A study on finite element model updating method for recovery airbag

J Y LI and S P SONG.
School of Non-Commissioned Officer, Space Engineering University, Beijing 102249, China.
E-mail: yang_zgy@sina.cn.

Abstract. It needs FE(finite element) model updating of recovery airbag for improving simulation accuracy of cushion process. In this paper, the FE model was updated based on drop tests of payload-airbags system. Firstly, FE model of payload-airbags was established. Two parameters, include discharge coefficient of vent and friction coefficient between airbag and ground, were selected for updating by sensitivity analysis. The response surfaces of impact response vs the two parameters were established based on Design of experiments and FE model. Based on the response surfaces, the optimal solutions were solved by Genetic algorithm. It indicated that the FE model updating of airdrop airbag was efficient through comparison of test results and simulate results before and after updating.

1. Introduction
Since airbag has the advantages of light weight, small volume when folded and reusability, it is widely used in the fields of recovery system, airdrop system and emergency protection of personnel. The airbag is deflected by compression to absorb shock energy, and releases energy simultaneously by venting for the purpose of cushioning.

The cushioning property of airbag is one of the highly focused issues by designers and users. Because of the airbag can prevent damage to payload by reducing maximum acceleration then the peak impact force will be constrained within the admissible range. The research methods of cushioning property of airbag mainly include experimental research and simulation. Experimental research is the most effective method, however there are some disadvantages such as long test period, high input cost and low efficiency, etc. Because of the merits of simulation such as economical efficiency, flexibility and repeatability, this method is more and more widely used in the research of airbag cushioning property.

Scholars at home and abroad have simulated the cushioning process of airbag by FEM, which has been applied in many fields. In the field of spacecraft recovery and landing, Taylor simulated the recovery airbag system of Beagle II by explicit FEM [1]. Willey simulated the recovery airbag of CEV by FEM [2]. In the field of UAV landing, Fang studied the influence of parameters of airbag on cushioning characteristics [3]. In the field of airdrop equipment landing, Wang simulated the cushioning process of airdrop equipment by explicit FEM, and optimized the parameters of airbag [4].

At present, although a lot of studies on FE modeling of airbag had been done, but there are errors with experimental results due to the assumptions and approximations in FE model of airbag.
FE model updating method is to make FE calculation results be closely to experimental results by updating the parameters in FE model. Many parameters in a complex system like airbag are hard to measure accurately. For improving simulation accuracy, the parameters of FE model must be updated.

FE model updating technology gets considerable development and have better application in a lot of project fields in recent years [5,6]. Traditional model updating method is a trial-and-error iteration method, it has the characteristics of poor computational efficiency and strong subjectivity. However, the simulation of an impact typically requires tens of hours. As a result, it is difficult to use the traditional iterative approach to update parameters of complex nonlinear FE model such as airbag system.

This paper presents a FE model updating method for recovery airbag by FEM (finite element method) and response surface model aimed at the necessity of updating FE model and the shortage of traditional FE updating method. Firstly, FE model of payload-airbags was established. The parameters which significantly affected impact response in sensitivity analysis were selected for updating. The response surfaces of impact response vs parameters for updating were established. Based on the response surfaces, the optimal solutions were solved by genetic algorithm. It indicated that the finite element updating of airdrop airbag was efficient through comparing between test results and simulation results before and after updating.

2. FE model updating method based on response surface

The method of FE model updating based on response surface is the product of response surface method and FE model updating. Its main contents include FE modeling, selecting of parameters for updating, response surface modeling, parameters updating and model validation. The process of FE model updating by response surface is shown in Figure 1.

(1) FE modeling. When FE modeling, it needs to Choose appropriate way to model and using reasonable simplifications include connection types and contact-impact models according to the objects and demands of FE analysis.

(2) Parameters for updating. It needs to select the parameters for updating because of not all parameters effect on objective function significantly. Sensitivity analysis is one of the most widely used methods for selecting of parameters for updating [7].

(3) Response surface method. The functional relation between design variables and objective function is always unknown in complex engineering problems. The approximation of partial or entire design space could be obtained by less times of analysis using response surface method. Then implicit function representing a complex engineering problem could be transformed into an explicit approximation function [8].

(4) Model updating. FE model updating method is to make FE calculation results be closely to experimental results by updating the parameters in FE model. If FE model updating is like optimization problem, then parameters of FE model are optimization parameters, minimizing the errors between FE results and test results is optimization target.

Figure 1. Flowchart of FE model updating.
(5) Model validation. Simulating the cushion process using FE model with parameters after updating. A comparison of the simulation results of the non-updated and updated FE model and the experiment result proves the credibility of model updating.

3. FE model of payload-airbags system

The payload-airbags system, which was composed of steel load platform, airbags system and data acquisition system, was showed as figure 2. The airbags system was composed of 4 square airbags with single air chamber, the size of airbag was 900mm×480mm×420mm. The vent of airbag was located in the geometric center of side of airbag, the circle radius was 50mm. The width of airbag was slightly larger than length for ensuring the lateral stability of the system. The vent was made from aluminium alloy and processing. Cover film was cover on the vent for controlling discharge pressure. The pressure film was hitched by rubber band in the experiment. Comparing with the method of pasting pressure film, this method was quite simple and reliable, and the operation time was greatly shortened.

