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Study on Risk Evaluation Model of Aircraft Hard Landing Events

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***Abstract*—The risk evaluation model of hard landing event is established to improve the risk management level in this paper. The hard landing evaluation index system is established. The risk of aircraft hard landing is calculated with the combination of the qualitative and quantitative method. The risk grade and the main risk factors affecting the aircraft hard landing risk are determined. The validity of the model is verified by an example analysis of the flight quality monitoring events of a certain airline's the B737 fleets in 2017. It is found the risk of the hard landing event is contributed greatly to high vertical g during landing, overweight landing, and high sink rate.**

Keywords*—risk management, safety evaluation, hard landing, flight operation quality assurance, exceedance events

I. Introduction

The hard landing event is an important typical event that occurs frequently during the landing phase. There are 600 hard landing events during landing phase in transport aviation in China from 2008 to 2017, and one of them is a serious incident, two of them are general incidents. According to the direct cause of the events, the main reasons for the 600 events are the crew reasons. The proportion was 91.5%.

The hard landing will damage the wing, landing gear, and engine structure of the aircraft, causing huge economic losses to the airlines. When the situation is serious, it will lead to catastrophic consequences and pose a threat to passengers' lives. There are two major accidents caused by hard landings in China's civil aviation history.

On May 8, 1997, a B737 aircraft of an airline in China performed a flight mission and encountered heavy rain during the final approach. The crew encountered poor visibility, runway water, and poor lighting effects. As the flight crew violated the regulations, blindly declined, and judged that the height was not accurate, the aircraft did not maintain a correct grounding attitude, resulting in a hard landing and causing a series of jumps. The aircraft structure was severely damaged, the aircraft disintegrated and the fire broke out, 35 people died and the aircraft was scrapped.

On June 9, 1999, a B737 aircraft of an airline in China performed a flight mission. The aircraft approached in heavy rain. The crew did not adjust the height of the barometer according to the regulations and flew at the wrong altitude as indicated. Meanwhile, the crew was improperly concentrated in teaching activities before the landing, causing the plane to crash into the ground and seriously damaged. The maximum vertical overload reached 4.71 G. The aircraft flew out of the runway, the landing gear was broken, the aircraft was scrapped, and 2 people were injured.

So it is particularly important to carry out risk evaluation and early warning monitoring of hard landing events. Then some specific measures are taken to reduce risk.

At present, the research on hard landing mainly focuses on three aspects. On the one hand, the diagnosis and detection of a hard landing, such as Wang Xuhui [1] and Cao Haipeng [2] analyzed the related factors that caused a hard landing, and used a quick access recorder (QAR) data to diagnose hard landing events. Nie Lei [3] and Xu Guimei [4] proposed an intelligent decision rule method for support vector machines and established a decision system for hard landing events. The second aspect is the prevention of hard landing. For example, Guo Hongbing [5] based on the normal landing process of Airbus aircraft, described how to effectively prevent Airbus aircraft from hard landing. Li Jiahua [6] and Liu Qinggui [7] discussed specific measures for preventing hard landing from the perspective of aircraft landing flight performance. Chen Zhihua et al. [8] analyzed the aircraft grounding process from two perspectives of physics and crew mentality to discuss the physical and psychological factors that caused the aircraft to hard landing. Wang Xuhui [9] proposed general methods for measuring the importance of landing risk factors under various landing environments and crew behaviors from the perspective of interaction of risk factors. The third aspect is the assessment of hard landing risk. For example, Wang Lei [10] used QAR data for quantitative assessment of hard landing risks. Liu Junjie [11] used the improved Bow-Tie model to conduct risk analysis on civil aviation hard landing events.

The risk evaluation model is established in this paper. The flight operational quality assurance project on hard landing risk as the evaluation index, using the analytic hierarchy process (AHP) to determine the weight of the index, with exceedance rate as the frequency of occurrence, and the risk of the hard landing event is evaluated [12-13].

II. Risk Evaluation Index Systems

The evaluation index system based on exceedance events is established. If an event occurs in a flight quality monitoring program, it is an exceedance event. Based on the flight operational quality assurance project, the monitoring items that have the major impact on the hard landing event are selected as evaluation index, and the specific evaluation index system is shown in Table I.

TABLE I. RISK EVALUATION INDEX SYSTEM

monitoring items	weight	severity
high speed during landing	0.05179	5
low speed during landing	0.02043	2
high roll during landing	0.08344	6
high pitch during touching down	0.08073	6
low pitch during touching down	0.01957	2
overweight landing	0.22872	8
high vertical g during landing	0.38565	9
high sink rate	0.12967	7

III. THE STUDY ON COMPREHENSIVE EVALUATION METHOD

A. Index Weight

The weight of each index is determined by the analytic hierarchy process. The importance of each index is compared by experts. The importance of each index was scored by the 9 scale method in this paper. The score is judged by layer by layer, and the eigenvector of the judgment matrix is calculated to determine the contribution of the lower index to the upper index. The result of the arrangement of the index of each variable layer to the target layer index is obtained. The weight of the upper index can be calculated by inputting the judgment matrix into the AHP software.

B. The Severity and Possibility of the Event

The expert survey method was adopted to determine the severity. The expert make a relative comparison of the consequences of each exceedance event. The experts are asked to score the severity of the consequences of different types of exceedance events according to their experience. The score is in the 0-10 range. The more serious it is, the higher the score is.

