Research on Reliability Assessment Method of Emergency Escape Parachute

Fangyun Ma1,2, Huajin Lei2, Wensheng Wang2, Jing Liu2 and Liying Jin3,*

1Aviation Key Laboratory Science and Technology on Life-Support Technology, Hubei Xiangyang, 441003, China
2Aerospace Life-Support Industries, Ltd., Hubei Xiangyang, 441003, China
3School of Mechanical Engineering, Hubei University of Arts and Science, Xiangyang 441053, China
Corresponding author: Liying Jin (e-mail: ggnjinliying@126.com).

ABSTRACT Aiming at the problem that emergency escape parachute cannot meet the requirements of the index using the binomial evaluation method, combined with the characteristics of emergency escape parachute products, comprehensively using emergency escape parachute components and system test data, the emergency escape parachute Bayesian reliability assessment method is proposed to solve the problem of reliability assessment in the case of small sample size of emergency escape parachute system test, which effectively reducing emergency escape parachute test expenses and development cycle.

1. INTRODUCTION
With the increase of the military’s requirements for weapons and equipment, the reliability index of the emergency escape parachute is also getting higher and higher. If the reliability assessment is carried out by using the classical binomial distribution method according to the test data at the time of identification alone, the general evaluation results can hardly meet the requirements of the index.

Starting from the essence of reliability evaluation [1,2], we should make full use of all kinds of information to evaluate. Generally, the classic binomial method is used only for the test information system, and there are many parts in the development process. The development experience of the test information subsystem and similar types of projects cannot be used. If these information are used, it can make up for the shortage of fewer system tests and improve the accuracy of the reliability assessment of emergency escape parachute.

Therefore, on the basis of the reliability analysis of the emergency escape parachute, it is of great practical value and engineering significance to study the reliability assessment method of comprehensively utilizing the test information of similar parts of the emergency escape parachute and the information of similar models.

The rest of this paper is organized as follows. Section II presents analysis and selection of emergency escape parachute reliability assessment methods. Section III research on reliability assessment method of emergency escape parachute. In Section IV, implementation of reliability assessment method of emergency escape parachute. Section V concludes the paper.
2. Analysis and Selection of Emergency Escape Parachute Reliability Assessment Methods

System reliability assessment refers to estimating the reliability characteristics of the system based on the reliability test data or other relevant system reliability information conducted by the system, and solving the lower limit of the system reliability.

At present, the reliability assessment of the pyramid system [3] is a comprehensive process from the reliability information at the bottom of the system to the reliability at the top. The comprehensive evaluation methods of pyramid system reliability can be divided into three categories: (1) Exact confidence limit method; (2) Approximate method; (3) Bayesian method.

Each of these three methods has its advantages and disadvantages and its scope of application. Generally speaking, the accurate method has strict limitations on the system reliability structure, the life distribution type and the test data type, but its calculation method is usually more complicated. The range of application of the approximation method is wide, but the calculation accuracy is difficult to control. Bayesian method has a wide range of applications, but how to quantify different types of engineering information and reduce it to a prior distribution is a very difficult problem.

Based on the above-mentioned comprehensive reliability assessment methods of various systems, the applicability of the system reliability assessment should be compared and analyzed. Due to the difficulty of finding the ranking function and the huge amount of calculation of nonlinear programming, the exact confidence limit method can only find the exact lower limit solution of the reliability of a series system consisting of up to three components. The emergency escape parachute systems is generally more than three components, the difficulty in finding the ranking function and the increase in the amount of non-linear programming calculations make it impossible to obtain the exact lower confidence limit solution. Therefore, the exact confidence limit method cannot be used. emergency escape parachute because of the high reliability requirement, the reliability of the system is more demanding, because for any a subsystem, if the failure in test, it is considered a very serious matter, will be disposed of by "zero", find the failure reason, until test without fail many times, so a prominent feature in the reliability assessment of emergency escape parachute is that the test data of each system is failure-free data, so it is difficult to control the calculation accuracy of the approximate method.

