed by combining with the static water surface simulation method and numerical wave method to form a wave surface.

2. The verification of hydrostatic surface simulation method

The water-entry process of the single ship hull is simulated using the nonlinear finite element software LS-DYNA. The aircraft structure adopts the Lagrange element algorithm, and the fluid adopts the ALE element algorithm. The element size is 0.02m, which satisfies requirements of the calculation result convergence, the simulation method uses the penalty function method to solve the contact force at the coupling interface. Figure 1 shows a calculation model for a single hull, including a single hull model, water and air. The research focuses on the water load and motion response of the aircraft. The deformation of the structure has little effect on the water load and motion response, only a few percent. Therefore, the single hull simulation model is rigidly processed, which is beneficial to improve the calculation efficiency. It is also possible to ensure the consistency of the weight, the position of the center of gravity, and the inertia of the calculation model by the definition of the rigid body attribute.

![Figure 1. FE model](image)

Figure 2 and Figure 3 show the simulation and experimental comparison of the acceleration and pitch attitude angles at the center of gravity of the model. It can be seen from the figure that the simulation and test data have a high degree of coincidence in the time history, which verifies the effectiveness of the simulation method.

![Figure 2. the acceleration at different cases](image)

![Figure 3. the pitch angle at different cases](image)

3. Numerical wave

Pushing waves is one of many imitation physics waves. The wave-making idea is like the real experimental wave pool, that is, the forced vibration of the simulated solid boundary is used as the disturbance source, thus generating the waves required for the experiment.
$H$ is the wave height, $h$ is the depth of the still water, that is, the height from the original still water surface to the bottom of the water tank, $S$ is the push plate stroke, the equation of motion of the push plate:

$$x = \frac{S}{2} \sin \omega t$$

(1)

Based on the assumption of the micro-wave, the relationship between the velocity potential and the speed of the push plate can be obtained:

$$\frac{\partial \phi}{\partial x} = u = \frac{S}{2} \cos \omega t$$

$$\frac{\partial \phi}{\partial z} = w$$

(2)

In the process of numerical wave making, when the fluid is treated as an incompressible fluid, the velocity potential satisfies the Laplace equation throughout the calculation region:

$$\frac{\partial^2 \phi}{\partial x^2} + \frac{\partial^2 \phi}{\partial z^2} = 0$$

(3)

Using the separation variable method to solve the Laplace equation, the expression of the velocity potential function can be obtained.

$$\phi = \sum_{n=1}^{\infty} C_n \frac{\omega}{k_n} \cos(k_n z) \sin(k_n x - \omega t) - \sum_{n=1}^{\infty} C_n \frac{\omega}{k_n} \cos(k_n z) e^{-k_n x} \cos(\omega t)$$

(4)

The following wave equation can be obtained:

$$\eta(x,t) = C_0 S \cos(k_n z) \sin(k_n x - \omega t) + \sum_{n=1}^{\infty} C_n \sin(k_n z) e^{-k_n x} \sin(\omega t)$$

(5)

among them: $C_0 = \frac{4 \sinh^2 k_n h}{2k_n h + \sinh 2k_n h}$

The first term on the right side of the upper middle is the expression of the traveling wave. The latter is the standing wave, which is generated during the movement of the wave-making plate. The standing wave disappears with its own propagation, so it can be ignored. The linear wave is obtained at a distance from the wave plate. For a wave with a given wave height, the stroke of the push plate is

$$S = \frac{A}{C_0}$$

(6)

The Euler mesh is used in the calculation of the flow field in this study. The geometrical dimensions of the water is 60m long, 1m wide and 1.5m high. The air field is 60m long, 1m wide and 1.5m high. The upper part is the air field. The lower part is water, and the finite element model information is shown in Table 1. The target wavelength is 6.25m, the wave height is 0.6m, and the period is 2s.

**Table 1. Model information**

|                     | Water domain | Air domain |
|---------------------|--------------|------------|
| Element type        | 8 node Euler elements | 8 node Euler elements |
| material            | *MAT_NULL | *MAT_NULL |
| Number of Element   | 90000        | 90000      |

Boundary conditions have an important influence on wave generation. For models without a wave-eliminating zone, except for the moving boundary and the upper surface of the flow field, the other boundaries must be bound in normal.
Figure 4 shows the waveforms at different times. By observing the wave generation process, the first wave is continuously consumed as the waveform propagates. This is due to the energy loss caused by the viscosity and numerical dissipation of the fluid. The waveform distortion closest to the wave-making boundary is more serious, but it will get closer and closer to the target waveform as the propagation distance increases.

The peaks of the four waveforms are selected to take the distance between the two adjacent peaks. The simulated wavelength is compared with the target wavelength. As shown in Table 2, the wavelength will decrease as the propagation distance increases, the overall error is small.

The waveform at different positions will be stable after 3-4 waves along the wave propagation direction. The average wave height and period at a position farther from the wave boundary will have a small decrease. The wave height and period at the four positions is like each other. The wave height and period of the waveform at 14m are compared to the target wave parameters to verify the quality of the generated wave. As shown in Table 2, the errors of the period and the wave height are within 10%, the wave quality can be further adjusted by adjusting the parameters of the boundary motion equation. As time goes by, the error tends to increase gradually. Therefore, when the simulation of the wave surface is forced to drop, the time with better wave precision can be selected as the water-entry time.

Table 2. Wave quality

| Wave length /m | error | period /s | error | Wave height /m | error |
|---------------|-------|-----------|-------|---------------|-------|
| simulation    | target|           |       | simulation    | target|
| 6.5           | 6.25  | 4%        | 2.18  | 2             | 9.0%  | 0.56 | 0.6 | 6.7% |
| 6.2           | 6.25  | 0.8%      | 2.18  | 2             | 9.0%  | 0.55 | 0.6 | 8.3% |
| 6.1           | 6.25  | 2.4%      | 2.17  | 2             | 8.5%  | 0.55 | 0.6 | 8.3% |

4. Simulation of aircraft landing on wave

Figure 5 shows the simulation of aircraft landing on wave simulated by the hydrostatic surface simulation method and the numerical wave-making technique. First, the model is stationary, the motion boundary conditions are set, and the wave is started. When the wave reaches the designated position, the aircraft starts to move achieving aircraft and wave encounters. It can be seen from the figure that after the aircraft encounters the wave, the aircraft gradually begins to rise. When the aircraft encounters the second wave briefly, it is bounced out of the water. Figure 6 shows the wave surface acceleration curve. Compared with the static water surface, the acceleration peak is reduced, but the duration is longer.
5. Conclusion
The main research conclusions are as follows.

1) The effectiveness of the simulation method is verified by comparing the simulation results of the hydrostatic surface with the experimental results.

2) Applying the pseudo-physical wave-making theory to the numerical wave-making process, the numerical wave is realized. The wave quality is quite well;

3) Based on the static water surface simulation technology and numerical wave-making technology, the simulation of aircraft landing on waves is realized. The simulation motion process and acceleration time history curve are calculated.

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