Research on Aircraft Falling in Water Based on Computational Fluid Dynamics

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Abstract

In order to completely perform the ditching, It is significant to study the motion of airplane, e.g.Three dimensional numerical model is established based on the volume of fluid (VOF) method in combination with the realizable viscous model, and dynamic grid technology. Six degrees of freedom (6DOF) trajectory were realized quantitatively in the simulation process . And the aircraft's attitude angle change, speed change and acceleration change are analyzed.

Keywords

The VOF method, 6DOF,Dynamic grid,Numerical simulation.

1. Introduction

The current research on the problem of structures dropping in water involves many fields, such as the entry of water in underwater vehicles, the falling of ships in the crash, or debris falling in aircraft debris, and deep-bomb underwater ballistics. Drops of structures in water are continuous, the environment in water is complex, and their trajectories are difficult to predict accurately.

Numerical simulation of submarine-launched projectile's launching and flow field was carried out [2]. The computational fluid dynamics (CFD) method is used to simulate the process of missile exiting from water by solving the Navier-Stokes equations. The free-surface problem is an important issue in fluid mechanics research. The multiphase flow model uses the free-surface tracking method such as MAC, VOF and Level-set methods [3]. The interface can deal with the flow problem where the free interface changes drastically but the interface is basically clear.

2. Organization of the Text

2.1 Theoretical basis

2.1.1 VOF Method

The VOF model can calculate a multiphase flow by solving a set of momentum equations and tracking the volume fraction of each fluid in the region [4]. The VOF equation is mainly applicable to two or more incompatible fluids.

The volume fraction of qth fluid in the grid is expressed as α_q, then $\alpha_q = 0$ means that the qth fluid of grid is empty, $\alpha_q = 1$ represents the grid filled with qth fluid, $0 < \alpha_q < 1$ represents grid q in the fluid and other fluids. Discrete formula of volume fraction is

$$\frac{\alpha_q^{n+1}\rho_q^{n+1}-\alpha_q^{n}\rho_q^{n}}{\Delta t}V+\sum_f \rho_q U_f^n \alpha_{q,f}^n=\left[\sum_{p=1}^{n}\left(\dot{m}_{pq}-\dot{m}_{qp}\right)+S_{\alpha_q}\right]V \qquad (1)$$

2.1.2 Dynamic Grid Method

Dynamic grids are generally used to grasp the dynamics of the flow field and track the dynamics of the boundary over time [5].In this paper, the approximate spring smoothing model is selected and the local reconstruction model of the grid is performed, in which the elastic constant is set to 0.5, the grid redraw method is applied to the local grids and local planes, and the size function is given. The other coefficients are always the default values. UDFs (user defined functions) are used to define the mass and moment of inertia of airplane.

In the inertial coordinate system, the center of gravity translation motion control equation is:

$$\dot{\vec{v}}_G = \frac{1}{m}\sum \vec{f}_G \tag{2}$$

Here, $\vec{v}_G$ is the translational movement of the center of gravity, m is the mass of the cylinder, and $\vec{f}_G$ is the vector of gravity.

2.1.2 Maintaining the Integrity of the Specifications

The realizable $k-\varepsilon$ viscous model contains an alternative formula for the turbulent viscosity. In the modified transport equation, the turbulence dissipation rate ε comes from the exact equation for the fluctuation of squared vorticity.

The transport equation is:

$$\begin{aligned}&\frac{\partial}{\partial t}(\rho k)+\frac{\partial}{\partial x_j}(\rho k u_j)=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right]+\\&G_k+G_b-\rho\varepsilon-Y_M+S_k\end{aligned} \tag{3}$$

And

$$\begin{aligned}&\frac{\partial}{\partial t}(\rho \varepsilon)+\frac{\partial}{\partial x_j}(\rho \varepsilon u_j)=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right]+\rho C_1 S\varepsilon-\\&\rho C_2\frac{\varepsilon^2}{k+\sqrt{v\varepsilon}}+C_{1\varepsilon}\frac{\varepsilon}{k}C_{3\varepsilon}G_b+S_\varepsilon\end{aligned} \tag{4}$$

Here,

$$C_1=\max\left[0.43,\frac{\eta}{\eta+5}\right] \tag{5}$$

$$\eta = S\frac{k}{\varepsilon} \tag{6}$$

$$S=\sqrt{2S_{ij}S_{ij}} \tag{7}$$

Where, G_k denotes the gradient turbulent kinetic energy from the average velocity, G_b represents the turbulent kinetic energy produced by buoyancy. Y_M is the swelled value of the compressible flow fluctuations, C_2 and $C_{1\varepsilon}$ are constants, σ_k and σ_ε are the turbulence Prandtl numbers for k and ε .