The lower limit of the probability interval of the Bayesian method is close to the lower limit of the exact confidence, which is a good method for the reliability assessment of large series systems and complex systems. Using the Bayesian method, especially when the test data is less, can make full use of various quantitative or qualitative pre-test information, combine expert experience and test data to make up for the lack of field test data, and can be well to tackle the problem of zero failure so as to solve many other methods can’t solve the problem. According to the analysis, the reliability assessment of the emergency escape parachute includes the test data of the subsystem, and also includes the reliability information of other similar products of the subsystem. Using Bayesian method, this information can be comprehensively used with the test information of the whole machine for assessment. The purpose of improving the reliability assessment accuracy of the emergency escape parachute with a small sample size of the whole machine.

3. Research on Reliability Assessment Method of Emergency Escape Parachute

The idea of the system reliability assessment method based on Bayesian theory is to collect various reliability information before system test [4-7], such as subsystem test information, reliability information of similar products, simulation test information or expert experience, etc., and then pass the information. The fusion method turns these information into pre-test information of system reliability, and then comprehensively evaluates system reliability based on the data of system test [8].

3.1 Acquisition of prior information

For the reliability assessment of general weapon systems, prior information can be summarized into the following six types: (1) Unit and sub-system test information; (2) Simulation test information; (3) Information on similar systems; (4) Test information of the system under different environments; (5)
Expert advice and engineering experience; (6) Historical information: including various previous test information of the unit or system.

The above-mentioned prior information mainly includes: prior data (such as drop point data, life, success or failure data), statistical characteristics of the performance parameters themselves (accuracy or reliability, such as prior mean, variance, quantile, confidence interval or upper and lower limits), simulation (simulation shooting) information and other related information, etc.

3.2 Fusion of unit reliability prior information

In the actual engineering background, prior information has two meanings: one is that the prior information has multiple sources, such as from multiple experts or from different test environments and stages; the other is that the prior information has multiple forms, such as the moments of various stages of the parameter, the upper and lower bounds of the parameter, the confidence interval of the parameter and the historical test data, and so on. Usually, such information is incomplete and only contains part of the statistical characteristics of the reliability parameters. Therefore, these information usually cannot completely determine the prior distribution of the reliability parameters. This requires the introduction of some subjective criteria of goodness. The maximum entropy method is a better representative of this criterion, and it can fuse and handle situations where there are multiple forms of prior information.

The Shannon-Jaynes entropy considering the prior probability density function of the reliability $R$ is:

$$H(\pi(R)) = -\int_0^1 \pi(R) \times \ln \pi(R) dR$$

In this way, the problem of solving a prior probability density function $\pi(R)$ under certain constraints can be expressed as:

$$\max_{\pi(R)} H(\pi(R)) = \max_{\pi(R)} \left[ -\int_0^1 \pi(R) \times \ln \pi(R) dR \right] \ s.t. \ S(\pi(R)) = 0$$

In fact, the method of deriving a constraint function based on various prior information is to turn the prior distribution and its parameters selection into a problem of finding conditional extremes, and it is a non-linear programming problem.

In actual engineering applications, the prior distribution of the reliability parameters of some units can be regarded as known. For example, when the test data is a binomial distribution, $Beta(R; a, b)$ is usually taken as the prior distribution of its reliability $R$. Engineering practice also proves that this assumption is reasonable and can meet certain accuracy. Based on this, it can be assumed that the form of the prior distribution $\pi(R)$ of the reliability $R$ of the binomial distribution is known. In actual engineering, generally there may be the following four forms of prior information:

1. The mean value $R_0$ of the reliability $R$ can be expressed as:

$$R_0 = \int_0^1 R \times \pi(R) dR$$

2. The lower limits $a_-$ and $b_-$ of the prior distribution parameters $a$ and $b$ can be expressed as:

$$a \geq a_-, \quad b \geq b_-$$

3. The confidence interval $[R_1, R_2]$ of the reliability $R$ can be expressed as:

$$\mu = \int_{R_1}^{R_2} \pi(R) dR$$

4. The lower limit $R_-$ of the reliability $R$ can be expressed as:

$$R \geq R_-$$

This prior information can be either expert experience or historical test data. The following is an example to illustrate the application process of maximum entropy method with the first kind of prior information known, namely the mean value $R_0$ of reliability $R$. Suppose the prior distribution of reliability $R$ of a subsystem is beta distribution $Beta(R; a, b)$, and its probability density function is:

$$\pi(R) = Beta(R; a, b)$$
\[ = \frac{1}{B(a, b)} \times R^{a-1} \times (1 - R)^{b-1}, \quad 0 < R < 1 \quad (7) \]

