The Simulation of Aircraft Ditching Based on ALE Method

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Abstract: Ditching is an emergency measure for landing on the water when the aircraft cannot continue to fly in an accident. In order to verify the performance of the aircraft ditching, this paper carry out a simulation study on ditching of fixed-wing aircraft on the water. First determine the simulation method, material model and constitutive equation, and then analyze the influence of the sinking speed and attitude changes on the ditching of the aircraft. The simulation method adopts arbitrary Lagrange-Euler method (ALE). The results show that as the sinking speed increases, the load will increase accordingly. As the initial attitude angle increases, the vertical acceleration gradually decreases, and the longitudinal acceleration is basically the same, the pressure acting area gradually moves backward, and the pressure area gradually decreases. It is necessary to take appropriate local strengthening measures on the dangerous region.

1. Introduction

Ditching is an emergency measure for landing on the water when the aircraft cannot continue to fly in an accident. Ditching can be divided into planned ditching and unplanned ditching. Civil aviation regulations stipulate that to apply for certification with ditching, various practical design measures compatible with the general characteristics of the aircraft must be taken to minimize the probability that the occupant will be injured or unable to evacuate due to the movement and state of the aircraft during an emergency landing.

Ditching is a typical fluid-structure coupling problem. When the structure is impacted, it will also stimulate the movement of the fluid. The movement and deformation of the structure during the impact will affect the movement of the fluid [1,2]. Fluid-structure coupling have always existed throughout the process and is complicated. The duration of water impact load is short and the peak value is high, which is easy to cause structural damage, instrument failure, control failure, personnel casualties and other hazards. Therefore, carrying out research into the water load of structures has important engineering application value. With the development of numerical calculation methods and computer hardware, computer simulation has become more and more widely used in ditching. Olovsson and Souli [3-5], Aquelet and Souli[6], Bereznitzki[7], and Le Sourness[8] analyzed a series of fluid-structure coupling problems by this method. Chen Zhen[9,10] applied MSC. Dytran software to analyze the influence of air cushion on slamming during the process of flat-bottomed structure entering the water , and concluded that the slamming pressure peak was mainly caused by the compression of the air layer. Chen Xiaoping[11] applied experiments and numerical methods to analyze the influence of elastic effect on the slamming pressure and structural stress response of the wedge. Luo Hanbing[12] simulated the hydroelastic slamming of a three-dimensional stiffened wedge-shaped structure using the ALE method.
2. Calculation conditions

The maximum take-off weight state is selected for simulation to study the influence of the sinking speed and initial attitude on the water load and motion. The horizontal speed is 40m/s, the vertical speed is 1.0m/s and 1.5m/s. The initial attitude angle of the aircraft is controlled within the range of 6° ~13°.

The arbitrary Lagrange-Euler (ALE) description method can well solve the problem of free boundary and motion interface tracking in the fluid-structure coupling. The ALE method makes the grid motion independent of material and space by introducing a reference coordinate system, which not only overcomes the large deformation problem described by Lagrange, but also solves the interface tracking problem described by Euler[13]. The basic equation is as follows:

\[
\frac{\partial \rho}{\partial t} + \mathbf{m} \cdot \nabla \rho = -\rho \nabla \cdot \mathbf{u}
\]

\[
\rho \frac{\partial \mathbf{u}}{\partial t} + \rho \mathbf{m} \cdot \nabla \mathbf{u} = -\nabla p
\]

\[
\rho \frac{\partial e}{\partial t} + \rho \mathbf{m} \cdot \nabla e = -\nabla (p \mathbf{u})
\]

where: \( \mathbf{m} \) is the convection speed; \( \mathbf{u} \) is material velocity; \( \rho \) is the density of matter; \( e \) is the total energy per unit mass; \( p \) is the external load.

The penalty function method is selected to process fluid-solid interface coupling, which is equivalent to defining a series of spring-damping systems between the fluid and the structural nodes. Penalty coupling force is a function of relative displacement and relative velocity, as shown in equation (2).

\[
F = kd + cd
\]

Where \( k \) and \( c \) represent the spring stiffness and damping coefficient, respectively.

In LS-DYNA, the constitutive model and the state equation are used to describe the fluid material at the same time. The material property is defined by the empty material model * MAT_NULL. The relationship between the pressure and volume of water and air is given by the linear polynomial state equation[14]

\[
p = C_0 + C_1 \mu + C_2 \mu^2 + C_3 \mu^3 + (b_0 + b_1 \mu + b_2 \mu^2)E
\]

where, \( p \) is pressure; \( \mu \) is the rate of change of density; \( E \) is the internal energy per unit volume; \( C_i \) is the material constant.

