ICAS 2021 SHANGHAI
International Council of the Aeronautical Sciences
32nd Congress of the International Council of the Aeronautical Sciences
September 6-10, 2021
Pudong Shangri-La, Shanghai, China

NUMERICAL ANALYSIS METHOD OF CIVIL AIRCRAFT DITCHING FLOATING PERFORMANCE

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Abstract

Floating performance analysis is an important aspect of civil aircraft cabin safety, and floating time determines whether crews and passengers on board can successfully evacuate after ditching. An iterative floating numerical analysis method based on Finite Volume Method and floating basic principles has been developed in this paper. This method employs STAR-CCM+ software as computation environment to analyze the floating time. A method has been established for calculating the floating performance of aircraft during ditching. The floating performance of civil aircraft was studied as analysis case and results show the method is suitable for floating analysis.

Keywords: floating performance, numerical analysis, accident survivability.

1. Background

According to aviation regulations, such as Article 1415 of CCAR(China Civil Aviation Regulation) 25-R4[1] , it must be shown that under reasonably possible water conditions, the floating time and trim of the aircraft can enable all occupants to leave the aircraft and board the lifeboat.

Several analysis methods and tools have been developed to calculate the floating performance. Patel and Greenwood reviewed accident data related to water impacts and ditching performance and described dynamic floating analysis process[2]. Wang Ming-zhen et al., established a method based on Archimedes' statics theory, calculating the floating performance by using the optimization module in commercial software [3]; Zuo Zai-bin et al., discretized the dynamic process of the aircraft floating on the water surface and sinking in a time-continuous quasi-static manner, based on fluid mechanics theory and the secondary development technology of commercial software[4].

A numerical analysis method for the floating performance of civil aircraft is proposed to refine the existing calculation methods above. The method is based on the Archimedes principle and the principle of fluid mechanics. The STAR-CCM+ software is employed to simulate the aircraft floating behavior.

2. Floating Process Analysis

After ditching, the aircraft will go through the initial bowing phase, the raising phase caused by the rear body suction, and the subsequent bowing phase[5]. The floating process of the aircraft entering and sinking on the water surface is a slow and continuous floating state change process [6]. According to Patel and Greenwood’s review[2], the process can be divided into two stages. The first stage is static analysis stage in which an initial dynamic equilibrium is reached when the aircraft stops moving along the water surface. During this process, the rear fuselage loses buoyancy. This stage can be seen as a static analysis stage. The second stage is a dynamic analysis stage, in which the aircraft starts to sink and maintains a dynamic equilibrium in a quasi-static manner. In the second stage of floating, the leakage source area of the aircraft is conservatively assumed to keep the largest.

3. Calculation Principle

According to Archimedes' principle, during the dynamic balance process of aircraft floating on water, the following two constraints need to be met: the line starting from the center of buoyancy to the center of gravity is perpendicular to the water surface; the buoyancy is equal to gravity [6].

The leakage of an airplane is that water flows from the outside of the airplane into the airplane. According to the outflow conditions, it can be divided into free outflow and submerged outflow, as shown in Figure 1 and Figure 2.

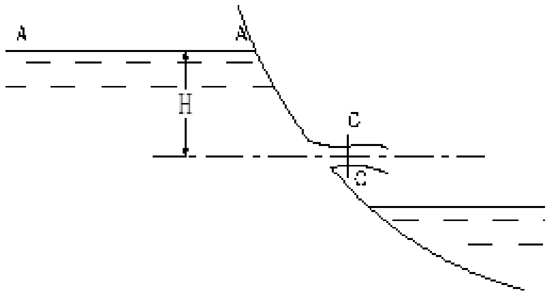

Figure 1：free outflow

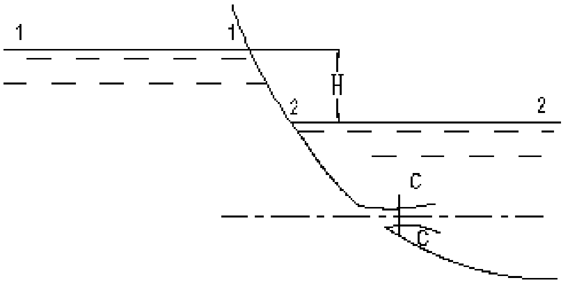

Figure 2：submerged outflow

In order to simplify the calculation, the constant total flow Bernoulli equation is adopted. For free outflow shown in Figure 1, the free water surface A-A, the height of the leakage centre line from A-A is H. The outside water flows from all directions to the leakage position. After flowing out from the leakage position, a contraction section C-C is produced. A-A and C-C Energy equation of two sections is given below:

$$Z_A + \frac{P_A}{\gamma} + \frac{\alpha_A \upsilon_A^2}{2g} = Z_C + \frac{P_C}{\gamma} + \frac{\alpha_C \upsilon_C^2}{2g} + he \tag{1}$$