Here, using the maximum entropy method to fuse the prior information is to determine the optimal value of \( a \) and \( b \) to maximize the entropy of \( \pi(R) \). According to the definition of Shannon-Jaynes entropy, the entropy of \( \pi(R) \) can be expressed as:

\[
H(\text{Beta}(R; \ a, \ b)) = H_a(a, b) = \int \text{Beta}(R; \ a, \ b) \times \ln(\text{Beta}(R; \ a, \ b)) dR
\]

\[
= \int \frac{1}{B(a, b)} \times R^{a-1} \times (1 - R)^{b-1} \times \ln\left(\frac{1}{B(a, b)} \times R^{a-1} \times (1 - R)^{b-1}\right) dR
\]

\[
= \int \frac{1}{B(a, b)} \times R^{a-1} \times (1 - R)^{b-1} \times \ln(R) \times (a-1) \times \ln R + (b-1) \times \ln R dR
\]

\[
= \ln(B(a,b)) - \frac{a-1}{B(a,b)} \int \times (1 - R)^{b-1} \times \ln R dR - \frac{b-1}{B(a,b)} \int R^{a-1} \times (1 - R)^{b-1} \times \ln R dR
\]

s.t. \( B(a, b) = \int x^{a-1} \times (1 - x)^{b-1} dx \) \( (8) \)

As mentioned above, the mean \( R_0 \) of reliability \( R \) is known, that is, \( R_0 \) is given. Substitute into formula (3), by calculation, we can obtain:

\[
\frac{a}{a+b} = R_0 \quad (9)
\]

In this way, the problem of finding the optimal values \( a^* \) and \( b^* \) becomes the problem of finding the extreme values under the constraints of the above formula:

\[
H_a(a', b') = \max(H_a(a, b)) \quad (10)
\]

This is a non-linear programming problem and can only be achieved by digital solutions. But as long as the number of prior parameters is greater than the number of equality constraints, the above-mentioned problem can be solved optimally, so it is feasible.

3.3 Calculation from the moment of unit reliability to the prior moment of the system reliability

For a complex system with any structure, its reliability can be expressed as a function of the unit reliability, denoted as \( R = R_i(t) = \varphi(R_1, R_2, \ldots, R_n) \), where \( R_i = R_i(t), \ i = 1, 2, \ldots, n \). It can be represented by a multivariable Taylor expansion. Here for some commonly used simple typical systems, the precise system reliability structure function is given, and a simple algorithm for quickly calculating the equivalent prior moment of the system is obtained from the known unit reliability information (assuming that the unit's prior reliability distribution is known). The algorithm consists of the following three steps:

1. Calculate the posterior moment of the unit reliability; 2. Derive system reliability structure function; 3. Calculate the prior moment of system reliability.

3.3.1 Calculation of Reliability Prior Moments for Series Systems

Assume that the system consists of \( n \) units such as \( R_1, R_2, \ldots, R_n \) in series. From the posterior distribution of the unit reliability, find the first \( M \)-order posterior moment:

\[
E[R_i^j], \ i=1,2,\ldots,n, \ j=1,2,\ldots,M \quad (11)
\]

The reliability structure function of the system is \( R = R_1 + R_2 + \ldots + R_n \).

