Research of Commercial Aircraft's Battery Layout Design Method Based on Ditching Situation

Li Wen Wu

Abstract From Airworthiness regulation, the electronic power supply system must meet the requirement of power demanding devices which are used to support emergency evacuation of passengers, during emergency landing, including ditching situation. In this situation, the main power supply is often failure, and battery will supply power instead. However, after ditching, the fuselage structure is often damaged, water will flow over into fuselage, if battery, charge or wires are under water and short circuit, then all the devices which are used to support emergency evacuation will failure to work, and passenger evacuation will be very dangerous. For this problem, this paper researches the ditching floating characteristics of commercial aircraft, especially the leakage time of compartment, time-variation of water level, etc. At the same time, this paper analyzes the time of passenger evacuation. Based on those impact facts, this paper researches the battery layout design method of commercial aircraft.

Keywords Commercial aircraft · Battery layout · Ditching

1 Background

Commercial aircraft's ditching situation is a special case of emergency landing, and its risk level is very high. The operation procedure of pilot during ditching is different from ground landing, and usually the bottom of rear fuselage will strike water surface firstly with high striking load in this situation, structure or system of aircraft, especially portion of the skin, beam, stringer or doors of rear fuselage and part of system devices may be damaged due to striking load. Furthermore, emergency evacuation procedure of ditching is also different from ground landing, for example, Life rafts' removal, releasing and launching must be added into evacuation procedure of ditching, so the evacuation time is usually longer than ground landing. After landing, the aircraft will continuously fall down below water surface due to water

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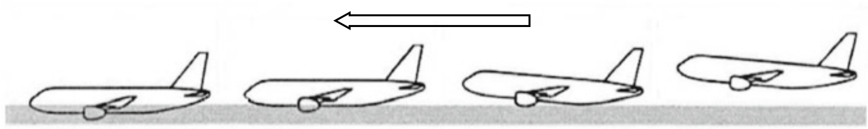


Fig. 1 Ditching process of commercial aircraft

flowing into fuselage, and the aircraft can't remain floating for a long time. In this situation, evacuation of all the crew and passenger during ditching will be more dangerous and difficult than ground landing. Figure 1 shows typical ditching process.

2 Analysis Procedure

The commercial aircraft which requests for certification with ditching must meet the ditching requirements of China Civil Aviation Regulations (CCAR part 25) in China, and the requirements are the same as Federal Aviation Administration's or European Aviation Safety Agency's.

The regulations related to ditching directly are CCAR25.801(a) ~ (e), 25.807(i), 25.1411, 25.1415(a), meantime, because ditching case is one of emergency landing cases, so it must also meet the regulations about emergency landing below:

