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Research on Airbags Landing System for Airborne Vehicle Airdrop ⋆

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Abstract

A numerical simulation model for the airbags landing system is developed by using control volume method to research the cushioning performance of the airbag landing system and analysis the affect of the typical external factors on the buffer characteristics. A series of experiments were conducted to verify the validity of the simulation model by comparing the calculation results and test data. By analyzing the simulation results, the influence of external factors on cushioning buffer are obtained. From the results we can see that the affect of the important factors such as the weight of airdropped loads, landing velocity and the altitude of landing site are significant. Based on the simulation model, the environmental adaptability of the airbags buffer system was analyzed too. Some suggestions for the adaptability of the airbags buffer system are provided and its cushioning characteristics are estimated.

Keywords: Applied Mechanics; Control Volume Method; Airdrop Landing; Airbag Buffer; Numerical Simulation

1 Introduction

The landing of airborne vehicles on land is a task with some risk. During descending, the vertical velocity of the airdrop system is about 8 m/s, as determined by the landing system terminal velocity under the parachute. The vehicle and its payload bear a large deceleration during hitting the ground at such a high speed. This may lead to the vehicle is damaged. So, the landing of the vehicle on the earth requires some kind of buffer device at the time of impact to protect the vehicle and its payload [1].

As one of important soft landing system, airbag landing systems offer an attractive means of cushioning the landing impact of the vehicle. Airbag landing systems absorbs the impact kinetic energy by exhausting the compressed gas through vent in this way that aims to bring the vehicle to landing with limited deceleration and velocity [2]. Main methods of study on the airbag include

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the experimental research, the theoretical calculation and the numerical simulation analysis [3]. With the development of computing technology, numerical simulation has been more and more widely used in the research on the airbag landing system. Many researchers have studied the airbag landing system using numerical simulation method [4-7]. The fluid-structure coupling method and the control volume method is usually adopted in the process of numerical simulation Numerical simulation. Most of the airbag simulation adopted the Control Volume method (CV) because it is simpler. Yongxiang Le [8] analyzed the process of double-chamber airbag landing by numerical simulation based on the control volume method. Liangchun Li [9] simulated a new type airbag landing system by using the control volume method. Their simulation results show that the design maximum deceleration of the airbag is conformed to the requirements. Yu Li [10] analyzed the transient flow field of a airbag during its opening process by using the control volume method and the fluid-structure coupled arbitrary Lagrangian-Eulerian method. By comparing the results it showed that the CV method is simple.

In this work, a numerical simulation model of the multi-airbags buffer landing system is build by using control volume method based on the ideal gas uniform pressure model. In this calculation, the influence rules of the external factors on cushioning characteristics are analyzed. The results showed that the influence of the typical external factors such as the weight of airdropping equipment, landing velocity, slave venting area, the ground obliquity and the altitude of landing point are prominent. A series of experiments were conducted on a multi-airbags buffer landing system. The validity of the simulation model was verified through comparing with experimental data.

2 Airbag Structure and Operating Principle

The airbag landing system is a multi-bag system, and it is composed of eight airbags and installs on the bottom of the vehicle by a special support (see Fig. 1). The structure sketch of the double-chamber airbag is shown in Fig. 2. From Fig. 2 it can be seen that each airbag consists of a main airbag and an auxiliary ballonet. In the process of the vehicle and the airbag system descending, air flow into main airbag through the inlet in the main airbag bottom until it is filled. During landing, the bottoms of the airbags are the first to hit the ground, then, the main airbag is compressed by the vehicle and the air inside the main airbag flow into the auxiliary ballonet through the vents during the deceleration process. As the vehicle drop, the pressure inside the airbag keeps to rise. When the pressure rises to a designed value, the air outlets open and begin to exhaust. The air leak method for the bag can keep the deceleration of the vehicle and its payload within a given scope, this aims to bring the vehicle to rest with minimum rebound.

3 Numerical Simulation of Multi-bag System

3.1 Governing Equation

The air inside the airbag can be hypothesis is the ideal gas with a constant specific heat capacity. During landing, the time of the cushion process time is very short, this suggests heat exchange between the air inside and outside the bag is limited. For adiabatic compression, the equation of

