A NEW METHOD OF CALCULATION THE DELAY TIME OF MULTI-CREW MEMBER EJECTION

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Abstract

The command system was the important method to resolve the track interference between crew-member at multi-crew ejection system. However, there were no effective and clear method to calculate the delay time of command system, which calculate was depend on the experience and experiments at most of time. The method of risk coefficient was put forward in this paper. The delay time of command system could calculate by compare the risk coefficient. Simulation result show that "0-0" ejection was the crucial condition for calculate delay time, and the other condition was insignificant. The effective trajectory diffusing can not attained only on the delay time, moreover, the track separate system was necessary. In addition, the risk of burn late ejection member was very small which accord with experiment. Comparing with the relevant data, this method could provide the effective reference for the command system design.

1 Introduction

Multi-crew member ejection was all along the difficult problem of aeronautics rescue technologies. In late several flight accidents, the B-52H six crew member all sustained fatal injuries, and the Su-27 one member sustained injuries, the other sustained fatal injuries. The F-15D two members' destiny was as same as the Su-72's. The command system was the primary method to resolve the multi-crew member ejection. Early multi-seat aircraft, such as B-52 and Tu-16, was not providing command system. Therefore, the ejection sequence and delay time between crew-member can not get reasonable control. The problem of eject track intervene between crew-member and dally over ejection opportunity could occurs at emergency ejection. The function of command system was determined ejection sequence and delay time of each member. The crucial technology of command system was calculate delay time. There are not effective and clear method to calculate the delay time of command system, which calculate was depend on the experience and experiments at most of time. The method of risk coefficient was present in this paper. The delay time of command system could calculate by compare the risk coefficient.

1.1 Multi-Crew Member Ejection Process

At present, the crew number of multi-seat aircraft is general three men, therefore, simulation calculate is based on the three men project in this paper. The collocation of members as shows figure 1.

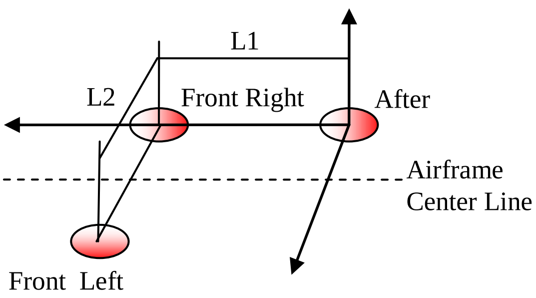

Fig. 1 Seat Install Sketch

The normal ejection sequence was that the ejection was initiated by any of the front crew members, the after crew member first ejection, followed by the front right crew, the final ejection is the front left member, that is pilot. The after crew member can only initiated its own ejection procedures, but not start the front member ejection procedures. The front member can decide whether or not the ejection after a certain period of delay time. The ejection sequence was normal process in this simulation, 3 crew members in accordance with the order of the ejection.

In order to avoid high-speed airflow to the crewmember injury, 3 crewmember ejection of the channel was clear difference and not a one – time clearance. There were many methods to clear ejection channel, throw hatch was the ways used in this paper. Normal ejection sequence is: the front of any crewmember initiated ejection, the delay time t1 to clear rear member ejection channel, the rear member start ejection after delay time t2; after rear crewmember ejection, delay time t3, clear front right crew member ejection channel and the front right crewmember start ejection after delay time t4; after right crewmember ejection, delay time t5, clear front left member ejection channel and the front left member start ejection after delay time t6, shown in figure 2. The value of t1 and t2 depends on the aircraft and seat design, and the signal transmission system as well as their own time error. The value of t1 and t2 take all 0.1 second in simulation in this paper.

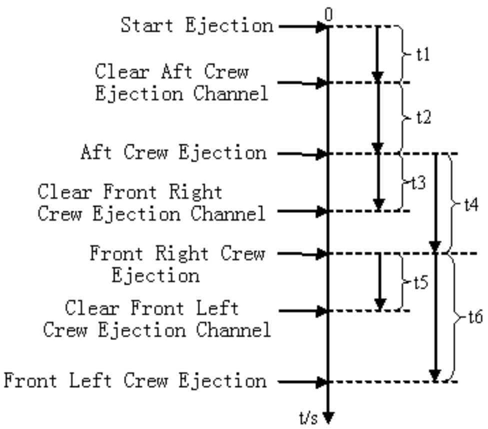

Fig. 2 Command Ejection Sequence

For more than a crew member ejection, the final ejection member will movement with aircraft for a long time. Aircraft movement state has an important impact on the late crew member, especially in adverse attitude. The ejection process and aircraft movement time as shown as figure 3.

