Safety Science 107 (2018) 55–61

Contents lists available at ScienceDirect

Safety Science

journal homepage: www.elsevier.com/locate/safety

Research on a new aviation safety index and its solution under uncertainty conditions

Lijie Cui, Jiakui Zhang*, Bo Ren, Haoran Chen

Equipment Management and Safety Engineering College, Air Force Engineering University, Xi'an, Shanxi 710051, China

ARTICLE INFO

Keywords:
Aviation safety
Safety index
Bow-tie model
Performance function
Tire burst

ABSTRACT

Aviation safety has been an eternal theme since aircraft is invented, and safety risk assessment is taken as the important method to evaluate the aircraft safety, but it is usually difficult to compute and compare because the aviation risk is often composite, discontinuous and difficult to quantitative. To overcome these drawbacks, a new aircraft safety index under uncertainty conditions is proposed after the definition of aircraft safety was suggested based on the safety concept. After that, the safety performance function under given accident severity was provided through analyzing and describing uncertain factors of the aviation action. Combing with the application of Bow-tie model in the aviation accident fields, the flowchart and solution are suggested to compute the proposed aircraft safety index. Finally, taking the tire burst accident as an example, the feasibility of the proposed index and property of the solution are testified.

1. Introduction

Since long time ago, the risk has been taken as the most important index to evaluate the aviation safety. That is, the aviation safety is a state that the consequences caused by aviation action could be accepted by people (Mcintyre, 2000). These consequences include casualties, property loss and environment pollution, etc. Thus, the aviation safety risk can be represented as a function of scenarios of aviation action, serious consequences and their possibilities (Ferdous et al., 2013), namely

$$R = f(s,c,f) \tag{1}$$

where R is the aviation safety risk, s is the scenario of aviation action, f is the possibility of serious consequence, and c is the serious consequence event.

Risk analysis is a systematic approach that gathers and integrates qualitative and quantitative information of potential causes, consequences, and likelihoods of adverse events.

However, it is obvious that the above aviation safety risk exhibits some deficiencies and limitations in practice because of its complexity. For example, to evaluate the safety of an aviation action, a risk matrix was required, and a series of quantitative and qualitative methods are needed to evaluate (Wong and Brooks, 2015; Brooker, 2011). Specially, the severity of the accident's consequence is a discontinuous index, even it is not a concrete value. Thus the traditional safety risk index is not conducive to analyze and compare the safety of different aircrafts or aviation actions, and it brings much difficulty to demonstrate and evaluate aviation safety.

In the aviation field, some serious consequences, such as, casualties, property loss or environment pollution, are attracted more and different attention by people. If the severity of the focused consequences is given, one can use the possibility to represent the safety of aircraft or aviation actions. According to the definition of aviation safety, a new aviation safety index can be defined: **A new aviation index can be defined as the probability of the event that the possibility of occurring of a severe consequence is not higher than the people's acceptable value when an aircraft is carrying out tasks in expected environments.** As such, the aviation safety index becomes a single quantity from a composite index, which simplifies the representation significantly. The evaluation, comparison and demonstration of the safety of an aircraft can be implemented more conveniently than before.

The remainder of the article is organized as follows. Section 2 provides the aircraft safety performance function according to the proposed safety index. Section 3 suggests the constructing methodology of safety model based on the Bow-tie model and suggested its solution. The feasibility and property of proposed index and suggested solution are testified by an example of the tire burst accident in Section 4. Finally, some analyzed conclusions are obtained through the example and some future researched thoughts are outlooked.

* Corresponding author.
E-mail addresses: lijie_cui@163.com (L. Cui), Azhangjiakui@gmail.com (J. Zhang), rabber2003@163.com (B. Ren), 1765667894@qq.com (H. Chen).

https://doi.org/10.1016/j.ssci.2018.04.001
Received 7 September 2017; Received in revised form 31 March 2018; Accepted 1 April 2018
0925-7535/ © 2018 Elsevier Ltd. All rights reserved.