For submerged outflow shown in Figure 2, H is height difference between the upper and lower free water surfaces 1-1 and 2-2. Outside water flows from all directions to the leakage. After flowing out of the leakage, a contraction section C-C will be produced. The energy equations of 1-1 and 2-2 sections is given below:

$$Z_1 + \frac{P_1}{\gamma} + \frac{\alpha_1 \upsilon_1^2}{2g} = Z_2 + \frac{P_2}{\gamma} + \frac{\alpha_2 \upsilon_2^2}{2g} + he \tag{2}$$

Where Z is the elevation of the selected leakage flow section related to the datum plane, P is the pressure at the leakage section, V is the average velocity of the corresponding section, α is kinetic energy correction coefficient of the corresponding section, *he* is the average pressure loss between two sections.

Floating behavior simulation process is shown in Figure 3.

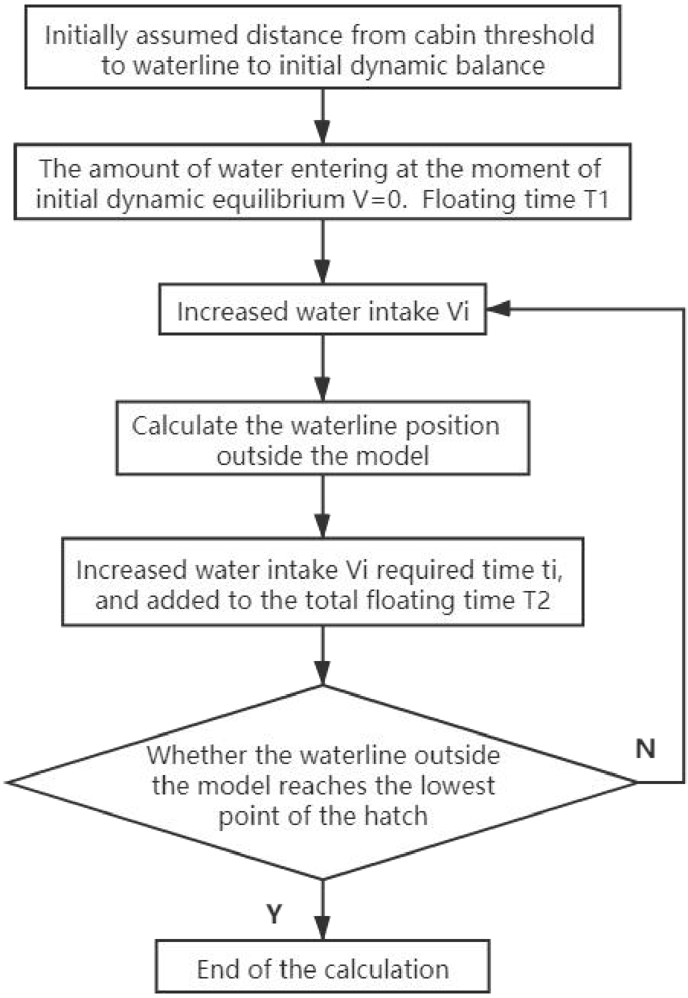

Figure 3：Floating behavior simulation flow chart

4. The Overall Aircraft Finite Volume Element Model

After importing the aircraft geometry into STAR-CCM+, geometry inspection and repair will be conducted, such as removing free edges and pierced surfaces. Surface mesh reconstruction needs to be performed to meet the subsequent volume mesh quality requirements. The overall aircraft model will be discretized using high-quality Trimmed Cell.

The damages of the aircraft are not considered for non-planning ditching. The aircraft fuselage has not considered additional leakage sources except for the body openings such as maintenance panels.

Figure 4 shows examples of leakage sources located in the rear fuselage and the bottom of the front fuselage.

