The Calculate Method of Flotation for Unbreakable Airplane

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Abstract. According to CCAR, the airplane which apply for cross ocean flight should do some airworthiness compliance on floatation after ditching. Because of the imperfect method in this area, we can not obtain the exact result which restrict the level promoted for airplane design. So an distinct and easy method is needed imminently. In this paper, we build a calculate method of attitude motion for floatation on hydrostatics, time domain and stepwise regression theories. Though decompose the yield of water into tiny part and make use of the relationship between float time and yield of water, we develop a software which is good at analyse the float time on the basic of CATIA If we study the floatation character in this way, we may save much time and simplify the complex question. In the end of this paper, we analyse the floatation for an airliner and the result shows that rhythms by calculate is good accord with that of experiment which declare the rationality of that method.

1. Introduction

Once ditching by accident, the aircraft will impact the water surface at high speed for the fast speed and heavy weight. At this time, the huge and complicated hydrodynamic and aerodynamic loads on the body will cause the fuselage serious damage, wing breakage and even aircraft capsiz. Under these above harsh conditions, the aircraft will enter the water quickly and eventually lose its floatation.

A great deal of research and practical experience show that. After the bottom of the fuselage is damaged, the external fluid entering the cabin through the floor is the main reason for the aircraft sinking. Among them, the rapid sinking of aircraft is the fatal cause of the failure of landing on water. According to incomplete statistics, at least 50% of the failure of ditching is due to the submergence of aircraft [1].

In order to reduce or even avoid the occurrence of such accidents, the floatation characteristics which is the one of safety performance indicators of aircraft should be fully considered and verified in the aircraft design and development stage [2]. For the lack of experience of airworthiness certification obtaining and no comprehensive and systematic study of floatation in our country. An analysis method is urgently needed to comprehensively evaluate the floatation of fixed-wing aircraft in order to meet the needs of aircraft development and airworthiness certification obtaining.

In this paper, a time-domain prediction method is proposed, which can fully express the inflow process of the breakage aircraft. Through the research of visualization analysis technology of floating process based on CATIA platform, the prediction of floating time of aircraft is realized. It provides necessary technical reserve for airworthiness verification of civil aircraft applications for ditching.
2. Research cogitation
Based on the relevant airworthiness regulations and the motion characteristics of the aircraft floating on the water surface, the inflow process of the aircraft is divided into two parts: the aircraft motion response analysis with different inflow weight and the regression analysis of the motion process. Because the inflow of a damaged aircraft is a slow and continuous process, the dynamic process is equivalently discretized into a number of inflow segments with the same volume in the whole flotation process of the damaged aircraft. By establishing a flow velocity and limit time calculation model based on different damaged areas and areas location, the floating time monitoring and forecast for different flooding quantity is realized [3]. The basic calculation program is shown in Figure 1 below.

![Diagram of flotation calculation procedure]

**Fig.1** The calculate procedure of flotation

3. Time-domain Prediction and Analysis of Damaged Aircraft Sinking Motion
When the damaged aircraft floating on water surface, the water will continue to enter those structures. Although the inflow is relatively slow, the influence of the increasing intake weight on motion response of aircraft in wave can not be ignored. According to the thinking of incremental weight method, supposing the added fluid in the cabin is the increase weight of the aircraft’ self, the time-domain conclusion of damaged aircraft floating on the water surface will be easily obtained by regression analysis way[4]. The details will be shown below.

3.1. The motion response analysis of aircraft on wave environment
Because the amplitude is far less than the characteristic length of aircraft, the fluid could be regarded as the uniform, incompressible and inviscid ideal fluid when study the motion character of aircraft on the wave surface. For this reason, the motion response can be analysed by Potential Flow Theory. Based on the above theory, this paper analysis the floatation of the aircraft with the software that widely used in marine structures’s hydrodynamic performace analysis[5].

Regarding the fluid as the uniform, incompressible and inviscid ideal fluid when analysis.

1) Establish the numerical model, dividing the whole CATIA model into numbers of grid and checking the mesh quality and number to satisfied with the computational requirements.
2) Solving the Wave Velocity Potential Function which meet the Laplace's equation and boundary conditions by panel method.
3) Solving the fluid force such as the fluid opposite reaction and static resilience of aircraft on the wave surface
4) Establish the frequency-response functions and solve the motion response RAOs of aircraft
5) Analysis the time domain movement of aircraft which on the specific wave environment
6) Post-processing and data output
7) Check the motion character of aircraft whether satisfied with the Physical truth. Then output the calculative result to the follow-up analysis—floating time calculation[6,7].

The mesh generation of the target aircraft is shown in Figure 2 below.

![Fig.2 Grid division for model](image)

3.2. Motion response accuracy verification
The veracity and precision of motion response prediction is closely connected to the precision of floating time calculation. Therefore, this paper verifies the computational accuracy with the tank test. The detailedness are revealed in the document[5]. The conclusion of that paper is shown in below.