(1) CCAR25.561(b)
(2) CCAR25.561(c)
(3) CCAR 25.787
(4) CCAR25.1362

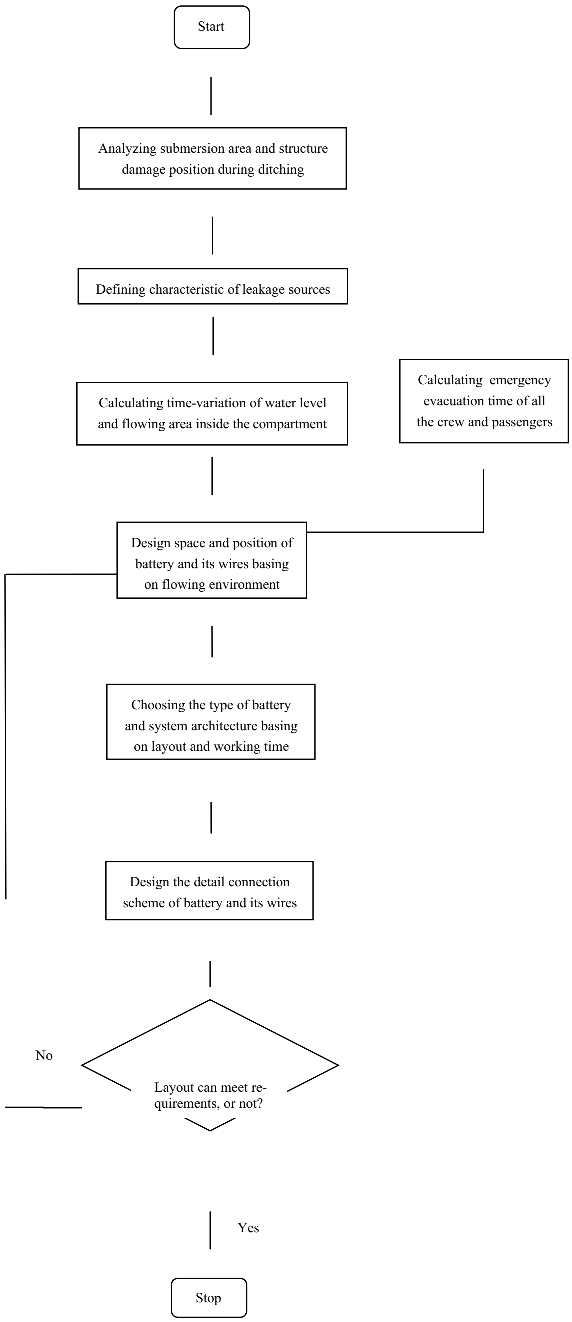
Based on regulations of CCAR25.801(b) ~ (e), floating characteristic and floating time of aircraft must be calculated, and based on CCAR25.1362, layout of battery and its wires must be isolated and avoided from impact of structure damage or the water that flowing into the compartment, in order to provide electric power to devices that supporting emergency evacuation. The analysis procedure of this problem is showed as Fig. 2.

3 Analysis of Structure Damage and Leakage Sources

3.1 Structure Damage During Ditching

The weight of commercial aircraft during ditching is usually maximum landing weight, and bottom of rear fuselage contact to water firstly, with water impact load which reaches to very high level, after contacting, the skin, frame, beam of rear fuselage's bottom structure may be damaged due to excessive stress, open section of

Fig. 2 Analysis procedure of battery layout design for ditching case



fuselage structure may be torn due to local stress concentration, and the dimension of clearance between compartment's door and skin will be too big due to deformation of fuselage structure, all these damage structure will cause water flowing into compartment. In the same time, structure broken and deformation will also damage the system devices near the structure. The characteristic and dimension of the structure broken can be calculated or tested by stress analysis method.

3.2 Leakage Sources During Ditching

Leakage sources means the non-sealing section of structure which is belonged to aircraft skin itself. When the aircraft floats on the water, the water can flow into compartment through those non-sealing section such as:

Drainage holes of fuselage skin under water level, ventilation holes of environment control system on the skin, normal structure clearance, and other structure without sealing.

Base on ditching operation procedure, pilot will shut off the ventilation holes of environment control system and other similar systems' holes before ditching, only the drainage holes of fuselage skin, normal structure clearance, and other structure without sealing which are under water level should be defined as leakage sources. Calculation of the position, shape, dimension, and structure's material of these sources are essential for analysis of water level time-variation and flowing impact zone inside the compartment.

4 Calculation of Flooding Process in Time-Domain

Based on the analysis results of structure damage and leakage sources, build mathematical model of flooding during aircraft's ditching, using Bernoulli equation, considering of steady flowing and ignoring energy losing.

In the structure broken or the leakage sources, the flowing speed equation is showed below:

$$v = \sqrt{2g(h_1 - h_2)} \tag{1}$$

In Eq. (1), g is gravitational acceleration, h_1, h_2 mean the vertical distance between inside, outside water level and the center of structure broken or leakage sources, when the water level inside the compartment is under structure broken or leakage sources, $h_2 = 0$, when $h_1 = h_2$, flow procedure stops, the sketch is showed as Fig. 3.

For the floating status is changed with time-variation, and is a dynamic procedure of aircraft's motion, water flowing into the compartment cause the aircraft's weight and core of gravity position changing, the water level will rise, the pitch angle and roll angle will be changed.