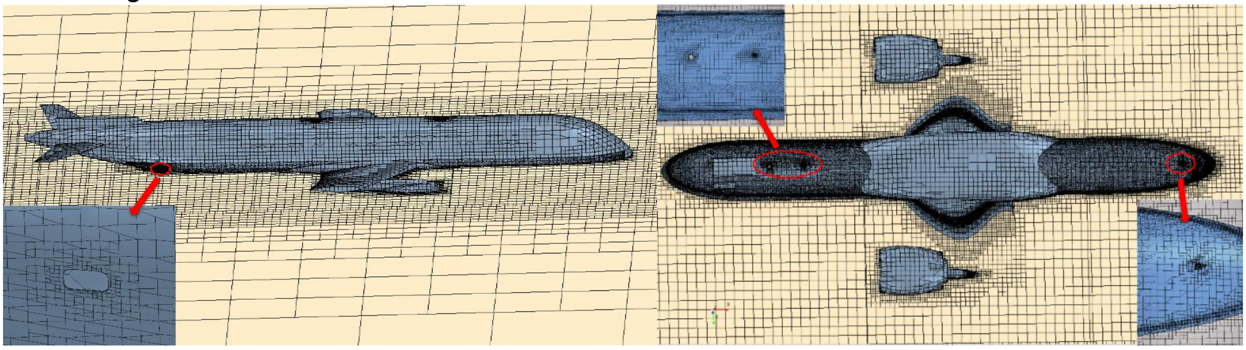

Figure 4：Meshing around leakage sources in front and rear fuselage.

5. Calculation and Analysis of the Floating Performance of a Civil Aircraft

A civil aircraft was investigated as a study case to calculate and analyse its floating performance on static water. In order to obtain conservative analysis results, several assumptions were made below: the inherent leakage source and the damaged leakage source were considered at the same time; the leakage source remains the largest area of the opening; the simulation was terminated when the contact waterline reached the rear point of any passenger cabin; the maximum takeoff weight and most rear center of gravity were chosen as the worst scenario.

Figure 5-7 show the floating top view, side view and floating performance curve of the static analysis stage, respectively. Figure 8 and Figure 9 show the floating side view and floating performance curve of the dynamic analysis stage.