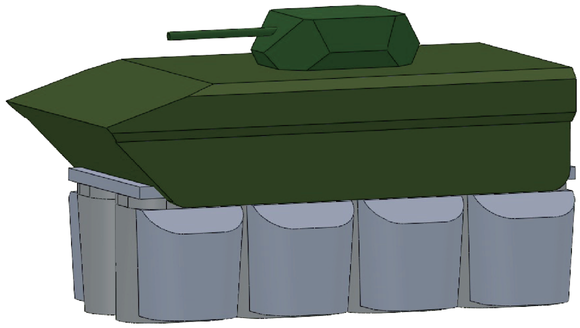

Fig. 1: Multi-airbags landing system

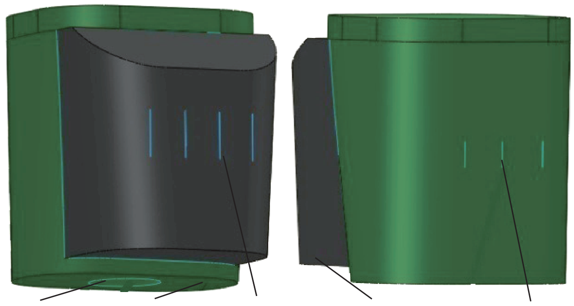

Fig. 2: Structure sketch of the airbag

gas state inside the airbag is as follows:

$$Pv = mRT = (k-1)\,U = (k-1)\,\frac{m}{M}C_vT \tag{1}$$

where P, T, m, U, M and C_v are the pressure, the temperature, the mass, the thermodynamic energy, the molar mass, the and specific heat at constant volume of the gas inside the airbag respectively; R is the gas constant, $R = 8.314$ J/mol·K; k is the adiabatic index.

3.2 Outlet Flow Equation

The air outlet flow rate can be expressed by the following equation:

$$\dot{m} = \dot{m}_z + \dot{m}_f = \mu\sqrt{2p\rho}\sqrt{\frac{k}{k-1}\left(q^{\frac{2}{k}} - q^{\frac{k+1}{k}}\right)} \tag{2}$$

where $q = \frac{p}{p_0}$, its critical values $q_{cr} = \left(\frac{2}{k+1}\right)^{\frac{k}{k-1}}$, when $q \geq q_{cr}$, $\dot{m} = \mu\sqrt{2kp\rho\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}}$, where p_0 is the pressure of the air outside the airbag, ρ is the density of the air inside the airbag, μ is the flow characteristic coefficient, $\mu = (c_zA_z + c_fA_f)\sqrt{g_e}$. In this formula, c_z and c_f are the flow coefficient of the outlet in the main airbag and the auxiliary ballonet respectively, A_z and A_f are the air outlet area of the main airbag and the auxiliary ballonet respectively; g_e is the gravity conversion coefficient.

3.3 Equation of Control Volume Method

During landing, the airbags are treated as dwindling volume control. Based on the Green theorem, the formula between the closed surface integral and the volume integral of the volume surrounded by the closed surface can be expressed by the following equation:

$$\iiint\left(\psi\frac{\partial\phi}{\partial x} + \phi\frac{\partial\psi}{\partial x}\right)\mathrm{d}x\mathrm{d}y\mathrm{d}z = \oint \phi\psi n_x \mathrm{d}\tau \tag{3}$$

where ϕ and ψ are the arbitrary functions in the domain of integration; n_x is the cosine of the angle between the surface normals and the x axis.

The cubature formula expression as follows:

$$V = \iiint \mathrm{d}x\mathrm{d}y\mathrm{d}z \tag{4}$$

Make $\psi = x$, $\phi = 1$, then

$$V = \oint x n_x \mathrm{d}\tau \approx \sum_{i=1}^{N} \bar{x}_i n_{ix} A_i \tag{5}$$

where $\bar{x}_i$ is average value of x coordinate of the element nodes; A_i is the area of the element; N is the number of the elements.

3.4 Motion Equation

During landing, the mechanical model of the airbag can be treated as the contact collision model, the equation of motion can be expressed by the following formula:

$$\int_V \sigma\delta_e \mathrm{d}V - \int_s r\delta_u \mathrm{d}s - \int_c f\delta_u \mathrm{d}c + \int_V \rho_a a \delta_u \mathrm{d}V = 0 \tag{6}$$

where σ is the stress matrix; δ_e is the virtual strain; s is the area of under external load; δ_u is the relative virtual displacement of the contact points corresponding to the force; r is the external load vector; c is the contact area between the airbags; f is the force acting on the contact area; ρ_a is the density of the airbag; a is the deceleration of the vehicle and its payload.

4 Results and Discussion

In reality, the environment is quite complicated in the process of the airdrop. During landing, many external factors, such as the payload mass, the landing velocity, the gas outlet area, and the landing site altitude, can affect the cushioning characteristics of the multi-airbags landing system. The research on the influence law of these factors is very important to improve the design of airbag landing system.

