MULTI-PARAMETER AND MULTI-MODE CONTROL SIMULATION ANALYSIS OF EJECTION SEAT

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Abstract

One of the primary goals of the 4th generation ejection seat was to improve the escape performance at low altitude and adverse attitude. To increase the ejection survivability at low altitude and adverse attitude, a new method of multi-parameter and multi-mode control was present in this paper and the influence of the plane parameters at ejection start to safe escape altitude were also put forward. The input parameters of multi-mode control were determined and thirty ejection modes had been constituted through simulation and compare of the minimum safe altitude with K36D-3.5A and ACES II ejection seat. The ejection under the condition of zero altitude, zero velocity and roll 90 degree was success when use the multi-mode control method. At the condition of roll 180 degree, the minimum safe altitude reduced about 40 meter in average. Analyses result shows that the goal of improved escape performance under the low and medium speed and low altitude condition can be obtained through multi-parameter and multi- mode control method.

1 Introduction

For a fourth generation escape system, the requirement is to expand the safe escape envelop relative to that of current, or third generation seats. The specific areas of the escape envelope in which increased capability is required are for escape under low altitude, adverse attitude conditions and for escape at extremely high speed. The critical technology of fourth generation seats was thrust modulated multi-nozzle rocket technology, controlled by sensors and microprocessors, to moderate acceleration and provide trajectory shaping (vertical seeking). One of the controllable propulsion systems, designated PEPS (Pintle Escape Propulsion System), was designed and developed by the Aerojet division of the GenCorp Corporation. The system consists of a solid propellant motor which has four pintle-controlled nozzles. The pintles are driven by actuators and the system supplied by Aerojet includes two controllers, with each controller being responsible for the contorl of two actuators. This controllable propulsion technology has been evaluated in a number of programs including the 4th Generation Escape Systems Technology Demonstration Programs Phase I and Phase II [1,2], MAXPAC (Multi-Axis Pintle Attitude Control) programs [3] and NACES P^{3}I Phase II [4]. However, the thrust vector control technology was a difficult technology to practical application on the ejection seat due to the time of ejection process was too short, less than 0.5 seconds. Therefore, the concept of multi-parameter and multi-mode control was present to improve escape capability at the low altitude, adverse attitude condition. This technology has successful verified by testing the Russian K36D-3.5A ejection seat. The critical technology of this method was classifying the ejection mode and select input parameters. In this paper, a new method, Safe Altitude Impact Factor (SAIF), was present to select input parameters and calculate their critical values. According to the selected input parameters, critical values and other criteria, such as the minimum safe escape altitude and multi-axial dynamic response criteria, the ejection mode can be plot out.

2 Multi-Parameter and Multi-Mode Control

2.1 Safe Altitude Impact Factor

To a crew escape system, safe escape altitude as a primary criterion is because the whole ejection process from ejection start to parachute full open until steady descend needs times, that is, this will be loss some lifesaving altitude. The losses height will be rest on the following condition:

1) aircraft active flight condition, that is, adverse attitude condition at ejection;
2) wreck velocity of aircraft;
3) the time which ready to ejection;
4) climbing height during ejection due to rocket thrust;
5) allow speed while open parachute;
6) the time which parachute full open;

In fact, all above-mentioned factors can be divided into two classes, that is, adverse attitude (include flight velocity and altitude) and seat climbing height during ejection, and can be denoted as loss height and increased height, respectively. Hence, we can define a safe altitude impact factor [SAIF] to describe the influence of adverse attitude to ejection trajectory height. The definition of SAIF as follows:

$$SAIF = \frac{Loss\ Height}{Increased\ Height} \tag{1}$$

Apparently, the value of SAIF increased while the *Loss Height* increased and the *Increased Height* decreased. The smaller of SAIF means that this condition is less influence on the ejection trajectory and be favored to crewmember escape.

There are six possible vertical ejection track curves considering every ejection condition, shown in figure 1.