The possibility of the exceedance event is the incidence rate of an exceedance event. The incidence rate of flight exceedance events is expressed as the percentage of the number of exceedance events and the number of the flights of the total take-off and landing. The number of the total take-off and landing flights in a certain period is M, the number of flight exceedance events is m, and the incidence rate of the flight exceedance event is

$$P = (m/M) \times 100\% \quad (1)$$

C. Risk Determination

According to the definition of risk, the risk = severity× frequency. It is

$$R = \sum_{i=1}^{n} K_i \times S_i \times (2 \times P_{1i} + 4 \times P_{2i} + 8 \times P_{3i}) \quad (2)$$

K is the weight of the index, I is the current index, and n is the total number of indicators. 2, 4 and 8 are the equivalent coefficients of the exceedance event level. The exceedance event is divided into three levels according to the severity of risk level. It refers to the severity of the consequences of the exceedance event itself. Level 1 is the lowest, level 3 is the highest. According to the judgments of experts on the severity of three risk level of exceedance events, the equivalent coefficient is 2, 4 and 8 respectively. S is the severity of the exceedance events, and the P_{1i}, P_{2i} and P_{3i} are the incidence rates of level 1, 2 and 3.

D. Risk Evaluation Set

According to each monitoring project of each flight occurs one event, and the maximum risk values of the first, second, and third-level exceedance events are calculated respectively, they are 15.1, 30.1 and 60.3. The evaluation set is divided into 3 levels (V): high risk (intolerable), medium risk (tolerable) and low risk (acceptable). These three levels constitute the evaluation set V= {V1, V2, V3}. See Table II.

TABLE II. RISK EVALUATON LEVEL

level	Risk index	Risk level	Measures to be taken[14]
V1	[30.1~60.3)	high risk	Stop operation or process mediately. Unacceptable under the existing circumstances. Do not permit any operation until sufficient control measures Have been implemented to reduce the risk to an acceptable level.
V2	[15.1~30.1)	medium risk	Perform or review risk mitigation as necessary
V3	[0~15.1)	low risk	Acceptable as is. No risk mitigation required.

IV. EXAMPLE ANALYSES

We take the exceedance events as the validation data from the B737 aircraft of a domestic airline in 2017 to verify the validity of the model, which are related to the hard landing event, and evaluate the risk of the airline in 2017. The evaluation risk index system is shown in Table I.

A. Index Weight Determination

The weight of each index is calculated according to the analytic hierarchy process. The importance of each index was scored, as shown in table III. The judgment matrix is putted into the AHP calculation software, and the consistency test is carried out. The consistency check is passed by CR=0.096<0.1. Weight values K=(0.052,0.020,0.083,0.081,0.020,0.229,0.386,0.130) and the weight values of each index are shown in Table I.

B. Determination of the Severity and Possibility of Events

The method of expert survey is adopted to determine the severity of events. Experts are asked to score the severity of the consequences of different types of exceedance events based on experience. The severity of the related exceedance events of hard landing event is shown in Table I.

The possibility of events is determined. According to the number of the first and second level and the third level exceedance events and the number of flights in the B737 aircraft in 2017, the incidence rate of exceedance events at all levels is determined. The incidence rate of exceedance events at all levels is shown in Table IV. (The company only set up the second and the third level exceedance event standard for the individual monitoring items).

TABLE III. JUDGMENT MATRIX

	high speed during landing	low speed during landing	high roll during landing	high pitch during touching down	low pitch during touching down	overweight landing	high vertical g during landing	high sink rate
high speed during landing	1	5.00	0.33	0.33	4	0.17	0.14	0.33
low speed during landing	0.2	1	0.2	0.2	1.00	0.13	0.11	0.14
high roll during landing	3	5	1	1	8	0.20	0.14	0.33
high pitch during touching down	3	5	1	1	7	0.20	0.14	0.33
low pitch during touching down	0.25	1	0.13	0.14	1	0.13	0.11	0.13
overweight landing	6	8	5	5	8	1.00	0.25	4.00
high vertical g during landing	7	9	7	7	9	4.00	1.00	5.00
high sink rate	3	7	3	3	8	0.25	0.20	1.00

TABLE IV. THE EXCEEDANCE EVENTS RATE

monitoring items	**Level 1**	**Level 2**	**Level 3**
high speed during landing	0	0.064	0
low speed during landing	0	3.670	0.008
high roll during landing	0	1.349	0.064
high pitch during touching down	0	0	0
low pitch during touching down	0	0.281	0.088
overweight landing	0	0	0
high vertical g during landing	1.750	0.201	0.008
high sink rate	0	0.112	0

C. Risk Determination

According to the weight values of each index, it is found that the risk of the hard landing event is contributed greatly to high vertical g during landing, overweight landing, and high sink rate.

According to the risk formula(2), the final risk is determined, R=19.3. According to the risk evaluation level, it can be determined that the airline's hard landing event risk level is at a medium risk, which needs to perform or review risk mitigation as necessary.

V. CONCLUSION AND FUTURE WORK

The risk index system of the hard landing event is established based on the exceedance event. And the risk evaluation model of the hard landing event is established. The evaluation model was verified by using the number of exceedance events of an airline B737's aircraft in 2017. At the same time, it is determined that the risk of hard landing event is contributed greatly to high vertical g during landing, overweight landing, and high sink rate. According to the formula of the risk evaluation model of hard landing event, it is found that the airline is at a medium risk, and it needs to perform or review risk mitigation as necessary.

The dynamic evaluation of the risk of the airline's hard landing event is realized. We only analyzed the data of an airline in 2017 in this study. The exceedance events can be scanned every other time to evaluate the risk level of hard landing event in this period to determine whether the risk mitigation measures are taken.

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