2.1.2 Other Methods

SIMPLC algorithm is applied to solve the pressure and velocity coupling, the least squares method to solve the gradient equation, PRESTO! to solve the pressure difference, and volume reconstruction to solve the volume fraction, the other are second-order upwind solution.

2.2 Data analysis

From Fig. 1,flying into the water after 0.2s, the wing began to interact with water. As the wing gradually entered the water, the speed of the aircraft began to decrease, and the lift generated by the air gradually decreased. At the same time, according to the theory of additional mass, with the increase of the part of the aircraft entering the water , the impact load increases, and the impact line gradually deviates from the center of gravity, causing the pitch angle to increase faster than that before 0.2s. Flying into the water at 0.8s, most of the aircraft fuselage entered the water, and the horizontal tail began to contact the water surface, causing the aircraft to form a pitching stable moment at the tail, which caused the aircraft to return to the original angle of attack, resulting in a slower pitch angle than before.At 1.8 s, the pitch angle of the aircraft changes again to -90°. After that, the pitch angle of the aircraft is less than -90°, and it keeps decreasing.

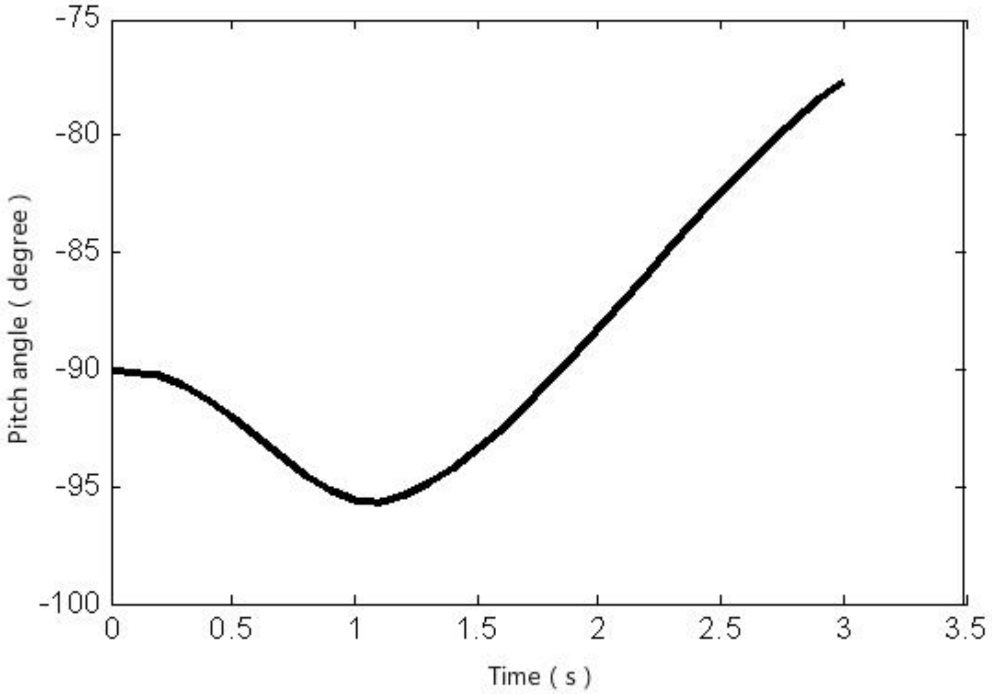

Fig. 1 Pitch angle changes during landing of aircraft

From Fig. 2,When the aircraft enters into the water, the initial deflection angle is -60 degrees, resulting in asymmetric forces on the left and right sides, making the aircraft's deflection angle continue to change: 0.3s before, only the head entered into the water.At t=0.4s, most of the left wing and right engine enter the water. That the water entered the fuselage causes a surge between the fuselage and the right engine, and the right engine is subjected to water impact loads to the right and upwards, which increases the deflection angle of the aircraft.