![Fig. 3 The correlation curves](image)

From the picture, we can see that the Amplitude of roll Angle gained by software is similar to that of the tank test which shows the wonderful conformance with actual condition. It shows that this method can effectively ensure the validity of motion response analysis.
3.3. Motion response analysis for damaged aircraft

From the result of motion response for different weight of aircraft, we can get to know that whether the curve of roll angle, pitch angle or heaving, are satisfying periodic changes. According to Fourier's research conclusion, any periodic function can be represented by a sequence of sinusoidal and cosine functions. So that, this paper choose the first order fourier function to fitting the curve equation after analyzing the fitting degree of curvilinear of that model. Subsequently, the equation of motion attitude curve of aircraft with different water inflow can be gained easily. The basic equation relationships are shown below.

\[
f(t) = a_0 + a_1 \cos(w \cdot t) + b_1 \sin(w \cdot t)
\]

In the formula, \(a_0, a_1, b_1\) are the function of aircraft weight \(M\), longitudinal position of center of gravity \(X\),vertical coordinates of the center of gravity \(Z\). \(f(t)\) is the function of rolling/pitch/heavy of motion response for different model state. So the series of motion attitude curve equations will be acquired and form the matrix which combined the parameters \(a, a_1, b_1\).

Treat the aircraft weight \(M\), longitudinal position of center of gravity \(X\),Vertical coordinates of the center of gravity \(Z\) as dependent variable, the parameters \(a_0\), \(a_1\), \(b_1\) as dependent variable, the twepwise regression analysis of ternary polynomial can be done notably [8]. The follow chapter shows the regression polynomial of the parameters \(a_0\).

\[
a_0 = \sum_{i=0}^{n_1} \sum_{j=0}^{n_2} \sum_{k=0}^{n_3} L_{ijk} M^i X^j Z^k
\]

According to the result of calculation, the number of \(n\) are choose the same number of 2. In other words \(n_1=n_2=n_3=2\). So the formula(2) can be transformed to the follow one.

\[
a_0 = \sum_{i=0}^{2} \sum_{j=0}^{2} \sum_{k=0}^{2} L_{ijk} M^i X^j Z^k
\]

Formula (3) is a non-linear function expression. To make use of the regression method processing data, the substitution variables is used to transform that formula to multiple stepwise expressions.

So, \(y=a_0, x_1=M, x_2=X, x_3=Z, x_4=MX, x_5=X^2, x_6=Z^2, x_7=M^2, x_8=MX^2, x_9=Z^2, x_{10}=MZ, x_{11}=X^2Z, x_{12}=XZ, x_{13}=MZ^2, x_{14}=X^2Z^2, x_{15}=XZ^2, x_{16}=M^2Z, x_{17}=M^2X^2Z, x_{18}=X^2Z^2, x_{19}=MZ^2, x_{20}=M^2Z^2, x_{21}=MXZ^2, x_{22}=MZ^2X, x_{23}=XZ^2, x_{24}=X^2Z^2, x_{25}=MX^2Z^2, x_{26}=M^2X^2Z^2\).

And:

\[
y = L_{000} + L_{100} x_1 + L_{200} x_2 + L_{010} x_3 + L_{110} x_4 + L_{210} x_5 + L_{020} x_6 + L_{120} x_7 + L_{220} x_8 + L_{001} x_9 + L_{011} x_{10} + L_{111} x_{11} + L_{002} x_{12} + L_{012} x_{13} + L_{102} x_{14} + L_{022} x_{15} + L_{122} x_{16} + L_{222} x_{17} + L_{003} x_{18} + L_{013} x_{19} + L_{103} x_{20} + L_{023} x_{21} + L_{123} x_{22} + L_{223} x_{23} + L_{004} x_{24} + L_{014} x_{25} + L_{104} x_{26}
\]

The number of variables introduced into the regression equation is related to the limit value of \(F\) that specified in significant test of variable contribution, the significance in this paper is 0.05. According to the method of stepwise regression analysis, the regression coefficient of significance called \(L_{ijk}\) can be caught by the statisticstool kit of MATLAB which can check the \(L_{ijk}\) by \(t\) test and check the regression
formula by F test. The expression of $a_0$ is shown in the formula (5). And the figure 4, figure 5 show the moving posture curves of damaged aircraft in the specified state by regression analysis method.

$$a_0 = -0.665M + 0.00845M^2 + 8.37$$ (5)

Fig.4 The trim angle curve of damage airplane in wave water

Fig.5 The heeling angle curve of damage airplane in wave water

During the fitting progress of those curve equation, the coefficient of determination is above 0.9 which illustrate that the fitted curve correspond well with the initial data and can better represent the intake motion of damaged aircraft in waves. Look over the change of parameter curve, the regular pattern is that the peak of the curve is declined with the increase of floating time. In other words, the stability will enhance and inclination will decreases when water intake increased and center of gravity declined which match the law of the real aircraft’s floating motion. In addition, due to the water emergency exits on both sides of the fuselage, the reduction of the aircraft inclination will increase the height between
the water emergency door and the water line surface at the tilting direction, thus effectively improving the aircraft's floating time.