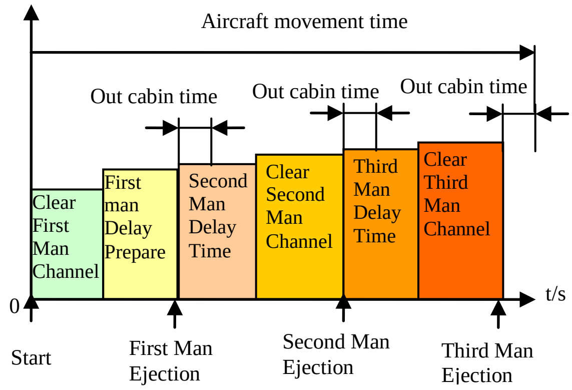

Fig.3 Ejection Process Sketch

By Figures 2 and 3 can be seen, t3 and t5 calculation depends not only on the interference risk between crewmember and hatch, but also depends on the out of cabin time and crew member delay time. According to the different types of seat, out of cabin time was different and the general time was 0.2 seconds.

1.2 Risk Coefficient

How to assess whether there has been interference between crew-member in the ejection process there was no clear standards. Life Threat Assessment Coefficient (LTAC) was present to evaluation life-threatening risk in the ejection process, the calculation formula as follows:

$$t_c = \frac{H_g}{V_s} - \frac{|\phi|}{k}$$

Where: tc, life-threatening risk, s;

Vs, man-seat system descend rate, m/s;

Hg, man-seat system height, m;

Φ, roll angle, degree;

k, the expecting rolling rate when correct man-seat system roll angle, deg/s;

However, this factor was used to evaluate life-threatening extent in the entire ejection process, and can not to assess the interference risk between crew-member for multi-crew member ejection. Simulation analysis multi-crew ejection, man-seat system center of gravity (CG), apart from distance, the range of rocket combustion wake affected area and the canopy trajectory were all need to take into account. The essence of analysis whether interference between crew-member was in fact analysis the relative position of two objects which was the function of time and position coordinates.

In simulation, the initial positions of each member had the same origin. Moreover, in order to easy calculate, the simulation mode was simplification. The relative distance of CG track is varying from time. At the ejection initial stage, the relative distance of CG track is small and increased with time. According to the ejection condition, in the subsequent ejection process, the relative distance of CG track was likely to continue to increase, and may be reduced. Therefore, it was not sufficient only relying on the relative distance of CG track to estimate whether interference between members. As a result, we can take arithmetical average of relative distance CG track with in a time to evaluate interference risk. To analysis interference risk between hatch and crewmember can take time that hatch fall ground. The time which calculates risk between crew-member is the time of first ejection member parachute full open. In order to facilitate comparative analysis, non-dimensional, that is, we can take the ratio value which was the smallest distance divide average distance of CG track. At the same time, the average relative distance should add the initial install position that was neglect in simulation.

$$F_c = \frac{D_{\min}}{\overline{D} + D_0}$$

Where: $\overline{D}$, average relative distance of CG track with in a time, start calculate from having relative movement, m; D_0, initial relative position of CG, m; D_{min}, the allowed smallest relative distance of CG, m; in this paper, 30 meters was the allowed smallest distance for member and member, and 25 meters for member and hatch.

The more the value of risk coefficient Fc ,the more the interference risk. On the contrary, the Fc is smaller, the interference risk is smaller. While the value of Fc was close to 1, the delay time which given in simulation can meet the requirement of the smallest relative distance of CG track.

For the problem of rocket combustion flames burns member, the scope of rocket combustion effecting area is the main problem which need to account. Rocket burning flame forms a cone which vertex was the rocket vent. At general condition, the problem of burn between fronts and after member can be neglect because the burning flame was spurt out along the inclined back direction due to exist an angle between rocket vent center line and vertical direction. Moreover, the after member was general first eject. In order to facilitate calculate, it was assumption that the vertex of rocket burning flame and man-seat system CG were converged at one point. Moreover, the rocket package installs angle was neglected and the combustion flame was spurt out along the vertical direction that forms a cone. In addition, it was also assumption that the max effecting scope was achieved once rocket fires and the max effecting scope was not changed in the entire rocket working time. As shown in figure 4, the late ejection member was not start move before the delay time was reached. When late ejection member was start move, the CG distance of two members was gradually greater because the first ejection member's speed was much greater than later. If the condition of no-burning at initial ejection was meeting, the burning risk was smaller at later ejection process. The rocket burning risk coefficient was present as follows:

$$F_r = \frac{Y_{\max} \times R_{\max}^2}{\Delta tY \times (\Delta tX^2 + (\Delta tZ - L_2)^2)}$$