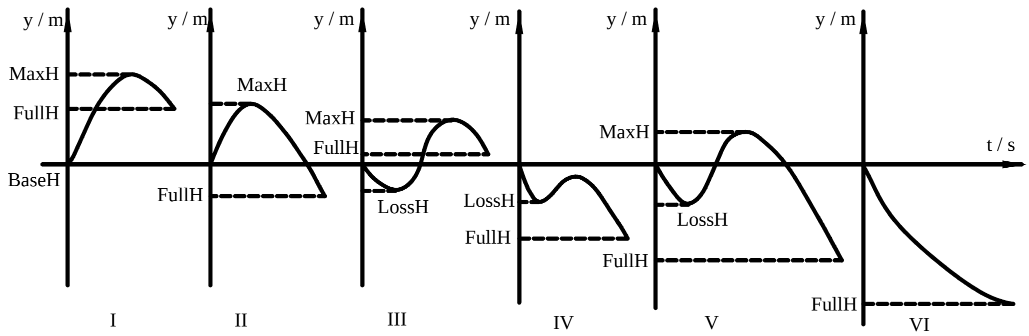

Fig.1 Possible Ejection Tracks (Vertical Direction)

The symbol of *MaxH*, *FullH*, *BaseH* and *LossH* in Fig.1 denotes the max ejection height, the parachute full blown height, the flight height and the loss height due to the plane movement respectively. The net increased height can be calculated through *MaxH* subtract *BaseH*, and the net loss height can be obtained through *MaxH* subtract *FullH*, as follows:

$$\delta H = MaxH - FullH \tag{2}$$

$$\Delta H = MaxH - BaseH \tag{3}$$

Where, δH is the net loss height, and ΔH is the net increased height.

Examining Fig.1, we see that the net increased height of the fourth and the sixth instance goes to zero, and then the result of Eq.1 will be goes to infinitely large and result to this equation meaningless. Therefore, the Eq.1 must be modified.

In general, lifesaving requirement can be met in the horizontal ejection events and the increased height will not be zero, as first instance in fig.1. Moreover, the speed is the primary factor effect the safe ejection altitude. Hence, we can define a formula to calculate the safe altitude impact factor [SAIF]:

$$SAIF(i,j) = \frac{\delta H_h + \delta H_a}{\Delta H_h + \Delta H_a} \tag{4}$$

Where, the SAIF(i, j) denotes the SAIF of parameter i at the condition of value j. δH denotes the loss height and ΔH denotes the increased height, which can be calculate through Eq.2 and Eq.3, the subscript *h* and *a* denotes the horizontal and adverse attitude ejection condition respectively. The SAIF is a dimensionless factor; the influence intensity of every parameter will be determined by comparing the SAIF of each parameter at the same speed and ejection height condition. Through calculation SAIF of each parameter at every flight condition, the input parameter can be selected according to the magnitude of each parameter SAIF.

2.2 Input Parameters

The movements of aircraft in space have six degrees of freedom, i.e., three linear displacements and three angle displacements, which can be stated by linear movement and rotational movement around the center of material. Linear displacement can be stated by velocity, angle of attack and angle of slide and rotational displacement can be stated by Euler attitude angle and attitude angle velocity. Velocity and flight altitude were the input parameters of the third generation dual-mode control ejection seat, therefore, velocity and altitude must be selected as input parameters of multi-mode control. Yaw angle and yaw angle velocity can be neglected because of foundation of man-seat system absolute coordinate. Pitch angle speed is small influence to the escape performance and the sink rate is an important parameter when aircraft wrecked, which is vertical component of aircraft absolute velocity. Therefore, there are six parameters, i.e., pitch angle, roll angle, roll angle speed, sink rate, attack angle and slide angle can be selected as the input parameters of the multi-parameters and multi-mode control.

As an example, we calculate the Safe Altitude Impact Factor (SAIF) of each parameter at velocity 450 kilometers per second and 100 meter flight altitude conditions. The SAIF of level flight at this condition is 0.0654. The mean SAIF of each parameter at this condition was shown inTab.1.

Tab. 1 Mean SAIF of Each Parameter

	Negative Pitch Angle	Positive Pitch Angle	Roll Angle	Roll Angle Speed
Mean SAIF	1.8913	0.0324	0.6027	0.2326
	Sink Rate	Attack Angle	Slide Angle	
Mean SAIF	0.6535	0.1162	0.064	

Form the tab.1 data, we can see that dive angle (negative pitch angle), sink rate and roll angle have bigger influence on the escape altitude, their mean value of SAIF bigger than the level flight. Attack angle and roll angle speed have small effect on the escape altitude, their mean value of SAIF near the level flight. However, slide angle and positive pitch angle is no influence on the escape altitude, their mean value of SAIF is small than the level flight.