4. Study on the calculation method of floating time in wave condition for damaged aircraft

The article 25.801 from Technical Consultation Manual on Airworthiness Standards for Transportation Aircraft showed that “The floating time of aircraft after ditching is the time segment from the aircraft stop moving to the waterline meet the position of emergency exit”. To obtain that parameter, monitor for the positions of waterline and emergency exit become the key to the question.

Since the inflow progress is a such long and sustain process, it is very difficult to obtain the floating state of the waterline touching the emergency exit. To solve this puzzle, the key parameters such as the quantity of water intake which related to model gesture and floating time should be analysis comprehensive[9].

According to the principle of fluid mechanics, the quantity of water flow into the plane can calculate by the following formula:

\[ q = AV \]  

With \( V \) is the water velocity

\[ V = \mu \sqrt{2g_0(H - h)} \]  

Where, \( q \) is the flow rate, \( \mu \) is the flow coefficient, when the damaged area is small or approach to the water surface \( \mu = 0.6 \). \( A \) is the leakage area, \( g_0 \) is the acceleration of gravity, \( H \) is the distance between the center of leakage and water surface outside the plane, \( h \) is the height between the center of leakage and water surface inside the plane. When the model begin to seepage, the number is 0.

Assume the whole influent time is the floating time named \( T \), in the time the volume of water is

\[ \forall = \int_0^T q dt \]  

 Resolve the volume of water to tiny part named \( \Delta t \), in this paper \( i = 1, 2, ..., n \) and

\[ T = \sum_{i=1}^{n} \Delta t_i \] . Assume the water inflow of every time quantum is equally. Then the whole volume of water is

\[ \forall = \sum_{i=1}^{n} \Delta \forall_i = \sum_{i=1}^{n} q_i \Delta t_i = \sum_{i=1}^{n} \mu \sqrt{2g_0(H_i - h_i)} \Delta t_i \]  

Where \( \Delta \forall_i \) is the volume of water in every time quantum and \( \Delta \forall_i = q_i \Delta t_i \).

There are 3 unknown quantities in floating time calculate. They are \( H_i, h_i \), and \( \Delta t_i \). Since the motion attitude curve of floating process for aircraft have been obtained in time-domain prediction, the curve of \( H_i, h_i \) with time will be obtained naturally. So the floating time calculate is equal to solve the volume of water in every time quantum. According to the relationship between inflow and above parameters, Delphi language is used to access CATIA platform for secondary development and realized the floating time calculation. Computing software and basic flow are shown in figure 6, figure 7.
5. **Floatation analysis for the fixed-wing aircraft**

In order to verify the applicability of the calculation method proposed in this paper, a fixed-wing aircraft is used as the background model, and the floating characteristics are calculated and analyzed. The selected calculation condition is corresponding to the three-level sea state, and the model is a full-machine model with a complete shape and a leakage source containing the fuselage. The peak is located at the center of gravity of the model at the initial time of calculation, and the calculation is stopped when the waterline reaches the lowest point of the hatch. The inclination state and variation law of aircraft floating on water surface are described in figs. 3 and 4. And the curves of height from emergency exit to the water surface and the water inflow are shown below.

It can be concluded that the vertical movement of the damaged aircraft is similar to the inclination of that, and both are periodic change. When the aircraft floating the transverse angle and sagittal angle are throughout the whole process. Because the aft body of fuselage and the emergency exit in the low wing side are immersion into the water more than the opposite one, so the emergency exit in the low wing side will touch the water surface more early (if all emergency exit have the same height position). Obviously, the floating time is the water surface touch that exit. For this aircraft, the floating time is 405s. Figure 8 and figure 9 show that the sinking depth and internal water both are increase with
the floating time increases. When the floating time comes to 405s, the water no longer enters the plane and the aircraft's water intake value reaches the maximum value of 0.18m$^3$.

![Fig.8](image)

**Fig.8** The distance curve between waterline and cabin door for airplane with some weight and center condition in wave water

![Fig.9](image)

**Fig.9** The yield of water for airplane with some weight and center condition in wave water

6. **Conclusion**

The paper divides the inflow process analysis into two parts. One is the motion response analysis and the other one is the floating time forecast. Base on the Three Dimensional Potential Flow Theory, the methods of incremental weight, inflow segments analysis and secondary development for CATIA, the calculation method and procedure apply for floatation analysis of damaged aircraft is put forward smoothly.

Though calculate the floatation of that fixed-wing aircraft. The results show that the motion parameters of damaged aircraft, such as pitch angle, roll angle and heave are changed periodically with
time on the wave surface. Among them, the fluctuation peaks of pitch angle, roll angle and distance between water line and emergency exit decrease with the increase of floating time.

The curve of water inflow with time shows a linear change law. It shows that the sinking depth and water inflow will increase with the floating time increase, but the inclination will decrease gradually. From such law, we can see that the ability of the aircraft will increase to maintain its own stability in the floating process. In order to avoid the reduction of floating time cause by aircraft roll, the engineer should carry out a research with sufficient theoretical analysis and experimental research in the aircraft development stage, then the comprehensive emergency evacuation measures will be formulated based on research results. And the needs of emergency rescue after ditching will meet as expected.

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