Where: ΔtX , ΔtY , ΔtZ ,CG track coordinate of first ejection member within some time, m;L2, the install initial CG distance of paratactic member, m; Y_{max}, the max effecting area of rocket combustion flame on vertical direction, m; R_{max}, the max radius of rocket combustion flame effecting area on level, m;

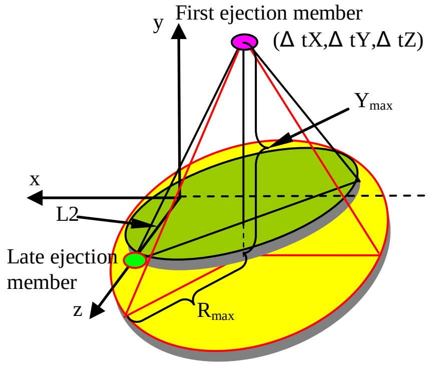

Fig.4 Rocket Burning Flame Sketch

The measures of rocket combustion effecting area was difficult because the rocket working time was very short, about 0.5 seconds, and the temperature of rocket combustion flame was very high. According to experiment, Y_{max} take 2.5 meters and R_{max} take 1.5 meters in this paper.

2 Simulation Calculate Result

The calculation of command system delay time was main depends on the “0-0” ejection condition and lower speed ejection condition. The effective trajectory diffusing can not attained only on the delay time, moreover, the track separate system was necessary.

Due to the move direction of hatch was after, and the move direction of man-seat system was front upward under the rocket action, therefore, the relative distance of CG track and risk coefficient between first ejection member and second throw hatch, first ejection member and second ejection member, second ejection member and third ejection member was main analysis and calculate in this paper. The simulation result at “0-0” ejection condition and 0 rocket impulse listed in Table 1.

Tab.1 “0-0”Ejection,Track Separate Rocket Impulse is 0

No.	t3 /s	t4 /s	t5 /s	t6 /s	F_{m1h2}	F_{m1m2}	F_{m2h3}	F_{m2m3}	F_r
1	0.30	0.75	0.40	1.00	0.8306	2.1653	0.8006	1.7701	0.0223
2	0.45	0.95	0.65	1.25	0.7592	1.7789	0.7005	1.4612	0.0123
3	0.50	1.25	0.75	1.60	0.7386	1.4127	0.6691	1.1851	0.0119
4	0.65	1.60	0.85	1.75	0.6845	1.1496	0.6414	1.1000	0.0133
5	0.50	1.65	0.75	1.75	0.7386	1.1208	0.6696	1.1001	0.0133

Where: F_{m1h2}, risk coefficient between first ejection member and second throw hatch;

F_{m1m2}, risk coefficient between first ejection member and second ejection member;

F_{m2h3}, risk coefficient between second ejection member and third throw hatch;

F_{m2m3}, risk coefficient between second ejection member and third ejection member;

F_r, rocket combustion burning risk coefficient between paratactic members

For all cases, the Fr was very small, that is, the relation of the rocket burning risk between paratactic members with delay time can be negligible. This is consistent with the experiment. The reason is that the action time of rocket combustion flame on crewmember was very short although the temperature on the crewmember’s shoulder and head achieved 144 centigrade. In addition, the risk between crewmember and hatch was small. The effective trajectory diffusing can not attained only on the delay time, which need the longer delay time, moreover, the track separate system was necessary.

Tab.2 Simulation Result of Lower Speed and Adverse Attitude Condition

No.	Condition	F_{m1h2}	F_{m1m2}	F_{m2h3}	F_{m2m3}	F_r
1	Speed 50km/h	0.7172	0.9215	0.6589	0.9115	4.1e-5
2	Speed 100km/h	0.6650	0.7521	0.6280	0.7419	9.4e-6
3	Speed 150km/h	0.6659	0.6824	0.6718	0.8913	7.2e-7
	Pitch 70°					
4	Speed 0	0.7958	0.6360	0.6039	0.4443	7.7e-7
	Roll rate 80° /s					
	Initial Roll 80°					

Table 2 shows the calculation result at lower speed and adverse attitude condition, which delay time between crew-member was the No. 5 data in Table 1. The results show that the risk was decreased for having cruise speed, but the risk was still higher at very lower speed. However, the risk between crewmembers at adverse attitude was complex, which could decrease or increase. The delay time of command system was not an effective method to improve the performance of ejection at adverse attitude.