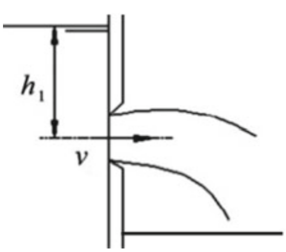


Fig. 3 Sketch of cabin flooding

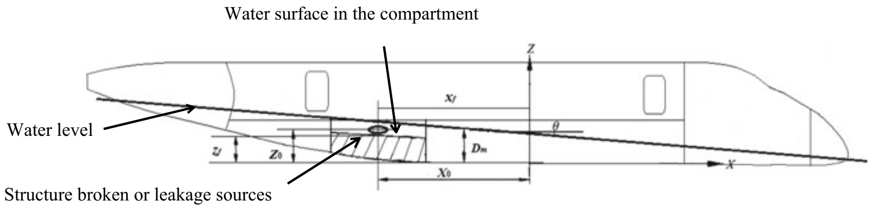


Fig. 4 Floating characteristic model

Changing of those data will change value of h_1, h_2, v, conversely.

Based on those variable data, build floating characteristic model of aircraft's ditching, this is showed as Fig. 4.

In Fig. 4, the reference coordinate system is rectangular coordinate system including z axis which goes through the meta-center of aircraft(the meta-center is refer to terminology definition of shipping), and x axis which goes through the mid-surface of fuselage and the two part which are divided by this mid-surface are symmetrical. For the roll angle which is caused by water flowing is very small, and the floating force of left and right wing can offset part of roll moment, this paper considers that the roll angle can be ignored, and only the aircraft's pitch angle changed during flowing on the water.

Due to changing of water level position outside aircraft and pitch angle, the vertical distance h_1 between water surface outside aircraft and structure broken is showed as Eq. (2), the vertical distance h_2 between water surface inside the aircraft and leakage sources is showed as Eq. (3):

$$h_1 = D_m - Z_0 + X_0 \tan\theta \tag{2}$$

$$h_2 = \left(z_f - Z_0\right)\cos\theta + X_0 \tan\theta \tag{3}$$

In Eqs. (2) and (3), D_m(m) is the average distance between water level and bottom of aircraft at a certain instant, $\theta(°)$ is the pitch angle of aircraft at a certain instant,X_0(m) is the distance between structure broken or leakage sources and z axis,

Z_0(m) is the distance between structure broken or leakage sources and x axis, X_f(m) is the distance between water surface inside aircraft and z axis, Z_f(m) is the distance between water surface inside aircraft and x axis.

Volume of flowing water at a certain instant is calculated as below:

$$dV = \int_0^t Qdt = \int_0^t C_d vAdt = \int_0^t C_d\sqrt{2g(h_1 - h_2)}Adt \tag{4}$$

In Eq. (4), Q is the rate of flow (m^3/s) at a certain instant, C_d is correction coefficient that considering factors such as the sharp of structure broken or leakage sources, the liquid viscosity, etc.

Volume of flowing water at a certain instant can also be calculated as below:

$$dV = \int_{z_{f1}}^{z_{f2}} A_{h1} dz_f \tag{5}$$

In Eqs. (5), A_{h1}(m^2) is the projection area in the fuselage's cross-section of compartment flowing water, z_f(m) is the distance between water surface inside aircraft and x axis.

Based on Eqs. (4) and (5), the function between z_f and t can be calculated.

Core of gravity position during water flowing in the compartment is showed as below:

$$x_G^{'} = \frac{m \cdot x_G + dm \cdot dx_g}{m + dm} \tag{6}$$

$$z_G^{'} = \frac{m \cdot z_G + dm \cdot dz_g}{m + dm} \tag{7}$$

For the z axis of reference coordinate goes through the meta-center of aircraft, changing about the position core of gravity can be corresponded to the changing of aircraft's pitch angle, and can be calculated as follows:

$$\tan\theta = \left|z_G^{'} - z_G\right| / \left|x_G^{'}\right| \tag{8}$$

Based on Eqs. (2)-(8), calculates parameters of floating characteristic and water flowing process of compartment in time-domain by means of weight added method which is compiled into computer program.