Then, the first \( M \)-order moments of the system reliability are:

\[
E[R^j] = \prod_{i=1}^{N} E[R_i^j], \ j=1,2,\ldots,M \quad (12)
\]

3.3.2 Calculation of Reliability Prior Moments for Parallel Systems

Assume that the system consists of \( n \) units such as \( R_1, R_2, \ldots, R_n \) in parallel. From the posterior distribution of the unit reliability, find the first \( M \)-order posterior moment:

\[
E[R_i^j], \ i=1,2,\ldots,n, \ j=1,2,\ldots,M \quad (13)
\]

The reliability structure function of the system is

\[
R = 1 - \prod_{i=1}^{N} (1 - R_i) \quad (14)
\]
Then, the first $M$-order moments of the system reliability are:

$$R^\prime_i = \left[1 - \prod_{i=1}^N (1 - R_i) \right] - \sum_{i=1}^N (-1)^i \times \left[\prod_{i=1}^N (1 - R_i) \right]$$

$$= \sum_{i=1}^N (-1)^i \times \left[\prod_{i=1}^N (1 - R_i) \right] - \sum_{i=1}^N (-1)^i \times \left[\prod_{i=1}^N (1 - R_i) \right]$$

Since the statistics of each unit are independent of each other, therefore, the expectation of satisfying sum is equal to the sum of expectation, and the expectation of product is equal to the product of expectation, then taking the expectations at both ends of the above formula, obtain:

$$E[R^\prime_j] = \sum_{i=1}^N \left[(-1)^j \times \left[\prod_{i=1}^N (1 - R_i) \right] \right] - \sum_{i=1}^N \left[(-1)^j \times \left[\prod_{i=1}^N (1 - R_i) \right] \right]$$

$$j = 1, 2, \ldots, M \quad (15)$$

3.4 The prior parameters are determined by moment - equivalent method

Considering the case where the system reliability model is a binomial distribution, Beta distribution is often used as the prior distribution of reliability. Because there are only two parameters in the Beta distribution, we only need to take the first two order prior moment $\mu_k = E[R^\prime_k]$, $k = 1, 2$ of the system obtained from the above to make the following formula true:

$$\mu_k = \mu_k(\alpha, \beta), \quad k = 1, 2$$

$$\mu_k = \frac{\alpha}{\alpha + \beta}, \quad \mu_k = \frac{\alpha(\alpha + 1)}{\alpha + \beta + 1} \quad (16)$$

where $\mu_k(\alpha, \beta)$ is the $k$-th moment of $\beta(R; \alpha, \beta)$. In this way, after the prior parameter $(\alpha, \beta)$ is obtained, the prior probability density function $\beta(R; \alpha, \beta)$ of the system reliability is obtained. Although it makes assumptions on the form of the prior distribution, it is subjective, but for the reliability model of the success or failure system, this assumption is more reasonable and has a higher approximation.

3.5 System reliability calculation

After obtaining the prior distribution $\beta(R; \alpha, \beta)$ of system reliability, collect field system test data $(N, S)$, $N$ is the number of field system tests, and $S$ is the number of field system test successes. By using the Bayesian method and according to the properties of the conjugate distribution, it can be obtained that the posterior distribution of the system reliability $R$ is $Beta(R; \alpha + S, \beta + N - S)$, and the comprehensive estimation $R_{LB}$, whose confidence level of the reliability $R$ is 1- $\alpha$, can be determined by the following formula:

$$\int_{0}^{R_{LB}} Beta(R; \alpha + S, \beta + N - S) dR = \alpha \quad (17)$$

The above formula is the basic equation of Bayesian system reliability evaluation method. According to this equation, under the condition of historical information and field system test data $(N, S)$, a comprehensive estimate $R_{LB}$ of the reliability $R$ with a confidence level of 1- $\alpha$ can be obtained. In addition, the verification test scheme $(N, S)$ can also be determined by historical information and reliability indicators (confidence level 1- $\alpha$, reliability $R$). That is, under the given test conditions, $N$-firing test is performed, and if it is full-fire, it proves that the system has reached the reliability index (confidence level 1- $\alpha$, reliability $R$). In other words, to verify a certain reliability index, a small number of system field tests can be performed on the basis of the comprehensive sub-system test data, and then based on the small number of field test results, it is determined whether the system has reached the reliability index.