Track separate system was present for compensate the deficiency of command system in trajectory diffusions. There are two kinds track separate rocket, that is, power rocket and side rocket, according to track separate device to staple. According to the seat move attitude, there are two separate ways, yaw movement track separate and side roll movement track separate. The side rocket track separate was used in this paper. The side rocket was installed in the right to separate to left for the after member, and for the front right member, was installed in the left to separate to right. For the front left member, that is, pilot, the side rocket was installed in the right to separate to left.

Because the install position of side rocket in seat was general certain, the goal of simulation was calculate the working state of separate rocket, that is, total impulse and working time.

According to the side rocket experiment, the total impulse of rocket was less than or equal to 110 Newton point second, and working time less than 100 milliseconds. Table 3 list the simulation results of combination calculate of track separate rocket and command system delay time. Due to the rocket burning risk was very small, the Fr will not calculate.

Tab.3 Simulation Result of Combination Calculate

No	t3 /s	t4 /s	t5 /s	t6 /s	I /N.s	T /s	F_{m1h2}	F_{m1m2}	F_{m2h3}	F_{m2m3}
1	0.50	1.65	0.75	1.75	0	0	0.73858	1.12080	0.66957	1.10015
2	0.5	1.65	0.75	1.75	110	0.1	0.75415	0.94293	0.68811	0.93972
3	0.5	1.0	0.5	1.0	120	0.05	0.76023	1.12895	0.78986	1.18184
4	0.5	1.15	0.5	1.15	120	0.05	0.76023	1.07320	0.79013	1.12233
5	0.5	1.15	0.5	1.20	130	0.05	0.76335	1.06515	0.79192	1.09252
6	0.65	1.20	0.70	1.35	110	0.05	0.70369	1.07987	0.70825	1.05844
7	0.65	1.20	0.70	1.35	120	0.05	0.70669	1.05562	0.71775	1.05073
8	0.60	1.25	0.75	1.45	110	0.05	0.72040	1.06112	0.69289	1.0235
9	0.60	1.25	0.75	1.45	120	0.10	0.71952	1.05859	0.69583	1.02867
10	0.60	1.25	0.75	1.40	120	0.08	0.72103	1.04985	0.69854	1.04095
11	0.60	1.30	0.75	1.40	110	0.05	0.72041	1.04292	0.69306	1.04084
12	0.60	1.35	0.75	1.45	110	0.05	0.72041	1.02538	0.69308	1.02367
13	0.60	1.35	0.75	1.45	110	0.10	0.71709	1.04388	0.68782	1.03730
14	0.60	1.35	0.75	1.45	120	0.05	0.72339	1.00597	0.70254	1.01819

The factor was need consider in selecting delay time and side rocket working state include the loss of ejection height, the long of delay time, and the minimal distance between crew-member at parachute full open phase. The error of risk coefficient within 5 percent, that is, the value of risk coefficient equal to 1.05, can be meet the requirement, because the risk coefficient was calculate based on the average of CG track relative distance. Moreover, the simulation model was simplified due to facilitate calculation.

From No. 9 to No. 14 in Table 3, risk coefficient can all be satisfying the requirement of the error of 5 percent. Compare with the condition of zero impulse, the loss of maximum ejection height was 6 meters for impulse of 120 Newton point second, and 4 meters for impulse of 110 Newton point second, as shown in figure 5. Figure 6 shows the curve of the relative distance of CG track.

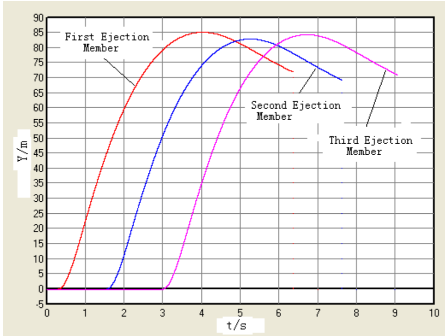

Fig.5a Y Direction Track (Side Rocket Impulse is 120N.s , Rocket Work Time is 0.1s)

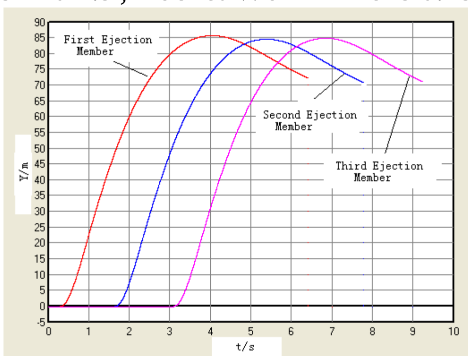

Fig.5b Y Direction Track (Side Rocket Impulse is 110N.s Rocket Work Time is 0.1s)