2. Safety performance function of aircraft

If the consequence of an aircraft accident can be quantified with the level of severity, the aircraft safety can be represented with the probability represented by the proposed new aviation safety index, which can be mathematically expressed as

$$R_{|S} = P\{P_{|S} < [P_{|S}]\} \tag{2}$$

where "$|S$" represents the consequence with a prescribed severity, $R_{|S}$ is the aviation safety index for the prescribed severity, $P_{|S}$ is the probability of the event that the consequence severity is equal higher than the prescribed value, $[P_{|S}]$ is its acceptable probabilistic value.

Modern aircraft is a significantly complex system composed of multiple systems and components, and its operational environment and mechanism are much more complex than ever. As the result, there exist lots of uncertainties in aviation accident's development process, such as the reliability of aircraft system or its components, the operational levels of pilots, environments of the mission, interaction of informational systems and the ability of supervision and management. These uncertain factors can be divided as basic events causing unsafe incidents and control events mitigating the severity of accidents, and these factors are represented as a vector of variables, e.g. $\boldsymbol{x} = \{\boldsymbol{x_b},\boldsymbol{x_c}\} = \{x_{b1},x_{b2},...,x_{bm},x_{c1},x_{c2},...,x_{cn}\}$.

All the uncertainties which influence the aviation safety can be transmitted into different serious accidents. It is the reason of that all kinds of aviation accidents have so much randomness and uncertainty, thus the probability of an aviation accident as assumed severity can be represented as

$$P_{|S} = f(\boldsymbol{x_b},\boldsymbol{x_c}) = f(x_{b1},x_{b2},...,x_{bm},x_{c1},x_{c2},...,x_{cn}) \tag{3}$$

If the threshold $[P_{|S}]$ as assumed consequence severity of aviation accident are stipulated previously, just as standards MIL-STD-882, SAE ARP4754A, etc. it can be transformed into computing the probability of safety performance functioned to obtain the aviation safety index

$$g(\boldsymbol{x}) = P_{|S}-[P_{|S}] \tag{4}$$

Solving the above performance function, one can compute the aviation safety index by

$$R_{|S} = P\{P_{|S} < [P_{|S}]\} = P\{g(\boldsymbol{x}) < 0\} \tag{5}$$

Mostly, people would pay attention to the acceptable state of multiple serious consequences' probabilities caused by unsafe incident or accident. in this station, the acceptable value of people for different serious consequences are different, just as described In FAR25.1309.(b).

If more than one consequences need to be considered, the aviation safety index can be transformed into computing the multiple-mode safety performance function, namely

$$\begin{cases} P_f = P\{(P_{|S_1} \geqslant [P_{|S_1}]) \cup (P_{|S_2} \geqslant [P_{|S_2}])...\cup(P_{|S_l} \geqslant [P_{|S_l}])\} \\ \quad = 1-P\{(g_1(\boldsymbol{x}) < 0) \cap (g_2(\boldsymbol{x}) < 0)...\cap(g_l(\boldsymbol{x}) < 0)\} \\ \quad = 1-\prod_{i=1}^{l} P\{(g_i(\boldsymbol{x}) < 0)\} \\ R = P\{(P_{|S_1} < [P_{|S_1}]) \cap (P_{|S_2} < [P_{|S_2}])...\cap(P_{|S_l} < [P_{|S_l}])\} \\ \quad = P\{(g_1(\boldsymbol{x}) < 0) \cap (g_2(\boldsymbol{x}) < 0)...\cap(g_l(\boldsymbol{x}) < 0)\} \\ \quad = \prod_{i=1}^{l} P\{(g_i(\boldsymbol{x}) < 0)\} = 1-P_f \end{cases} \tag{6}$$

where $g_1(\boldsymbol{x}) = P_{|S_1}-[P_{|S_1}]$, $g_2(\boldsymbol{x}) = P_{|S_2}-[P_{|S_2}]$, $g_l(\boldsymbol{x}) = P_{|S_l}-[P_{|S_l}]$, and l is the number of different serious consequences. Therefore, thus Eq. (6) can be transformed into computing the probability of multiple safety performance functions $\boldsymbol{g}(\boldsymbol{x}) = \begin{Bmatrix} P_{|S_1}-[P_{|S_1}] = 0 \\ P_{|S_2}-[P_{|S_2}] = 0 \\ ... \\ P_{|S_l}-[P_{|S_l}] = 0 \end{Bmatrix}$.