On the adverse attitude condition, the mean value of SAIF of attack angle, roll angle and sink rate was shown in tab.2 and tab.3 respectively.

Tab.2 Mean SAIF of Attack Angle and Slide Angle at Adverse Attitude Condition

Pitch angle(°)	-30	-75	40	85
Pitch Angle SAIF	1.084	3.188	0.031	0.027
Attack Angle mean SAIF	1.1042	3.3002	0.0351	0.0272
Roll Angle(°)	60	90	120	150
Roll Angle SAIF	0.100	0.200	0.847	1.344
Slide Angle Mean SAIF	0.1786	0.4727	0.9028	1.3699

Tab.3 Mean SAIF of Sink Rate at Adverse Attitude Condition

Pitch angle (°)	30	85	Roll angle (°)	45	150
Sink rate mean SAIF	0.066	0.052		0.7664	2.001

From the tab.2 and the tab.3 data, we can see that attack angle and slide angle have some influence on the escape altitude at the adverse attitude condition. When the pitch angle is positive, the effect of sink rate is decreased and increased at the roll state. Therefore, pitch angle and roll angle were the primary factors influence escape altitude.

Although the conclusion was obtained under the velocity 450 kilometer per hours and the flight altitude 100 meter condition, it can be application to others flight state. Due to the control configuration of sink rate is difficulty implement based on the modern seat, the sink rate was not selected as an input parameter of multi-mode control in this paper even though the sink rate have bigger influence on the escape altitude. So, the input parameters of multi-mode control in this paper were velocity, flight altitude, pitch angle and roll angle.

2.3 Parameter Critical Values

Except to selecting input parameters, the critical values of each selected parameter are also the important factor to classify the ejection mode. The critical value of velocity and altitude can be determined by analysis the ejection instance. Reference 5 give the percentage of ejection incidents by speed for 390 ACES-II ejection seat non-combat ejections overlaid with 170 combat ejections in Southeast Asia from 1936 to 1971, as shown in table 4.

Tab.4 Combined Crew Ejection Success Rates at Various Flight Conditions (Number of Incidents)

Speed	Altitude (ft)				
(knot)	1-10	11-100	101-100	1001-10000	10000-50000
610-700	0%(0)	0%(0)	0%(0)	0%(0)	100%(1)
501-600	0%(0)	0%(0)	60%(0)	60%(5)	0%(0)
401-500	0%(0)	50%(2)	40%(5)	40%(5)	100%(4)
301-400	0%(0)	0%(1)	67%(6)	67%(6)	89%(9)
201-300	50%(2)	0%(2)	78%(9)	78%(9)	96%(24)
101-200	100%(10)	85%(26)	97%(68)	97%(68)	100%(13)
0-100	91%(22)	84%(19)	50%(6)	50%(6)	100%(0)

From the data in tab.4, we can see that 52 percent of ejection incidents occurred at altitude from 100 to 10,000 foot, and 19 percent occurred in 101 to 1000 foot, and about 16 percent occurred in zero to 100 foot. Only 12 percent of ejection incidents occurred at altitude excess 10,000 foot. About ejection speed, the majority of the ejection incidents, 48 percent, occurred in 101 to 200 knot range. The next most frequent speed where aircrew ejection happened was the 0 to 100 knot range, where 19 percent occurred. In the 201 to 300 knot range, where 18 percent transpired, the number of aircrew ejection incidents is progressively lower with each higher speed. Less than 3 percent of ejection incidents occurred in speeds excess of 500 knots.

The overall average ejection speed from all the incidents observed was about 194 knots. The average ejection speed significantly increases with the severity of the injury category. For the no reportable injuries category, the average ejection speed was only 169 knots. For the minor and major injury categories, the average ejection speeds were 188 and 229 knots, respectively. Disabilities or fatalities were much higher at average ejection speeds of 283 and 304 knots, respectively.

The success rate observed increase with altitude. The lowest altitude (0-100 feet) had a success rate of about 82 percent, while the highest altitude (above 10,000 feet) had a success rate of approximately 97 percent. The intermediate altitude (101-1,000 feet and 1,001-10,000 feet) had success rates of 86 percent and 94 percent, respectively.