4. Implementation of Reliability Assessment Method of Emergency Escape Parachute

According to the Bayes system reliability evaluation method selected above, combined with the characteristics of emergency escape parachute products, this evaluation method is applied to the reliability evaluation of emergency escape parachute. The data processing of the information of each unit of the emergency escape parachute is completed by a software program, and finally the reliability assessment of the emergency escape parachute is realized.
4.1 Research on Bayes Reliability Evaluation Method of Emergency Escape Parachute

4.1.1 Collect test data
The test data for kit bag, deployment bag, main umbrella, harness system and withdrawal line, and scheme bottom, engineering development test data. Note: The test data of the scheme bottom is: \( n_k, f_k, \) engineering development test data is \( n_i, s_i, f_i \); the test data of the kit bag, deployment bag, main umbrella, harness system and withdrawal line are \( n_{1k}, s_{1i}, f_{1i}; n_{2k}, s_{2i}, f_{2i}; n_{3k}, s_{3i}, f_{3i}; \) Design finalize test data: I, II, III, recorded as: \( N_1, S_1, F_1; N_2, S_2, F_2; N_3, S_3, F_3. \)

4.1.2 Determine the prior distribution parameter \((a, b)\)
(1) If the sub-system and scheme bottom, engineering development are all zero failure data, then \( a \) is the sum of the minimum number of trials in the sub-system, and the scheme bottom, engineering development test number; \( b \) take 1;
(2) If there is non-zero failure data in the sub-system, the CMSR (Combined MML and SR, for short. MML stands for Modification of maximum likelihood; SR stands for Sequential reduction.) \[9-11\] method is used for conversion. The smallest number of trials is selected from the zero failure data, and other non-zero failure data are converted according to the following formula:

1. Compressing the zero failure number unit, the system's equivalent data sequence becomes:
   \[
   (n_1, s_1), (n_2, s_2), \ldots, (n_m, s_m), (n_k, s_k). \tag{18}
   \]
   The first \( n \) units in this sequence are all non-zero failures.
2. Only the zero failure number unit \((n_k, s_k)\) and the non-zero failure number unit \((n_m, s_m)\) with the minimum number of tests were compressed by SR method once. The equivalent data of these two units is \((n_m, s'_m)\), and the conversion formula is as follows:
   when \( s_k > n_k \), then
   \[
   \hat{n}_m = \frac{n_m \times n_k}{s_m}, \quad \hat{s}_m = s_k = n_k \tag{19}
   \]
   when \( s_k \leq n_k \), then
   \[
   \hat{n}_m = n_m, \quad \hat{s}_m = s_m \tag{20}
   \]
3. Applying the method of equal first and second moments of the same series system, the equivalent data sequence of the \( m \) units obtained is:
   \[
   (n_1, s_1), (n_2, s_2), \ldots, (n'_m, s'_m). \tag{21}
   \]
   Among them, all units are non-zero failures, and the equivalent success or failure data \((N, S)\) of the system is calculated as follows:
   \[
   N = \sum_{i=1}^{m} \frac{n_i}{s_i} - 1, \quad S = N \times \prod_{i=1}^{m} \frac{s_i}{n_i}
   \]
   \[s.t. \quad s_m = \hat{s}_m, \quad n_m = \hat{n}_m \tag{22}\]
   Then, \( a \) is the sum of the equivalent test number \( S \) in the sub-system, the scheme bottom and engineering development successful number, \( b \) takes the sum of the equivalent test number \( F = N - S \) in the sub-system, the scheme bottom and engineering development failures number.

4.1.3 Determine inheritance factor
Record the historical sample \((m, y)\) from the overall \( Y \), \( m \) as the number of tests, \( y \) as the number of successes, and \( f = m - y \) as the number of failures; sample \((n, x)\) from the overall \( X \), \( n \) as the number of tests, \( x \) as the number of successes, and \( f = n - x \) as the number of failures.

\[
K = \left\lfloor \frac{1}{2} \left( \frac{m + n}{x + y} \right) \left( x + y \right) \left( f + f \right) \left( m + n \right) \right\rfloor \tag{23}
\]
\[ Q(K) = P\left(\frac{x^{2}}{2} > K\right) = \int_{K}^{\infty} \frac{1}{\sqrt{2\pi} \times \sqrt{k}} \times e^{-\frac{x^2}{2}} \, dx \]  
(24)

\[ \rho = \sqrt{Q(K)} \]  
(25)