A calculation example is showed as Figs. 5 and 6. In this example, the original average distance between water level and bottom of aircraft is $D_m = 1.0$ m, original weight of aircraft is $m = 50000$Kg, original core of gravity coordinate is $x_G = 3.0$ m, $z_G = 1.2$ m, original equivalent position of structure broken and leakage sources

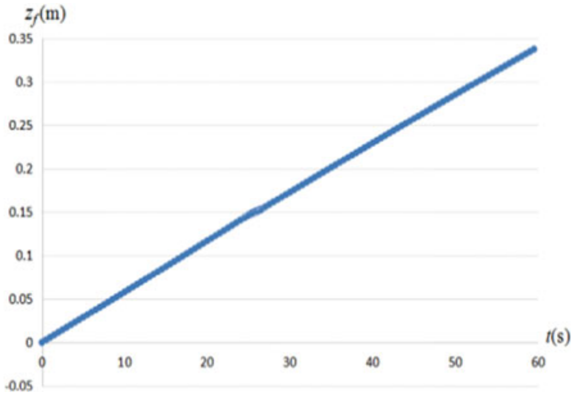


Fig. 5 Relationship curve of z_f(z coordinate value of water surface inside the compartment) and t(time)

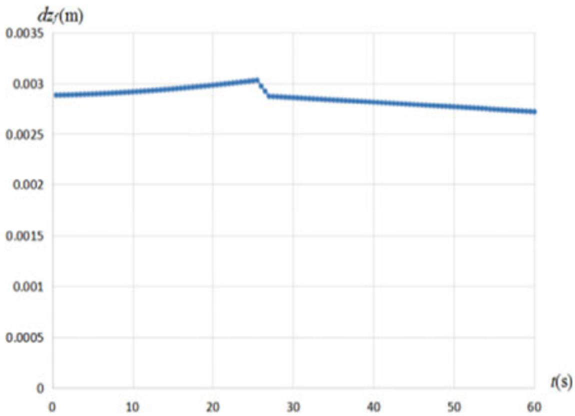


Fig. 6 Relationship curve of dz_f(incremental z coordinate value of water surface inside the compartment) and t(time)

is $X_0 = 5.0$ m, $Z_0 = 0.15$ m, the equivalent area of structure broken and leakage sources is $A = 0.0017\text{m}^2$, correction coefficient is $C_d = 0.60$.

From Fig. 5, z coordinate value of water surface inside the compartment z_f increases from 0 m to 0.35 m in 60 s, and the relationship curve is approximately straight line (ignore the curvature).

From Fig. 6, incremental z coordinate value of water surface inside the compartment increases with time until the position of water surface inside compartment is higher than the equivalent position of structure broken and leakage sources, then the incremental value decreases continuously.

Based on this calculation, the emergency evacuation time, the position of water surface inside compartment and impact zone of flowing in time-domain can be analyzed, and this information can be used for layout design of emergency battery and its wires.

5 Battery Layout Design Method for Ditching

For the battery and its wires are often connected to the fuselage structure by bracket, so the layout of battery and its wires must be designed to avoid from the impact area of damage structure which will damage battery and its wires due to distorted and sharp edge.

Normally, the rear fuselage will strike water surface first during ditching, damage structure and water flowing location are in the bottom of rear fuselage, so it is not a ideal position for installation of battery and its wires, this position usually includes the bottom zone and triangle zone of after cargo.

Based on the types of water-resistant test for airborne devices from RTCA (Radio Technical Commission for Aeronautics) DO-160G, the types of battery are:

(1) Type Y devices which achieve test of resisting condensation
(2) Type W devices which achieve test of resisting water drop
(3) Type R devices which achieve test of resisting water spray
(4) Type S devices which achieve test of resisting continuous water splash.

The priority type of battery and its wires for ditching and emergency evacuation is type R or type S devices which have achieve high level water-resistant test. However, the battery and its wires do not only suffer damage from water flowing of structure broken or leakage sources, but also suffer damage from submerging due to water surface rising inside the compartment, and the damage from distorted and sharp structure, so type R or type S devices may not work normally during this situation, meanwhile, the selection considering factor of battery type and its wires also includes price, volume, capacity of electricity, compatibility with other systems, maintenance performance, etc., ditching situation is only one of all those factors, so this ditching impact problem can't be solved only by the way of selecting battery and its wires type. Best method to solve this problem is appropriate layout design.