It is important to note that ejection injuries sustained in a combat environment may be of more significance than those suffered in peacetime.

According to these ejection incidents and others data, altitude will be divided into four parts, i.e., exceed lower altitude (0-150 m), lower altitude (150-2,000 meters), intermediate altitude (2,000 -5,000 meters) and high altitude (over 5,000 meters). About speed, three classes were divided in this paper, that is, lower speed (0-200 kilometers per hour, km/h), intermediate speed (200-650 km/h) and high speed (over 650 km/h).

About pitch and roll attitude, there are three modes, i.e., single pitch movement, single roll movement and roll pitch movement. According to the flight speed and altitude, the critical value of pitch angle and roll angle was different and can be calculated according to the SAIF of each parameter at various conditions.

3 Simulation Result

After the input parameter was determined, mode of ejection can be classified using the minimum safe altitude and the max open parachute load as criterion. Through simulation and adjust the critical value of pitch angle and roll angle, thirty ejection modes had been constituted in this paper. Compared performance with other seat is shown in Tab.5.

Tab.5 Performance Comparisons

No.	Fly Attitude		Speed	Minimum Safe Altitude(ft)		
	Pitch Angle	Roll Angle	KEAS[2]	ACESII	K36D-3.5A	Simulation result
1	0	60	120	0	0	0
2	0	180	150	150	96	117
3	0[1]	0	150	116	137	200
4	-60	0	200	335	288	321
5	-30	0	450	497	518	451
6	-60	60	200	361	299	323
7	-45	180	250	467	323	369

Note: 1 the plane has 10,000ft/min sink rate

2 KEAS is abbreviation of Knot equivalent airspeed, 1 knot=1.85 km/h

Consider only from the minimum safe escape altitude, except to the 3rd condition in tab.5 which has the dive velocity, the simulation result in this paper smaller than the ACES II ejection seat. Compared with the K36D-3.5A ejection seat, the simulation result was near to the requirement of the minimum safe escape altitude.

Figure 2-5 was the multi-mode control ejection track (vertical direction) comparisons with no-attitude control at various ejection conditions. Form the curves in figures, we can see that escape altitude of multi-mode control get great increase than no attitude control. The minimum safe escape altitude average decreased about 23 meters. Compare track curves in Fig.2 with Fig.3 and Fig.4, we can also see that the effect of roll attitude control was good than pitch attitude control, especially in high speed condition. It is important to note that the condition of zero altitude, zero speed and roll 90 degree can be successful escape if using the multi-mode control as shown in Fig.5.

Under the roll and pitch down ejection condition, the multi-parameter and multi-mode control can attain the target of improving the performance of ejection seat in lower speed condition. However, this method cannot improve the escape performance at middle and high speed condition due to the pitch down attitude have the bigger effect on the escape altitude. About the higher speed ejection condition, this method cannot improve the escape performance because of the aerodynamics.

Under the upside down condition, that is the roll angle is 180 degree, rocket unfired has the obvious effect to increase the escape altitude. Moreover, with the speed increase the escape altitude was increase too, as shown in figure 6. The minimum escape altitude reduced 40 meters in average. About the control of pitch attitude, the effect was not obvious due to the impulse of the pitch attitude control rocket smaller than the rocket package, and cannot offset the effecting of the rocket package. The average reduced escape height less than 10 meters.

4 Conclusions

A new method, multi-parameter and multi-mode control, was present in this paper to enhance the escape ability at adverse attitude condition. Safe Altitude Impact Factor (SAIF) was defined and used to analysis the influence of flight parameter while ejection to escape altitude and selected input parameters of multi-mode control according to each parameter SAIF magnitude. According to the selected parameter and its critical values, the thirty ejection control mode was divided. Through compare vertical direction ejection trajectory of multi-mode control and no-attitude control, the present method in this paper can be meet the goal of improve the escape performance at lower altitude and adverse attitude ejection condition. However, this method cannot improve the escape performance at high speed condition.