### 4.1.4 Calculate the lower limit of reliability

Accumulate the design finalize test data to get the test data as \((S, F)\).

\[ \Gamma(s) = \int_{0}^{\infty} x^{-1} \times e^{-x} \, dx, \quad x > 0 \]  
(26)

\[ \beta(a,b) = \frac{\Gamma(a) \times \Gamma(b)}{\Gamma(a+b)} \]  
(27)

\[ M = (1 - \rho) \times \beta(a,b) \times \beta(S + 1, F + 1) \]  
(28)

\[ N = \rho \times \beta(a+S, b+F) \]  
(29)

\[ \pi(R) = \text{Beta}(a,b) = \frac{\Gamma(a+b)}{\Gamma(a) \times \Gamma(b)} \times R^{-1} \times (1 - R)^{b-1} \]  
(30)

\[ \pi_p(R | S,F) = \frac{M \times \text{Beta}(S + 1, F + 1)}{M + N} + \frac{N \times \text{Beta}(a+S, b+F)}{M + N} \]  
(31)

\[ \int_{0}^{R_{L}} \pi_p(R | S,F) \, dR = 1 - \gamma \]  
(32)

Given \(\gamma\), get \(R_{L}\).

### 4.2 Bayes Reliability Evaluation of Emergency Escape Parachute

Through the above analysis and research of Bayes reliability evaluation of emergency escape parachute, a Bayes reliability software program for the emergency escape parachute is written and completed, and the reliability evaluation of the emergency escape parachute is completed through the software program. The compiled emergency escape parachute software evaluation interface is shown in Figure 1.

![Figure 1. evaluation interface](image)

Input the data of the emergency escape parachute, including unit test data and system test data. Unit test data also includes withdrawal line, deployment bag, main umbrella, suspension lines, and harness system, etc. System test data includes the number of design finalized tests and the number of success, as well as the confidence level and other parameters. After all the data are input, different calculation algorithms can be selected according to whether the test data is zero failure or non-zero failure. When all the data are zero failure, click the "Bayes estimate when the number of failures is zero" button to calculate the reliability of the emergency escape parachute. When there is non-zero failure data, click the "Bayes estimate when the number of failures is non-zero" button to calculate the reliability of the emergency escape parachute, the result is displayed in the text box to the right of the lower reliability limit.
4.3 Comparative analysis of Bayes method and original binomial distribution method

Given under the condition of the same sample size, use the Bayes method and the classic method of the binomial distribution are calculated respectively, the results are shown in Table 1, the calculation results show that the Bayes method to evaluate the results are slightly higher than that of the binomial distribution evaluation result, since studies have shown that the binomial distribution of evaluation results is conservative, so under the condition of the same sample size using the Bayes evaluation results will be more accurate. For the case where the number of failures is non-zero, the Bayes method evaluation results are more obvious.

| Serial number | Scheme bottom test data (tests, successes) | Engineering development data (tests, successes) | Design finalize test data (tests, successes) | Bayes evaluate results | Binomial distribution evaluation result |
|---------------|-------------------------------------------|-----------------------------------------------|---------------------------------------------|-----------------------|----------------------------------------|
| 1             | (10,10)                                   | (10,10)                                       | (20,20)                                    | 0.9696                | 0.9440                                  |
| 2             | (5,5)                                     | (10,10)                                       | (20,20)                                    | 0.9668                | 0.9363                                  |
| 3             | (5,5)                                     | (10,10)                                       | (15,15)                                    | 0.9559                | 0.9261                                  |
| 4             | (10,10)                                   | (10,10)                                       | (15,15)                                    | 0.9637                | 0.9363                                  |
| 5             | (10,10)                                   | (10,10)                                       | (30,30)                                    | 0.9769                | 0.9549                                  |
| 6             | (5,5)                                     | (10,10)                                       | (30,30)                                    | 0.9752                | 0.9501                                  |
| 7             | (20,20)                                   | (10,10)                                       | (30,30)                                    | 0.9795                | 0.9623                                  |
| 8             | (20,20)                                   | (20,20)                                       | (30,30)                                    | 0.9815                | 0.9676                                  |
| 9             | (20,20)                                   | (20,20)                                       | (50,50)                                    | 0.9867                | 0.9747                                  |
| 10            | (20,20)                                   | (20,20)                                       | (100,100)                                  | 0.9921                | 0.9836                                  |