Airbag was composed of inside and outside fabric with the same structure and shape. The inside fabric was functioning sealing while the outside fabric was functioning supporting.

The payload-airbags system was established by FE soft. The payload was modeled by the same mass plate because the structure of payload was without consideration. For the structure of payload was without consideration, it was modeled by the same mass plate which was meshed by hexahedral elements. The airbags were meshed by 20mm shell elements. The FE model of payload-airbags system included 28632 elements.

Airbag was modeled by control volume method, which was the earliest and most frequently used method in the field of airbag research. Control volume method was based on the following assumptions: (1) the pressure and temperature in airbag were the same every time and everywhere; (2) the gas in airbag was perfect gas; (3) the coefficient of thermal capacity of gas was constant; (4) there were no heat exchange with outer gas. The control volume was defined by closed volume, which includes gas properties, air inlet and air outlet. The contact models among payload, airbag and ground were also needed to be defined in payload-airbags FE model. The payload-airbags FE model was shown in figure 3.
4. Drop tests
Before the drop tests of payload-airbags system, pressure films were covered on the vents and the airbags were inflated. The system was lifted up to the test height by elevator to simulate the drop velocity. Data collection system, which was place on payload, could collect acceleration of payload and pressure in airbags. The researchers did three experiments, the test conditions and results were shown as table 1. Some main moments of drop test were shown in figure 4.

Table 1. Results of experiments.

| Height (m) | Mass of payload (kg) | Peak acceleration (g) | Peak pressure (kPa) |
|-----------|----------------------|-----------------------|--------------------|
| Test 1    | 1.8                  | 380                   | 15.12              | 122.54             |
| Test 2    | 1.8                  | 380                   | 14.71              | 120.68             |
| Test 3    | 1.8                  | 380                   | 14.68              | 121.92             |

5. FE model updating
As the flowchart reviewed in the paragraphs above, the research on model parameters was proceeded by orthogonal experimental design and analysis of variance firstly. The parameters which significantly affect impact response in sensitivity analysis were selected for updating, then the parameters were optimized for improving the reliability of simulation model.

5.1. Selecting parameters for updating
For avoiding the blindness of model updating and improving the efficiency of model updating, the parameters which significantly affect impact response must be analyzed, that was parameters selection. Parameters for updating selection could according to the following guidelines: (1) parameters that cannot be accurately measured; (2) parameters determined by experiment or estimated by simple method.
4 parameters were selected, including: fabric modulus of elasticity, thickness of airbag fabric, friction coefficient between airbags and ground, discharge coefficient of vent. The orthogonal design which had 4 factors and 3 levels was performed. The acceleration and pressure of airbag were obtained by FE simulation of the orthogonal design points. The parameters sensitivity was analyzed by analyzing variance to the results of the experiments. Test schemes and results of orthogonal experiments were shown in table 2. Sensitivity of model parameters was shown in figure 5.

Table 2. Test schemes and results of orthogonal experiment.

| Test number | Modulus of elasticity (MPa) | Friction coefficient | Fabric thickness (mm) | Discharge coefficient | Acceleration (g) | Pressure (atm) |
|-------------|-----------------------------|----------------------|-----------------------|----------------------|------------------|----------------|
| 1           | 400                         | 0.2                  | 0.5                   | 0.6                  | 10.3             | 1.28           |
| 2           | 400                         | 0.4                  | 1.0                   | 0.8                  | 16.6             | 1.39           |
| 3           | 400                         | 0.6                  | 1.5                   | 1.0                  | 13.5             | 1.32           |
| 4           | 500                         | 0.2                  | 1.5                   | 0.8                  | 10.8             | 1.26           |
| 5           | 500                         | 0.4                  | 0.5                   | 1.0                  | 14.7             | 1.35           |
| 6           | 500                         | 0.6                  | 1.0                   | 0.6                  | 19.1             | 1.45           |
| 7           | 600                         | 0.2                  | 1.0                   | 1.0                  | 9.9              | 1.24           |
| 8           | 600                         | 0.4                  | 1.5                   | 0.6                  | 17.8             | 1.41           |
| 9           | 600                         | 0.6                  | 0.5                   | 0.8                  | 17.2             | 1.40           |

Figure 5. Sensitivity of model parameters.

From the analysis results above, friction coefficient was the most significant effect on both acceleration and pressure, discharge coefficient of vent was second, fabric modulus of elasticity and thickness of airbag were least, and the error caused by interaction among model parameters was small. So friction coefficient and discharge coefficient of vent were selected as parameters for updating.