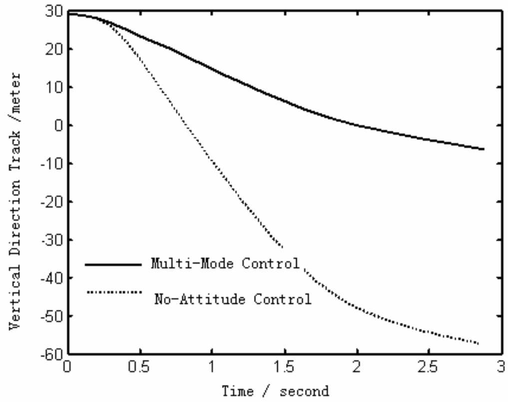

Fig.2 Zero Pitch Angle, 180 Degrees Roll Angle, 150 KEAS Speed Trajectory

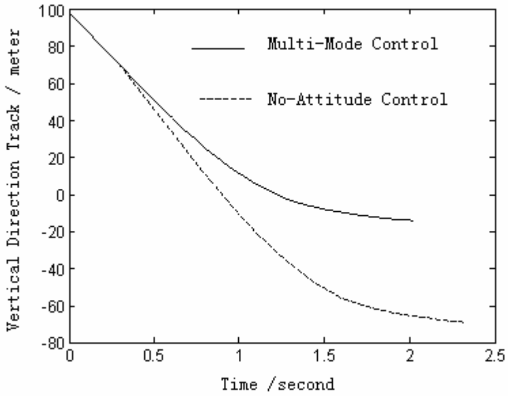

Fig.3 Pitch Angle -45 Degrees, Roll Angle 180 Degrees, Speed 250 KEAS

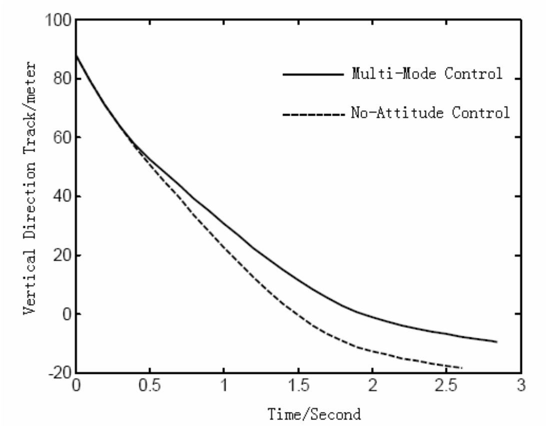

Fig.4 Pitch Angle-60 Degrees, Roll Angle 60 Degrees, Speed 200KEAS

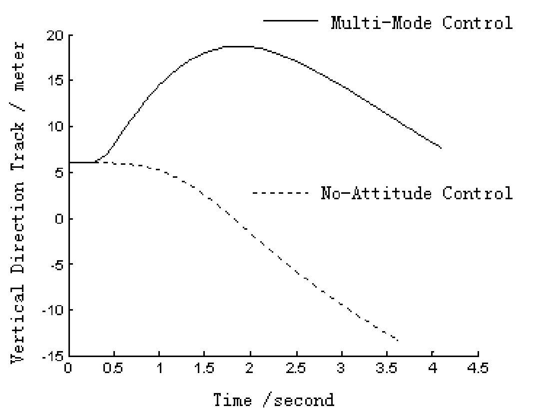

Fig. 5 Zero Height, Zero Speed, Roll Angle 90 Degrees

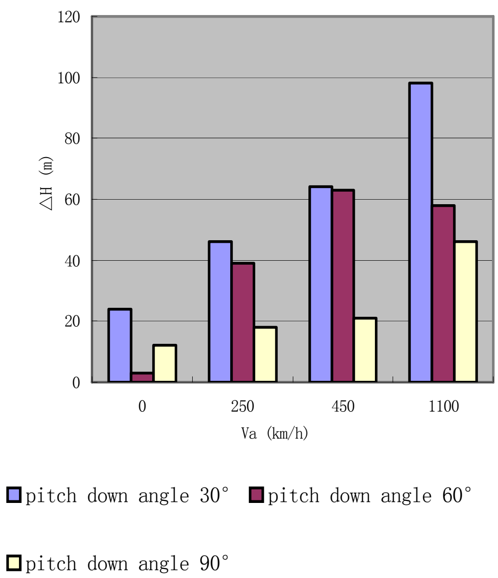

Fig.6 the Increased of Altitude at Different Speed and Roll Angle 180 Degrees

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