Note 1: the Bayes evaluation in the table refers to the evaluation method based on the statistical theory of Bayes, in which the scheme bottom test data and engineering development test data are regarded as prior information, and the design finalize test data are regarded as posterior information, and then the lower limit of reliability is calculated based on the Bayes formula.

5. Conclusions

In summary, this paper makes full use of various information in the development of emergency escape parachute, and establishes a set of comprehensive evaluation methods for the systems reliability of emergency escape parachute based on Bayesian theory. This method can improve the system reliability evaluation accuracy of the emergency escape parachute by comprehensively using the historical information accumulated in the development of various similar models of emergency escape parachute and the test data of the sub-systems of the emergency escape parachute under development. The method reduces the number of test samples, greatly reduces the research funding and shortens the development cycle.

APPENDIX and ACKNOWLEDGMENTS

Funding acquisition, Aviation Key Laboratory Science and Technology on Life-Support Technology, HubeiXiangyang; Reliability design, Fangyun Ma and Liying Jin; Supervision, Huajin Lei; Validation, Wensheng Wang and Jing Liu.

We would like to thank the anonymous reviewers whose thoughtful comments improved the quality of this paper. This work was supported by the Aviation Key Laboratory Science and Technology on Life-Support Technology, HubeiXiangyang.

REFERENCES

[1] Chao Zhang, Rentong Chen, etc. Reliability estimation of rotary lip seal in aircraft utility system based on time-varying dependence degradation model and its experimental validation [J]. Chinese Journal of Aeronautics. 2019, pp 1-12.
[2] Yuanyuan Guo, Youchao Sun, etc. Reliability assessment for multi-source data of mechanical parts of civil aircraft based on the model [J]. Journal of Mechanical Science and Technology, 2019, Vol.33 (7): 3205-3211.

[3] Xiaokun Zhang. CNC Machines Electrical System Reliability Evaluation Based on Bayes Theory [D]. Changchun, Jilin University, 2011.

[4] Haipeng Dong, Ruijiao Cai, etc. Bayesian Reliability Assessment Method of Rocket Ejection Seat [J]. Transactions of Beijing Institute of Technology, 2007, 27(8): 671-674.

[5] Yongshan Wang. Power System Reliability Assessment Based on Bayesian Theory [D]. Chengdu, University of Electronic Science and Technology of China, 2018.

[6] Huajin Lei, Fangyun Ma, etc. Bayesian Method for Reliability Assessment of Life-Saving Ejection Seat of Fighter Plane Based on Inheritance Factor [J]. Journal of Nanjing University of Aeronautics & Astronautics, 2017, 49(2): 264-268.

[7] Rong Wang. Collection and Analysis of Civil Aircraft Reliability Data [J]. Science & Technology Vision, 2019, pp 242,257.

[8] Xuemei Tang, Jinhuai Zhang, etc. Test Analysis and Evaluation of Weapon Systems in Small-Sample Circumstances [M]. Beijing: Press of National Defense Industry, 2001, pp 188-194.

[9] Gang Xiao. Reliability Assessment of Solid Rocket Engine Based on Converted Information [J]. Journal of Xi’an Jiaotong University, 1999, 33(7): 33-36.

[10] Yuehua Lai, Haipeng Dong, etc. Reliability Estimation of Aviation Pyrotechnics System Based on Mixed Beta Distribution [J]. Journal of Donghua University, 2014, 31(6): 766-769.

[11] Jing Wang, Tianmei Li, etc. Research on Multi-source Data Equivalent Methods for Testability Integrated Evaluation [J]. ACTA ARMAMENTARII, 2017, 38(1): 151-159.