4.1 Influence of the Airdropped Payloads Mass

Other things being equal, the influence law of the payloads mass on the performance of airbag buffer system is analyzed. During impact, as the airdrop equipment close to the ground, the pressure inside the airbag increases rapidly, the resistance from the airbag increases too. As a result, the deceleration of the airdrop equipment increases rapidly. When the pressure rises to the designed value, the air outlets open and begin to exhaust. As a result, the deceleration of the airdrop equipment diminishes rapidly. Fig. 3 shows the cushioning performance curves of the multi-airbag landing system under different quality. From the calculated results we can see that the variations of the payloads mass has a significant influence on the cushioning properties. With the increase of the airdropped payloads mass, the maximum deceleration decreases. The effect of the airdropped payloads mass on its descent velocity is illustrated in Fig. 3 too. When the mass is large, the airdrop equipment lands safely with less relative speed without rebound. As the airdrop mass decreases, the peak overload on the airdrop equipment increases significantly.

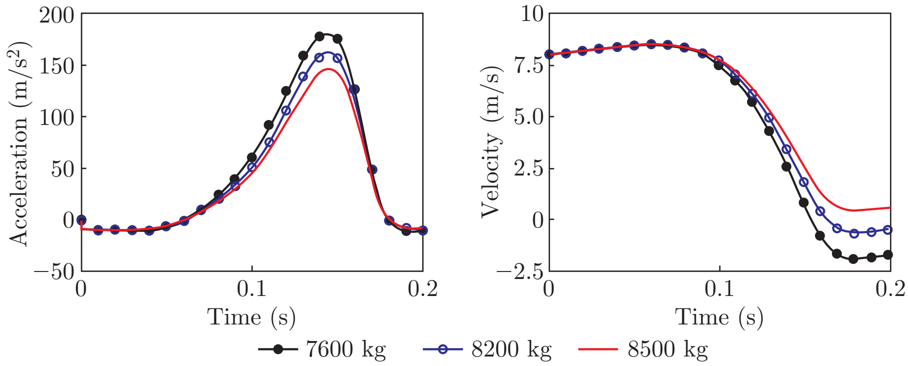

Fig. 3: The influence of airdropped payloads mass

4.2 Influence of the Landing Speed

The landing speed of the system is defined as the velocity of the system at the initial time of the landing process, and it is determined by the airdrop velocity with the parachute system. The variety of the environment will cause the change of the performance of parachute system, then, the landing speed of the system will change.

Fig. 4 shows the cushioning performance curves of the airbag buffer system under different landing speed. From the calculated results we can see that the variations of the landing speed has a significant influence on the cushioning properties. From Fig. 4 we can see that the speed is 7.0 m/s, 7.5 m/s and 8.0 m/s, conversely and the peak overload on the airdrop equipment is 119.4 m/s^2, 140.1 m/s^2 and 166.6 m/s^2 respectively. With the increase of the landing speed, the maximum deceleration increases. The effect of the landing speed on the descent velocity is illustrated in Fig. 4 too. When the landing speed is small, the airdrop equipment lands safely with less relative speed without rebound. As the landing speed increases, the airdrop equipment will crash with the ground at more and more large velocity, and the risk of equipment damage will increased.

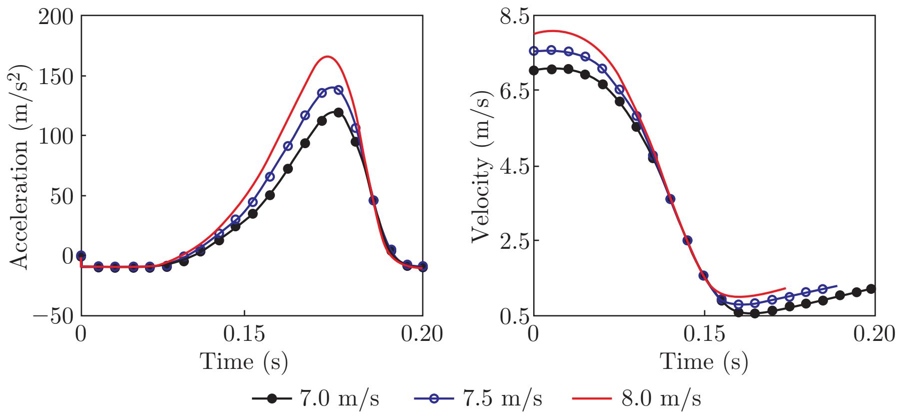

Fig. 4: The influence of landing velocity

4.3 Influence of the Landing Environment

For real work, the landing system may face a wide variety of environments. So, the influence of the environment on the cushioning characteristic of the airbag landing system must be considered.