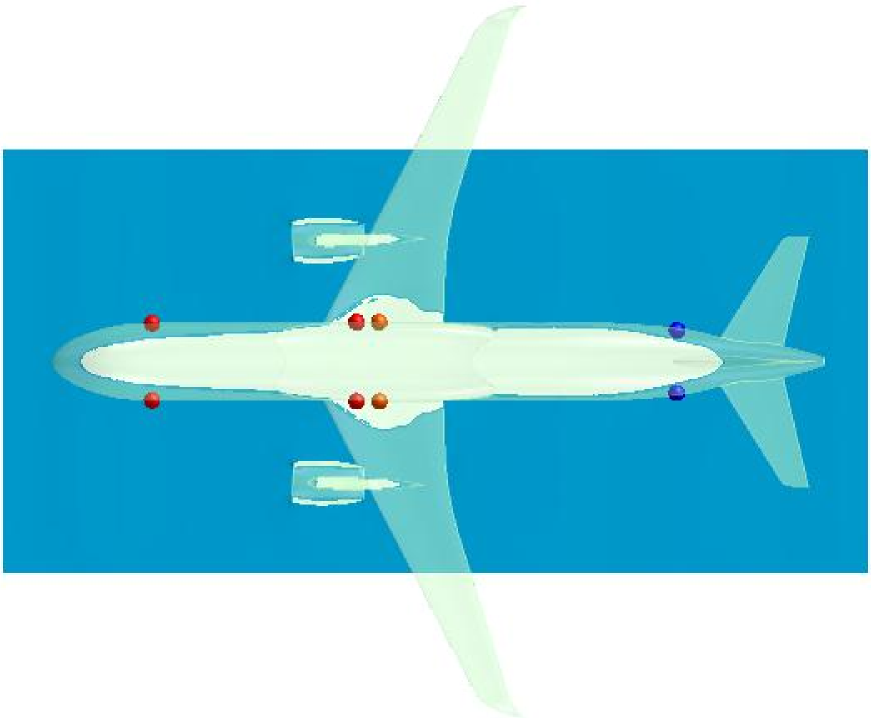

Figure 5: Floating top view

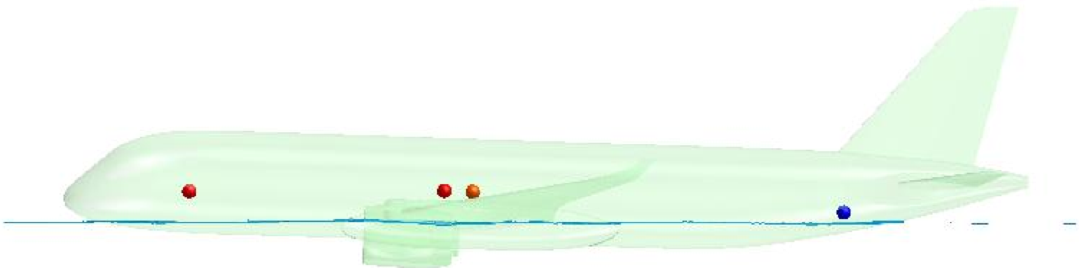

Figure 6: Floating side view

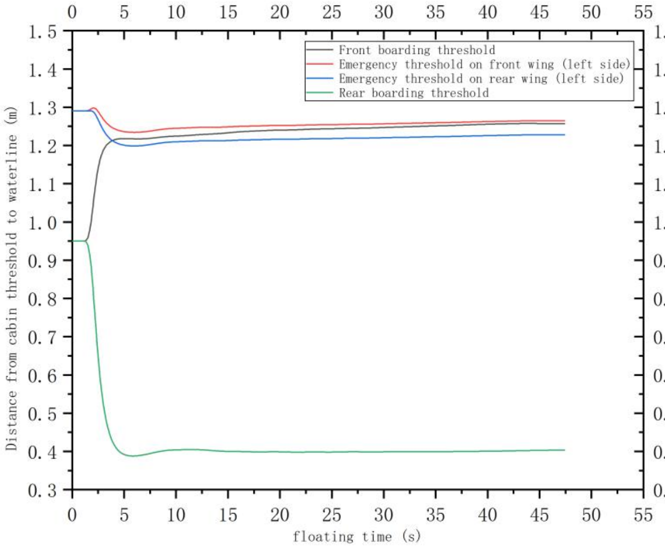

Figure 7: Floating performance curve

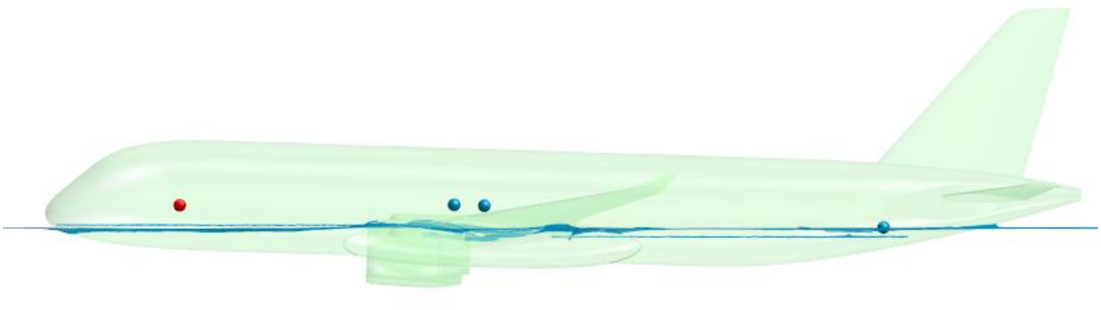

Figure 8: Floating side view

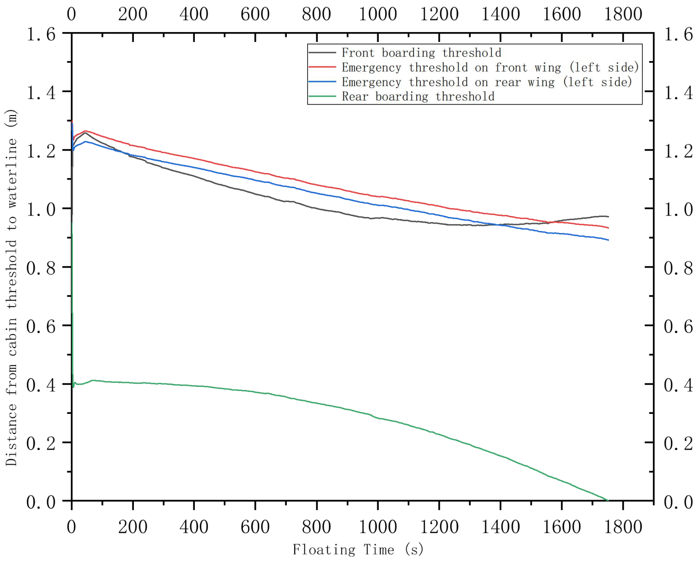

Figure 9: Floating performance curve

The results show that as the aircraft floats on the water surface, the water intake of the aircraft gradually increases and the distance between the rear door and the water surface gradually decreases. Meantime, the distance between the front door and the water surface gradually increases and the trim angle gradually increases. The increasing speed of the water intake gradually decreases. This is because with the increase of the aircraft water intake, the height difference between the inner and outer water surfaces gradually decreases. The calculation results are consistent with the theoretical analysis results and the actual surface floating phenomenon of the aircraft.