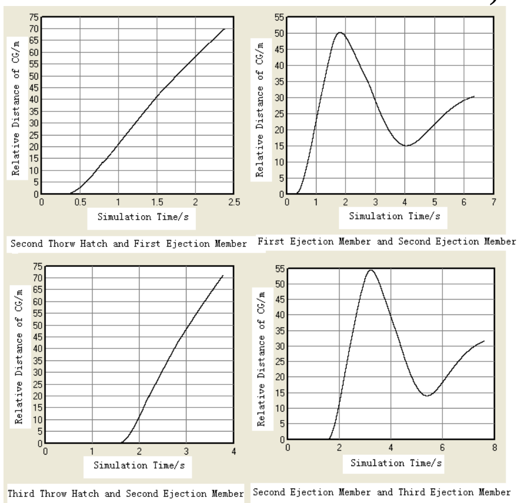

Fig. 6 Relative Distance of CG Trace (No. 9 Data)

Although the minimum distance of CG track was not meet at parachute full open phase, the distance between crewmember at the first ejection member parachute full open can be meet the requirement of minimum distance.

From comprehensive consider, the delay tine of command system was given in this paper was that, t4 was about from 1.2 to 1.25 seconds, t6 was about from 1.35 to 1.40 seconds. The time of throw hatch was determined by the crew member delay time and the time of out of cabin. The working state of track separate rocket was that, the total impulse was 100 Newton point second and working time was 50 milliseconds, or the total impulse was 120 Newton point second and working time was 100 milliseconds. Table 4 lists the delay time and working state of track separate rocket was given in this paper. The simulation result based on this data at lower speed and adverse attitude condition was shown in Table 5.

Tab.4 Delay Time and State of Track Separate Rocket

Delay time of	t1	t2	t3	t4	t5	t6
Command system/s	0.1	0.1	1.25	0.60	0.75	1.35
State of track	Total impulse / N.s			Working time/ s		
separate rocket	110			0.05		

Tab.5 Simulation Result of Adverse Attitude

No.	Simulation condition	F_{m1h2}	F_{m1m2}	F_{m2h3}	F_{m2m3}
1	Speed 50km/h level fly	0.6957	0.5514	0.6685	0.5549
2	Speed 50km/h Pitch angle -30° Attack angle 20°	0.3421	0.5795	0.3014	0.5734
3	Speed 50km/h pitch angle70° Attack angle -15°	1.3037	1.1194	0.8661	1.0609
4	Speed 450km/h Pitch angle -50° Roll angle 30°	0.6241	0.2796	0.5218	0.2949
5	Roll rate 60° /s Roll angle 120°	0.5918	0.2447	0.5418	0.2555
6	Speed 0 Roll rate 80deg/s Roll rate 80°	0.6976	0.5876	0.6599	0.4131

As shown in Table 5, the interference risk between crewmembers at lower speed was relative small, but the circus was complex at adverse attitude. Some ejection condition the interference risk was increased, such as No. 3, and another condition the interference risk was decreased but the loss of ejection height was increased, such as No.4. Therefore, the delay time of command system and track separate system were not the effective method to improve adverse attitude ejection performance.

3 CONCLUSIONS

Command system was the primary method to resolve the track interference problem of multi-crew member escape system. Extensive analysis and study were necessary to arrive at precision calculate delay time. The conclusions were attained in this paper through simulation analysis as follows:

1) Only depends on the delay time of command system can not arrive at the effective trajectory diffusion, track separate system was necessary.
2) "0-0" ejection condition was crucial condition to calculate the delay time and state of track separate rocket, lower speed and adverse attitude condition was negligible factor.
3) The interference risk between crewmember and hatch was small, and the time of throw hatch was determined by the crewmember delay time and the time of out of cabin. The interference risk was secondary factor.
4) Rocket combustion flame burning risk between paratactic crewmembers can be negligible.
5) The effective working mode of track separate rocket was bigger impulse and shorter work time. However, if the impulse of rocket was too bigger, the loss of ejection height will increased, and the effective trajectory diffusion can not attained if the work time of rocket was too long.

Although theses conclusions were general proved by the experiments or the instance of ejection, theory calculation was present in this paper to give an analysis of theoretic. Extra study was necessary to calculate the delay time and state of rocket of different seat and different crewmember. Moreover, if the hatch was the dissymmetrical, the movement track of hatch will need anew calculation.

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