Computer Estimation Method of Static Floating Characteristics of Airplane by Numerical Simulation

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Abstract. Floating characteristics research involves the airworthiness certification of aircraft for ditching. This article takes the static floating characteristics of the aircraft as the goal, and studies the stated floating attitude of the aircraft without loss of buoyancy. This paper also calculates the floating attitude of a certain up-wing airplane passenger aircraft, and analyzes its static floating characteristics.

Keywords: Static floating characteristics, Engineering estimate, Ditching, Civil airliner, Numerical Simulation.

1. Introduction
The research on the performance of forced landing on water is an important work for civil aircraft to obtain airworthiness certification [1]. To implement a planned emergency landing on the water, it is necessary to implement a reasonable emergency landing procedure to ensure the safety of passengers and obtain sufficient time to escape [2]. The emergency landing process is generally divided into 4 stages, approach, impact, landing, and floatation. Among them, the approach, impact, and landing phases of research focus on the attitude changes of the aircraft and impact overload. The existing research results in this part are relatively rich. Mainly based on theoretical research [3][4], experimental research [5],[6] and numerical research [7][10] Floatation is the final escape stage of emergency landing on water. At this stage, the aircraft basically stopped taxiing and floated on the water. The research object of static floating characteristics is the floating attitude and stability of the aircraft on the water surface without damage in the confined area of the aircraft. There are relatively few studies at this stage, and it is also the focus of this article.

2. Parameter solution
Static floating characteristics study the stable attitude of aircraft floating in static water. The condition is that gravity is equal to buoyancy and the external moment is zero. Specifically, the solution is guided by Archimedes principle and moment equation:

\[ F_{\text{float}} = \rho_{\text{water}} V_{\text{sub}} g \]
\[ M = F \times L \]
2.1. Model discretization
Two sets of coordinate systems are required for calculation, the body coordinate system \((x_b, y_b, z_b)\) and the ground coordinate system \((x_g, y_g, z_g)\). The origin of the ground coordinate system is on the water surface, and \(z=0\).

First, simplify the airplane model and keep a complete confined area. For example, passenger cabins, cargo warehouses and wing fuel tanks. Remove non-pressurized areas and components that may be damaged, and subtract the weight of damaged components from the total weight of the aircraft to determine the new center of gravity and moment of inertia.

2.2. Buoyancy solution
After the water surface position and the aircraft attitude are determined, the current aircraft immersion volume can be calculated. The following first uses the fuselage as an example to solve the immersion volume. Discrete the airplane model into points and slice them along the axis of the fuselage (the wings are in the span direction). The coordinate conversion matrix is as follows:

\[
\begin{bmatrix}
x_g \\
y_g \\
z_g
\end{bmatrix} =
\begin{bmatrix}
\cos \alpha & \sin \alpha \sin \beta & \sin \alpha \cos \beta \\
0 & \cos \beta & -\sin \beta \\
-\sin \alpha & \sin \beta \cos \alpha & \cos \alpha \cos \beta
\end{bmatrix}
\begin{bmatrix}
x_b \\
y_b \\
z_b
\end{bmatrix} -
\begin{bmatrix}
y_{b,g} \cos \beta - z_{b,g} \sin \beta \\
0 \\
y_{b,c,g} \sin \beta + y_{b,c,g} \sin \beta \cos \alpha + z_{b,c,g} \cos \alpha \cos \beta
\end{bmatrix}
\]  

In the formula, \(\alpha\) is the trim angle and \(\beta\) is the heeling angle. \((x_{b,c,g}, y_{b,c,g}, z_{b,c,g})\) is the coordinate of the center of gravity in the plane body’s coordinate system.

The trapezoid method is used to solve the area and integrate to obtain the submerged area. Knowing the immersion area and tangent distance of each tangent plane, then integrate to solve the immersion volume. Knowing the immersion volume, get the fuselage buoyancy according to formula (1).

2.3. Buoyancy moment solution
After the immersion volume between slices is obtained, the buoyancy of the immersed part between slices is made to take moments with respect to the center of gravity of the aircraft. Through integration, the complete buoyancy moment is obtained.