There is a great influence of the latitude on the key environment factors, such as atmospheric pressure, air density, and ambient temperature. As an important factor, the altitude of the landing site is the biggest factor in cushioning characteristic.

Fig. 5 shows the cushioning performance curves of the airbag buffer system in different landing environment. From the calculated results, it can be seen that the variations of the landing environment has a significant influence on the cushioning properties. From Fig. 5 we can see that the influence of the environmental parameters on the maximum deceleration of the airdrop equipment is not obvious. The reason for this result is the overload on the equipment is determined by the pressure difference between the internal and external of the airbag. The influence of the environmental parameters on the descent velocity is illustrated in Fig. 5 too. When the landing speed is small, the airdrop equipment lands safely with less relative speed without rebound. As the altitude increasing, the impact velocity between the airdrop equipment and the ground increases.

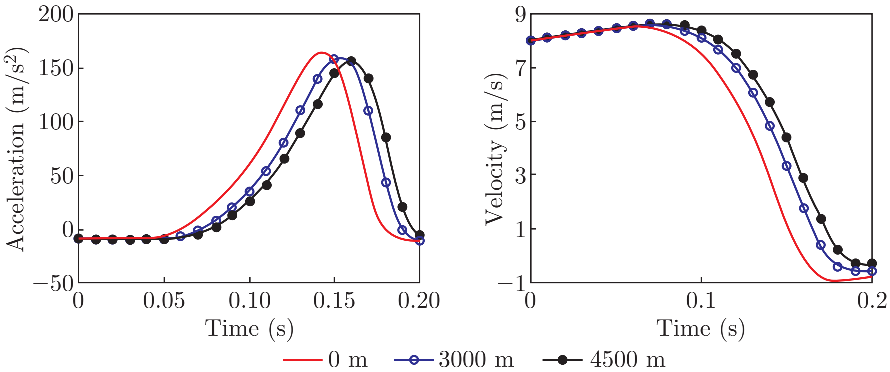

Fig. 5: The influence of altitude

4.4 Experimental Comparisons

In order to verify the correctness of the calculation results, experiments were conducted on a multi-airbag landing system. The simulation calculation results are almost concordant with the experiment data of the overload and drop speed of the airdropped equipment during landing, as shown in Fig. 6. The main source of error is not considered the variation of the leakage of the gas from the airbag in the process of the buffer.

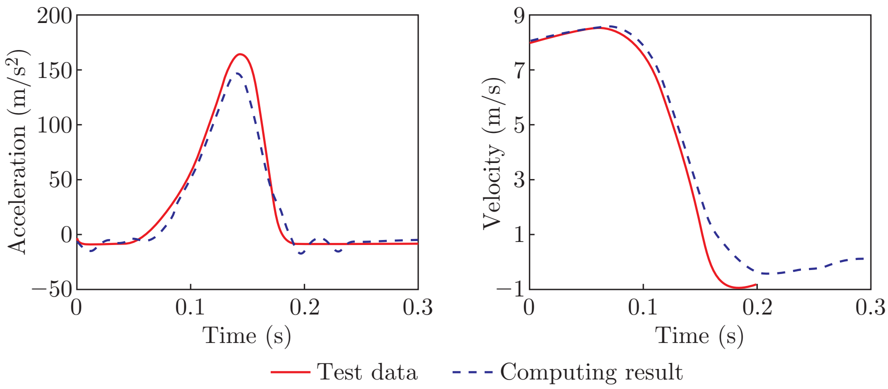

Fig. 6: The contrast of analytical result and test result

5 Conclusion

In this work, in order to search the influence of the external factors on the buffer performance of the multi-airbag landing system, a numerical simulation model of the multi-airbags buffer landing system is build by using control volume method based on the ideal gas uniform pressure model. By comparing the calculation results with the test data, the correctness of the numerical calculation model is verified. Based on the results, the important conclusions are derived as follows:

(1) The influence of the airdropped payloads mass on the cushioning performance is significant. With the increase of the airdropped payloads mass, the airdrop equipment lands safely with less relative speed without rebound. If the weight of the airdropped payloads does not exceed the allowable values, the safety of the equipment can be guaranteed.

(2) The landing speed of the landing system is actually fluctuating within a certain range. As the landing speed increases, the airdrop equipment will crash with the ground at more and more large velocity, and the risk of equipment damage will increased.

(3) For a determined multi-airbag landing system, the environmental adaptability is limited, such as altitude of the airdropped site. So, the influence of the environment on the cushioning characteristic of the airbag landing system must be considered.

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