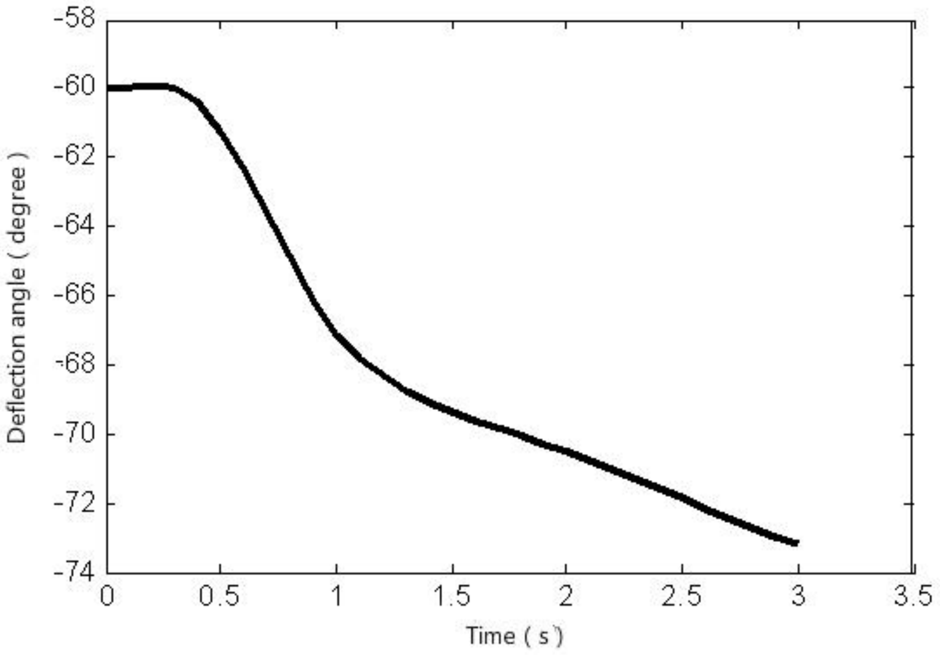

Fig. 2 Deflection angle changes during landing of aircraft

From Fig. 3,It can be seen that the vertical velocity of the aircraft has been reduced, and there are two peaks in the acceleration of the aircraft. 0-0.22s, the nose part hits the water surface, and the aircraft is subjected to an upward water impact load, which causes the vertical acceleration of the aircraft to change from negative to positive. At 0.4 s, the left wing of the aircraft entered the water and the acceleration increased to 41 with the first peak. After 0.4s, the vertical acceleration showed a decreasing trend. At 0.9 s, the right wing is completely filled with water and the second peak of vertical acceleration occurs. Because the speed of the aircraft is less than the speed at which the left wing completely enters the water, the impact load on the aircraft is relatively small, so the second vertical acceleration peak value is smaller than the first peak value. After 1.1s, the aircraft taxied in water, which was mainly affected by buoyancy, water resistance, and gravity. The vertical acceleration decreased and stabilized.

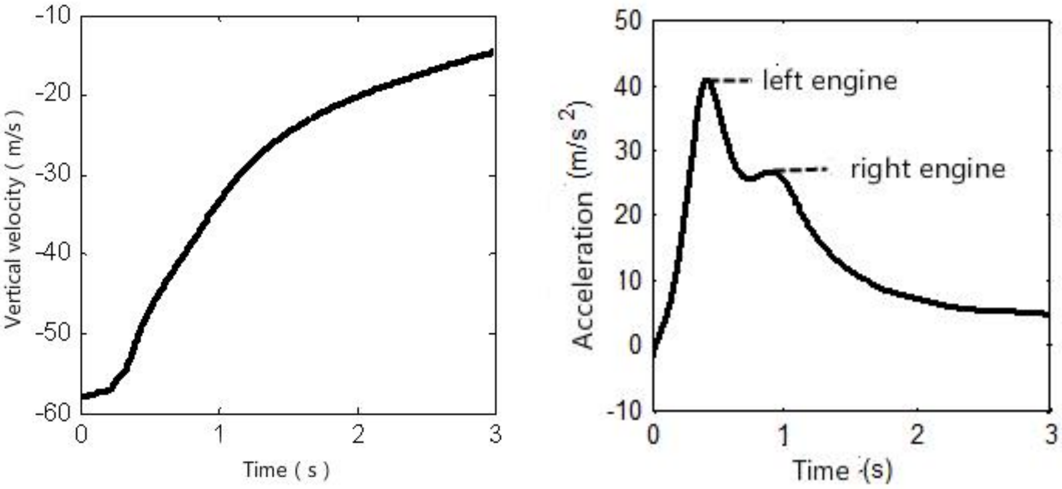

Fig. 3 Vertical velocity and acceleration changes during landing of aircraft

3. Conclusion

The simulation reflects the process of aircraft flying into water .The aircraft is forced to adjust according to changes in attitude and force of the aircraft. And according to the condition of the aircraft, the connection between the wing and the engine of the aircraft is strengthened.

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