Figure 10 and Figure 11 show the distance between the rear boarding threshold and the waterline versus floating time and the distance between the front boarding threshold and the waterline versus time under five different combinations of weight and centre of gravity. It can be found that the floating performance of the combination of front weight centre of gravity conditions and rear weight centre of gravity conditions respectively show basic consistency.

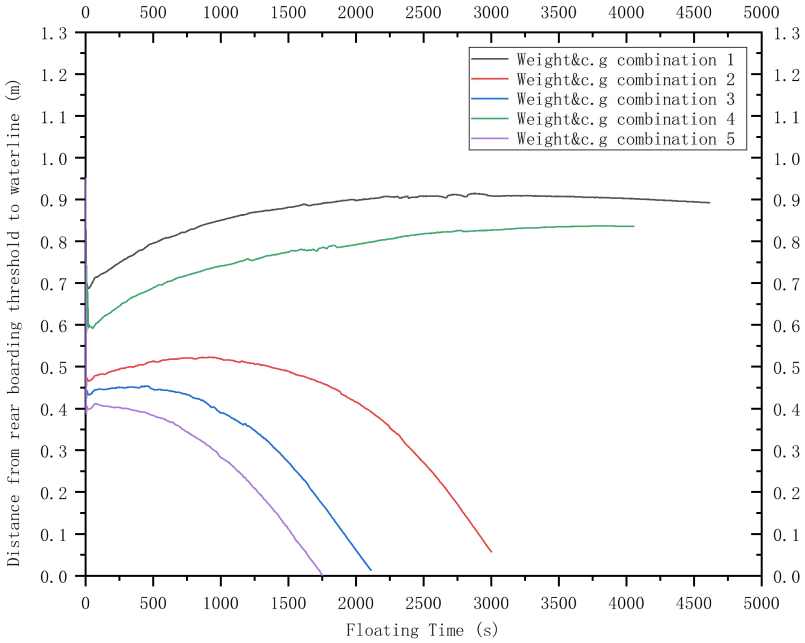

Figure 10: The distance from the rear boarding threshold to the waterline

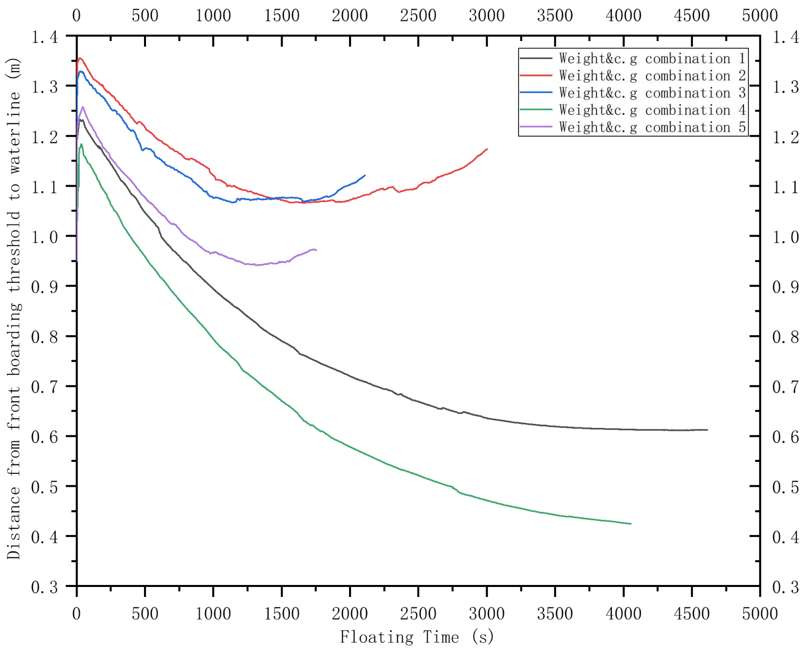

Figure 11: The distance from the front boarding threshold to the waterline

6. Conclusions and Discussions

The dynamic process of aircraft floating on the water surface has been investigated in a time-continuous dynamic balance manner. A calculation method of the aircraft floating performance has been established. The dynamic balance process satisfies the hydrostatic balance relationship and follows the principles of fluid mechanics and Archimedes principle. By using the STAR-CCM+ software, the aircraft floating performance has been simulated. The floating performance of civil aircraft has been studied as analysis case and results show the method is suitable for floating analysis.

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8. Copyright Statement

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