3. Construction and solution of the safety model

To compute the above safety index, the quantitative and qualitative relations between uncertain factors and consequences of aircraft accident need to be raveled out firstly. Based on that, their propagating models are required to build and their solutions need to be suggested.

3.1. Model construction

Many researchers have proposed quantity and quality models to research and analyze these aviation accidents and incidents in different views, and many of those have obtained certain preferable effects (Badreddine et al., 2014; van Thienen-Visser et al., 2014; Nivolianitou et al., 2004). Fault Tree analysis (FTA) and Event Tree Analysis (ETA) are two graphical tools to analyze the accidents quantitatively and qualitatively (Bellamy, 2015). Nevertheless, applying the FTA and ETA into analyzing aviation accident, cannot point out relationship between hazards and consequence of the accident directly, counter-measures proposed by them cannot be targeted and intuitively enough as well. Recently, a synthesis of FTA and ETA, the Bow-tie model, provide an "best of both world" solution in accident analysis (Delvosalle et al., 2006). The model takes the top event as critical event to connect basic events and outcome events of the accident, and it breaks through their barriers so that one can find and understand the relationships between hazards and consequences of accident. Based on that, some researchers have the results analyzed quantitatively using mathematic tools, and proposed many targeted preventive and mitigate counter-measures (Ferdous et al., 2012). So to speak, the Bow-tie model overcome many shortcomings (Skelt, 2006) of traditional accident analyzing methods, e.g. insufficiency quantification, highly fragmented and less intuitive and targeted, etc., and it has provided a new way in accident analysis and risk assessment (Dianous and Fievez, 2006; Cockshott, 2005; Gowland, 2006; Duijm, 2009; Markowski et al., 2009).

Generally, the Bow-tie model is composed of two parts, the Fault tree (FT) in the left and the Event tree (ET) in the right, as sketched in Fig. 1. The FT involves all events induce to the accident, which defines basic events or unexpected events, and these events are connected by logical gates. The ET defines all the consequences of the accidents, and many mitigate and remedy measures are displayed in the model. The Bow-tie model displays the basic events and consequences of accident in a single diagram, and which presents the causes and results of accidents by a visible mean (Dianous and Fievez, 2006).

Because Bow-tie model is made up by the FT and ET, a series of methods are used to build the Bow-tie model based on FTA and ETA. Generally, most of these methods depend on the experts knowledge and experience, so these methods are not only simple and feasible but they are also strongly subjective and difficult to quantified. To overcome these problems, some new methods were proposed (Gowland, 2006; Markowski et al., 2009; Saud et al., 2014). On the whole, these

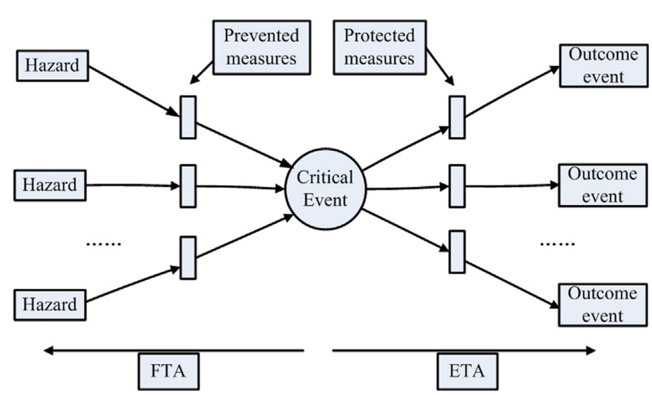

Fig. 1. The schematic diagram of the Bow-tie model.

Download English Version:

https://daneshyari.com/en/article/6974832

Download Persian Version:

https://daneshyari.com/article/6974832

Daneshyari.com