The fuselage element type is shell163, and the flow element type is solid164. Figure 1 shows the finite element model.

![Figure 1 Finite element calculation model](image)

3. Calculation result analysis

Based on the analysis of the effects of different sinking speeds, different initial attitude angles and other factors on the ditching load and motion, the change law of the load is summarized. The impact occurs in a short period of time and then slides.

3.1 Effect of different sinking speeds on acceleration

Selecting the initial state of attitude 11°and simulating the water landing at 1m/s and 1.5m/s sinking speed. Figure 2 shows the comparison results of the vertical acceleration and heave at the center of gravity of the aircraft at different sinking speeds. The greater the sinking speed, the greater the peak value of vertical acceleration, the shorter the time to reach the peak value of acceleration. The depth of
water immersion is zero at the initial moment. The aircraft begins to sink after landing. At the same time, the landing of the stern causes the aircraft to bow down and further intensify the vertical movement of the center of gravity. The greater the vertical velocity, the shorter the time to reach the maximum water depth.

![Figure 2 Acceleration at different sinking speeds](image)

**Figure 2** Acceleration at different sinking speeds

### 3.2 Effect of different pitch angles on acceleration

Figure 3 and Figure 4 respectively show the vertical acceleration and heading acceleration curves at the center of gravity at the initial pitch angles in the range of 6-13°. Comparison shows that horizontal acceleration is much smaller than vertical acceleration, and the maximum value of horizontal acceleration is 0.49g. The maximum value of vertical acceleration is 3.99g, and the time of occurrence of the both is basically within 0.4s, which reflects the characteristic of short impact load time.

![Figure 3 Vertical acceleration](image)

**Figure 3** Vertical acceleration

![Figure 4 Heading acceleration](image)

**Figure 4** Heading acceleration

The landing position gradually moves back as the initial pitch angle increases. The farther the landing position is from the center of gravity, the greater the influence of the rotation of the fuselage on the acceleration at the center of gravity. Changes in the form of the fuselage under different landing positions will also cause changes in external loads, so the acceleration at the center of gravity is affected by the location and the configuration of landing point. It can be seen from Figure 5 that the horizontal acceleration peak at all angles has almost no change and the vertical acceleration peak decreases with the increase of the initial pitch angle. The main reason for this phenomenon is that as the initial pitch...
angle increases, the water landing part moves toward the tail of the fuselage, the farther the force action point is from the center of gravity. The greater the bowing moment that the aircraft receives, the greater the turning angular velocity, which reduces the acceleration at the center of gravity.

Figure 5 Peak acceleration comparison

3.3 Pressure distribution analysis

Arrange the pressure measuring points at the bottom of the fuselage in the horizontal and vertical directions. As shown in Figure 6, 25 pressure measuring points are arranged at the intersection of 8 transverse sections and 4 longitudinal sections on the one side of the fuselage to analyze the pressure distribution characteristics. In Table 1, the peak pressure of a certain working condition is counted and dimensionless processing is performed. It can be seen that with the increase of the initial attitude angle, the maximum pressure and the area of pressure distribution moves to the rear of the fuselage as a whole, and the pressure area gradually became smaller. The two areas circled in Figure 6 are the arcuate transition area at the belly of the fuselage and the rear of the fuselage, respectively. The arc-shaped transition zone will not directly collide with water, so the water pressure in such areas will be small or zero. As can be seen from Table 1, the cross-sections \( \odot 4 \) and \( \odot 8 \) have no pressure measured under all working conditions. The cross section \( \odot 7 \) is near the starting point of the arc-shaped transition of the tail. When the pitch angle of the fuselage is less than 11°, the position is always facing away from the direction of the incoming flow, so no pressure fluctuation is measured. When the pitch angle of the fuselage is greater than or equal to 11°, the location gradually changes from the backflow state to the up-flow state, and the pressure value and the pressure action range gradually increase.