5.2. Constructing of response surface model

Samples selection concerned the accuracy of response surface model and computational expense. Small sample size cannot reflect the characteristics of the system entirely, and too many samples could increase computational expense, though the accuracy is good. In this paper, 20 experimental design was carried out by Latin supercube method because of fine space filling performance [9]. Then response surface model between response and model parameters was fitted by Moving Least Square Method. The response surfaces were shown as figure 6 and figure 7.
The fitting accuracy must be checked after response surface constructed. Evaluation indexes of response surface fitting could describe the goodness of fit well. Evaluation indexes such as square of negative correlation coefficient ($R^2$) and root-mean-square error (RMSE) are well-known. Evaluation results of the goodness of fit were shown in Table 3.

### Table 3. Evaluation results of the goodness of fit.

|                     | Response surface of acceleration | Response surface of pressure |
|---------------------|---------------------------------|-----------------------------|
| $R^2$               | 0.9998                          | 0.9999                      |
| RMSE                | 0.0363                          | 0.0428                      |

Because of $R^2$ was close to 1 and RMSE was close to 0, we could get a conclusion that the response surface had a high accuracy which fitting by Moving Least Square Method.

Iterative modification in the response surface was carried out by Genetic algorithm. Genetic algorithm is a kind of optimization algorithms which simulates Darwin’s genetic choice and natural elimination biology evolution process [10]. Optimum solution of parameters for updating could be obtained by optimization based on response surface. The optimal friction coefficient was 0.22 and optimal discharge coefficient of vent was 0.84.

The updated model was obtained by plugging the optimal solutions into the non-updated FEM. Comparison of impact responses and test results was obtained by simulation, as shown in Table 4. Comparison of prediction results by response surface model and test results was also given in Table.

### Table 4. Model validation.

|                     | Test results | Simulate results |
|---------------------|--------------|------------------|
|                     | Test number  | Peak acceleration (g) | Maximum pressure (kPa) | Peak acceleration (g) | error | Maximum pressure (kPa) | error |
| Comparison before updating | Test 1 | 15.12 | 122.54 | 22.49% | 12.58% |
|                      | Test 2 | 14.71 | 120.68 | 18.52 | 25.90% | 137.95 | 14.31% |
|                      | Test 3 | 14.68 | 121.92 | 26.16% | 13.15% |
| Comparison after updating | Test 1 | 15.12 | 122.54 | -5.56% | 5.17% |
|                      | Test 2 | 14.71 | 120.68 | 14.28 | -2.92% | 128.87 | 6.79% |
|                      | Test 3 | 14.68 | 121.92 | -2.72% | 5.70% |
| Comparison of prediction results | Test 1 | 15.12 | 122.54 | -4.83% | 5.26% |
|                      | Test 2 | 14.71 | 120.68 | 14.39 | -2.18% | 128.99 | 6.89% |
|                      | Test 3 | 14.68 | 121.92 | -1.98% | 5.80% |

As seen from the table, the error of peak acceleration dropped to 6% from 22% before updated, the error of maximum pressure in airbag dropped to below 7% from above 12% before updated. This shows, the updated FE model could simulate the dropping process well, and the accuracy of updated FE model
is rather high. The veracity of response surface model was verified by the comparison of prediction results by response surface model and simulation results again.

6. Conclusions
(1) The influence of parameters of FE model on impact response was carried out by orthogonal experimental design and analysis of variance. The results showed that friction coefficient and discharge coefficient of vent were the two parameters which significantly influence the accuracy of FE model.
(2) When the error between test results and simulate results based on response surface was treated as optimization objective, optimum solutions of parameters for updating were obtained by Genetic algorithm. Through the comparison of test results and simulate results before and after updating, it was verified that FE model updating based on response surface method could improve the accuracy of FE model, so that the purpose of model updating was achieved.

References
[1] Taylor A P and Gardinier D J 1999 AIAA (Design Optimization of the Beagle II Mars Lander Airbags Through Explicit Finite Element Analysis) 99-1743
[2] Willey C E, Sandy C, Welch J and Timmers R 2007 AIAA (Impact Attenuating Airbags for Earth and Planetary Landing Systems) 2007-6172 1-13
[3] Fang Kangshou 2008 Zhejiang University (The FEA Research on Aseismic Performance of Recovery Airbag on UAV)
[4] Wang Hongyan, HONG Huangjie and LI Jianyang, et al 2012 Acta Armamentarii 33 1461-66
[5] Wang Beijing and WANG Hongyan 2011 Journal of Academy of Armored Force Engineering 25(6) 40-4
[6] Han Wanshui, Wang Tao and LI Yongqing et al 2011 Journal of Traffic and Transportation Engineering 11(5) 18-27
[7] Chen Xueqian, Xiao Shifu and LIU Xin’en 2012 Mechanics in Engineering 34(3) 32-5
[8] Wu Xianyu, Luo Shibin and CHEN Xiaoqian et al 2007 Journal of Astronautics 28(5) 1127-32
[9] Ren Weixin and Chen Huabin 2008 China Civil Engineering Journal 41(12) 73-8
[10] LIU Xin, Han Xu and Wen Guilin 2008 China Mechanical Engineering 19(6) 729-32