3. Static floating characteristics calculation process
The static floating characteristics of the aircraft need to obtain the parameters of the balance attitude of the aircraft floating on the water surface under different aircraft weights and center of gravity positions. Including roll angle, pitch angle, height of center of gravity and height of emergency exit from water surface during balance. After the aircraft weight and the position of the center of gravity are given, the
aircraft center of gravity height, pitch angle, and roll angle are continuously adjusted through the dichotomy. Finally, the combined external force, rolling moment, and pitching moment of the aircraft are all 0 at the same time, and the current balance attitude can be obtained.

4. Analysis of the static floating characteristics of the up-wing airplane
Due to its shape and structure characteristics, up-wing airplanes face more severe problems in terms of floating characteristics than low-wing planes. The center of gravity of the up-wing airplane is high, and the roll angle may change greatly during the floating process, which will affect the escape process.
The length of the model aircraft fuselage is about 24.713 m, the maximum cross-sectional area of the fuselage is about 5.961 m, the wingspan is 27.513 m, the wing root chord is 3.323 m, and the wing tip chord is 1.264 m. The model is simplified as follows:

![Diagram of aircraft model](image)

**Figure 3.** The position of each door of the aircraft model.

**Table 1.** The coordinates of the midpoint of the bottom of each hatch.

|            | X    | Y    | Z   |
|------------|------|------|-----|
| Cockpit door | 5.565 | -1.229 | 0   |
| Emergency exit | 7.095 | 1.229  | 0   |
| Left service door | 22.530 | -1.109 | 0   |
| Right service door | 22.530 | 1.109  | 0   |

4.1. Solution uniqueness verification

First, determine the number of stable equilibrium points when the aircraft is floating. Taking the maximum take-off weight of 26500 kg and 15% of the front center of gravity position as an example, the pitch angle is -5° to 15°, and the roll angle is 9° to 15° near the water contact with the wing. Calculate the buoyancy moment when the aircraft's gravity is equal to the buoyancy. The calculation parameters are as follows:

**Table 2.** Quality and coordinate parameters.

| Ixx (kg \cdot m^2) | Iyy (kg \cdot m^2) | z_{b,c,g} (m) | y_{b,c,g} (m) | x_{b,c,g} (m) |
|---------------------|---------------------|----------------|----------------|----------------|
| 333577              | 1092718             | 0.630          | 14.102         | 0.020          |
Project the curve where the rolling moment and the pitch moment are 0 to the XY plane to get an intersection point. The pitch angle is 0.550781°, and the roll angle is -10.386619°. According to the slope of the moment curved surface, this point is judged to be a stable equilibrium point.

Figure 4. Pitch moment and roll moment.

Figure 5. Zero moment point.
4.2. Static floating characteristics calculation results

(a) The height of the center of gravity.  
(b) Pitch angle.  
(c) Roll angle.  
(d) Height of the right service door bottom edge

Figure 6. Floating posture under different center of gravity positions and gravity.

The average aerodynamic chord of the airliner is used as a reference for the change in the axial position of the center of gravity. The weight varies from 14500kg to 38500kg. Calculate the equilibrium initial floating state of the aircraft. Obtain the variation range of the center of gravity height, pitch angle, roll angle and the bottom position of the most dangerous hatch (right service door).

When the height of the center of gravity is lower, the pitch angle and roll angle are larger, and the height of the right service door from the water surface is smaller, that is, the more dangerous it is.

The contour map of the height of the right service door from the water surface can be used to judge whether the aircraft is in a dangerous area. It can be seen from Figure 7 that the empty weight and center of gravity change range of the regional passenger aircraft are within a safe range.
Conclusions
Starting from hydrostatics, this article uses Archimedes' principle to solve the problem of buoyancy and stability of static floating characteristics. The static floating characteristics of the up-wing airplane have been studied. This method maintains a low calculation cost while ensuring a certain calculation accuracy.

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