For emergency landing on the ground, FAA (Federal Aviation Administration), CAAC (Civil Aviation Administration of China) require that the total time of evacuation must be less than 90 s [1, 2] (be called as golden 90 s), and this time must be designed, test and verified by commercial aircraft's manufacturer. However, the evacuation time is more than 90 s in ditching, because of more evacuation procedure and more difficulty. So the water flowing into compartment and aircraft falling down to the water will continue for a long time before all the crew and passengers have evacuated, thus, battery and its wires' layout design must be ensure that these devices are not fail to work during the time, and based on the method from Chap. "Analysis of Supersonic Axisymmetric Air Intake in Off-Design Mode" of this paper, select and design position to avoid impact zone of water surface and water flowing which are changing in time inside compartment. In Fig. 7, the shadow part in the cross-section of fuselage is the impact zone.

From Chap. "Analysis of Supersonic Axisymmetric Air Intake in Off-Design Mode" of this paper, water flowing speed is very fast, and water surface rises quickly inside the compartment, though the area of structure broken and leakage sources is

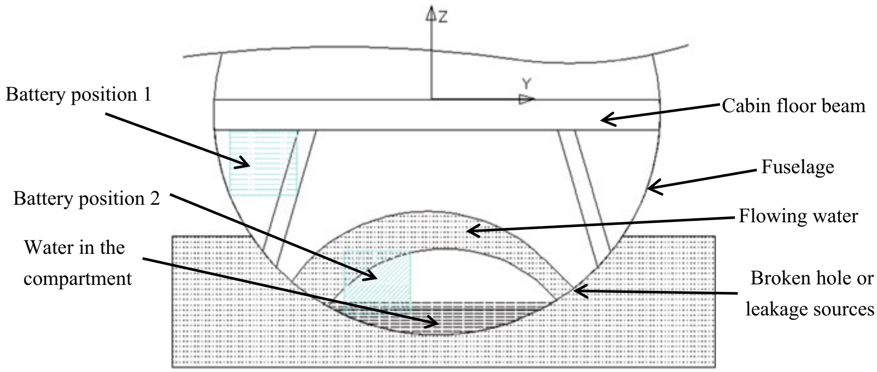


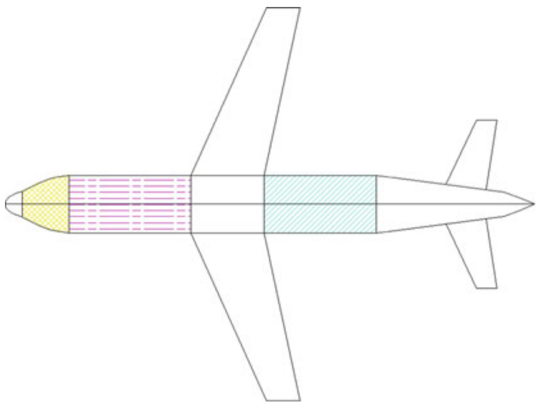
Fig. 7 Impact zone of water surface and water flowing inside compartment

small, considering the typical aircraft's parameters during ditching situation. So the best layout of battery and its wires should be that the devices are all installed in the forward fuselage zone which is up to the cabin floor, the distance from battery and its wires to water flowing zone is farther than other layout types, and this layout provides more time to avoid from impact of water flowing, at the same time, other devices which require electric power of battery should be installed far from water flowing zone, too. Best layout zone is the yellow and purple zone which is showed as Fig. 8.

If the battery and its wires can't be installed up to the cabin floor of forward fuselage, another zone of forward fuselage should be the zone between cabin floor and cargo ceiling, or triangle zone of cargo.

If these devices can't be installed in the forward fuselage, then install them in the zone between cabin floor and cargo ceiling, or triangle zone of cargo, or the cabin of rear fuselage, considering the impact zone of water flowing and the rising altitude of water surface inside compartment during evacuation exactly.

Fig. 8 Probable installation zone of battery and its wires



6 Conclusion

This paper provides method of calculating leakage time and time-variation of water level during ditching. Based on these calculating, this paper introduces commercial aircraft's battery layout design method for ditching case.

The layout design of battery and its wires must consider a lot of factors [3], for example, the lithium-ion battery must be far from fire zone of aircraft, because electrolyte of this battery is inflammable, and should be installed in the bottom of compartment in order to avoid electrolyte leaking and impacting other devices unexpectedly, furthermore, the leakage electrolyte can be drained out of aircraft easily. However, this layout contradicts to the layout design requirement for ditching, so all the factors should be considered systematically in layout design.

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