Figure 6 Arrangement of pressure measuring points
### Table 1 Peak pressure statistics

| Pitch | Peak pressure | h1 | h2 | h3 | h4 | h5 | h6 | h7 | h8 |
|-------|---------------|----|----|----|----|----|----|----|----|
| 6°    | z1            | 0.000 | 0.230 | 0.297 | 0.000 | 0.089 | 0.294 | 0.000 | 0.000 |
|       | z2            | 0.000 | 0.225 | 0.070 | 0.000 | 0.115 | 0.278 | 0.000 | 0.000 |
|       | z3            | 0.000 | 0.192 | 0.000 | 0.000 | 0.064 | 0.211 | 0.000 | -    |
|       | z4            | -    | 0.205 | 0.000 | -    | -    | -    | -    | -    |
| 7°    | z1            | 0.000 | 0.126 | 0.317 | 0.000 | 0.140 | 0.366 | 0.000 | 0.000 |
|       | z2            | 0.000 | 0.115 | 0.120 | 0.000 | 0.174 | 0.304 | 0.000 | 0.000 |
|       | z3            | 0.000 | 0.106 | 0.000 | 0.000 | 0.090 | 0.270 | 0.000 | -    |
|       | z4            | -    | 0.096 | 0.000 | -    | -    | -    | -    | -    |
| 8°    | z1            | 0.000 | 0.004 | 0.295 | 0.000 | 0.177 | 0.372 | 0.000 | 0.000 |
|       | z2            | 0.000 | 0.004 | 0.168 | 0.000 | 0.187 | 0.356 | 0.000 | 0.000 |
|       | z3            | 0.000 | 0.004 | 0.000 | 0.000 | 0.117 | 0.314 | 0.000 | -    |
|       | z4            | -    | 0.001 | 0.000 | -    | -    | -    | -    | -    |
| 9°    | z1            | 0.000 | 0.000 | 0.227 | 0.000 | 0.173 | 0.391 | 0.000 | 0.000 |
|       | z2            | 0.000 | 0.000 | 0.135 | 0.000 | 0.152 | 0.410 | 0.000 | 0.000 |
|       | z3            | 0.000 | 0.000 | 0.000 | 0.000 | 0.109 | 0.365 | 0.000 | -    |
|       | z4            | -    | 0.000 | 0.000 | -    | -    | -    | -    | -    |
| 10°   | z1            | 0.000 | 0.000 | 0.079 | 0.000 | 0.125 | 0.555 | 0.000 | 0.000 |
|       | z2            | 0.000 | 0.000 | 0.041 | 0.000 | 0.122 | 0.439 | 0.000 | 0.000 |
|       | z3            | 0.000 | 0.000 | 0.000 | 0.000 | 0.082 | 0.351 | 0.000 | -    |
|       | z4            | -    | 0.000 | 0.000 | -    | -    | -    | -    | -    |
| 11°   | z1            | 0.000 | 0.000 | 0.000 | 0.000 | 0.055 | 0.611 | 0.002 | 0.000 |
|       | z2            | 0.000 | 0.000 | 0.000 | 0.000 | 0.052 | 0.476 | 0.000 | 0.000 |
|       | z3            | 0.000 | 0.000 | 0.000 | 0.000 | 0.023 | 0.439 | 0.000 | -    |
|       | z4            | -    | 0.000 | 0.000 | -    | -    | -    | -    | -    |
| 12°   | z1            | 0.000 | 0.000 | 0.000 | 0.000 | 0.008 | 0.539 | 0.025 | 0.000 |
|       | z2            | 0.000 | 0.000 | 0.000 | 0.000 | 0.008 | 0.498 | 0.015 | 0.000 |
|       | z3            | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.480 | 0.000 | -    |
|       | z4            | -    | 0.000 | 0.000 | -    | -    | -    | -    | -    |
| 13°   | z1            | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.419 | 0.079 | 0.000 |
|       | z2            | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.494 | 0.050 | 0.000 |
|       | z3            | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.419 | 0.000 | -    |
|       | z4            | -    | 0.000 | 0.000 | -    | -    | -    | -    | -    |

Note: h is a horizontal section and z is a vertical section.

### 4. Conclusion
Through the simulation and analysis of the aircraft ditching, the main conclusions obtained are as follows:

1) The greater the sinking speed, the greater the peak vertical acceleration, the shorter the time to reach the peak acceleration, and the shorter the time to reach the maximum depth;

2) The peak value of vertical acceleration at the center of gravity is gradually decreasing with the increase of the initial pitch angle, and the heading acceleration is less affected by the attitude;

3) As the initial attitude angle increases, the pressure action range gradually moves back and decreases;

4) The arc-shaped transition streamline makes the area at the bottom of the fuselage facing away from the incoming flow, and such areas are hardly affected by the impact pressure;
5) The local pressure near the cross section ②, ③, ⑤, ⑥ is relatively large. In order to better ensure the safety of the aircraft's during ditching, appropriate local strengthening measures may be taken in the corresponding area.

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