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Study on the Method of Prediction of Complete Inflation Time of Parachute

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Abstract

In general, the parachute test is a long test period, expensive, and difficult to measure with accuracy, which makes it a very laborious and laborious task due to the strong nonlinearity of the fabric of the parachute. Therefore, attempts have been made to overcome this by using a parachute testbed or by simulation, but in our country, there is no numerical simulation of the parachute, and no research has been done on it. According to the development of military techniques, it is very important to determine the complete inflation time of the parachute. So far, there is no method to predict the total expansion time of a parachute, which depends on empirical formulas and various data. In this paper, we discussed how to determine this. Finally, a model of the parachute was developed using the fluid-structure interaction technique (FSI) in the LS-DYNA program, which is a transient dynamic finite element code. In general, it has been considered difficult to predict the total inflation time of a parachute, and measurements have been made by approximate calculations and experimental methods. Predicting the correct divergence time is of great importance in determining the standard drop height and the rate of the drop. To this end, we have investigated how to calculate the air-filling time of a parachute. A mathematical model for calculating air-filling time is developed and verified by a numerical example, combining the mass conservation equation and the equations of motion of the parachute system for a circular parachute.

Keywords: Air-filling time, circular parachute, instantaneous speed of the parachute system, ALE method, inflation time

INTRODUCTION

Parachutes generate very large loads during air-filling, which cause large stresses in the parachute and parachute ropes [1–3].

It is necessary to calculate and design the maximum dynamic load acting on the parachute through theoretical methods at the design stage of the parachute [4–9].

However, when calculating the maximum overload, the air-filling time of the parachute must be determined, which is the main problem in the parachute design.

In addition, when performing the parachute simulation, the ventilation time of the parachute must be calculated, and the changing rule of the drag characteristics during the ventilation of the parachute must be established [10–16].

Generally, the air-filling time of a parachute is determined by factors such as the type of parachute, falling speed, geometry, type of fabric, and folding method of the parachute.

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CALCULATION OF AIR-FILLING TIME OF A PARACHUTE WITHOUT BREATHING HOLES

The air-filling time of a parachute is related to the quality of the air flowing into the acid and the amount of air flowing through the acid gap.

The supply air volume is related to the instantaneous velocity of the parachute system.

The outflow air volume is related to the difference in the pressure inside and outside the mountain.

The instantaneous velocity of the system and the difference in the internal and external pressures of the acid change during the air-filling process, and the equation of motion must be obtained by solving the equation of motion.

We introduce the following assumptions:
1. During air-filling, the parachute projected area changes linearly with time.
2. During air-filling, the parachute drags coefficient remains unchanged.
3. The effective air flow rate of the parachute is unchanged.
4. The air density remains unchanged.
5. After complete divergence, the parachute is hemispherical.

The shape of the parachute is a hemisphere with a diameter of Dp, an inverted cone with an upper diameter of Dp, and a lower diameter d.

From the basic assumption, the parachute projected area Sp during air-filling can be written as

$$S_p = \frac{\pi D_p^2}{4} = \text{kt} \tag{1}$$

t=tf; that is, when the umbrella is fully filled, D p = Dmax, from which we obtain

$$k = \frac{\pi D_{\text{max}}^2}{4t_f} \tag{2}$$

In the expression, tf is the fill time.

The umbrella with a nominal diameter of D0 becomes dome-shaped when fully filled, and Dmax can be written as

$$D_{\text{max}} = \frac{2D_0}{\pi} \tag{3}$$

Substituting the above expression into Equation (2), we can write

$$k = \frac{D_0^2}{\pi t_f} \tag{4}$$

Substituting Equation (4) into Equation (1), we obtain

$$S_p = \frac{D_0^2}{\pi} \frac{t}{t_f} \tag{5}$$

The diameter of the parachute's projected area is

$$D_p = \frac{2D_0}{\pi} (\frac{t}{t_f})^{1/2} \tag{6}$$

Based on the geometric relationship of the ideal shape of the parachute during air-filling, we can write:

$$\frac{d}{L_s} = \frac{D_p}{L_s + \frac{D_0}{2} - \frac{\pi D_p}{4}} \tag{7}$$

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Summarizing Equations (6) and (7), we obtain

$$\frac{t}{t_f} = T \tag{8}$$

During air-filling of the parachute, the inlet diameter d is expressed as

$$d = \frac{2D_0}{\pi}\left[\frac{2L_s T^{1/2}}{2L_s + D_0 - D_0 T^{1/2}}\right] \tag{9}$$

Using the difference between the amount of air entering the parachute and that leaving the gap, we obtain the following relationship:

The mathematical relationship is as follows:

$$\frac{\pi d^2}{4} v_{\text{in}} \rho - \frac{\pi D_p^2}{2} U \rho = \frac{d}{\text{dt}}(\rho V) \tag{10}$$

where v_{in} is the air inflow rate, and U is the air outflow rate.

When air-filling begins, the inflow velocity of the air stream is close to that of the free stream.

Assuming that the ratio of the inflow velocity to the free flow rate decreases linearly with time, we obtain

$$\frac{v_{\text{in}}}{v} = 1 - T \tag{11}$$

Where, T is the influence coefficient.

Again, assuming that the airflow rate and inflow rate through the membrane are directly proportional, we obtain

$$U = C v_{\text{in}} \tag{12}$$

Coefficient C in the equation is the 'effective ventilation' of the parachute material.

Substituting Equations (6), (9), (11), and (12) into Equation (10) and dividing, we obtain:

$$\frac{\text{dV}}{\text{dt}} = \frac{D_0^2 v(1-T)T}{\pi}\left[\left(\frac{2L_s}{2L_s + D_0 - D_0 T^{1/2}}\right)^2 - 2C\right] \tag{13}$$

rewrite

$$\text{dr} = t_f \text{dT} \tag{14}$$

Substituting the above expression into Equation (13), we obtain

$$\frac{\text{dV}}{\text{dt}} = \frac{D_0^2 v t_f (1-T)T}{\pi}\left[\left(\frac{2L_s}{2L_s + D_0 - D_0 T^{1/2}}\right)^2 - 2C\right] \tag{15}$$

This equation is the basic equation that determines the gas-filling time.

Where, v is the instantaneous velocity of the parachute system and C is the effective ventilation.

As can be seen from Equation (15), the air-filling time of the parachute is determined by the instantaneous velocity of the parachute system, the geometry of the parachute, and the airflow rate of the parachute cover.

The geometry of the parachute and the ventilation rate of the parachute garment are usually known. If the instantaneous velocity can be obtained, the ventilation time can be obtained by integrating

Equation (15). For the “infinite mass” air-filled state, the instantaneous velocity of the parachute system can be considered equal to the system velocity in linear tension.

The instantaneous velocity changes during the air-filling must be expressed as a function of T.

So, the velocity of the parachute system can be expressed like this.

$$\frac{d}{\mathrm{dt}}\left[\left(\frac{W}{g}+m_i+m_a\right)^2 v\right]=-\frac{\rho}{2}C_D S_{v^2}+W \tag{16}$$

where W/g is the mass of the parachute, mi is the mass of air entering the mountain, ma is the mass flowing through the mountain gap, and $-\frac{\rho}{2}C_D S_{v^2}$ is the drag of the parachute.

The mass of air entering the parachute during air-filling, and the mass flowing out of the gap is given by [1]

$$m_i=\rho V=\frac{2\rho D_0^3}{3\pi}\left[1.058-\frac{(T-1.31)^2}{1.62}\right] \tag{17}$$

$$m_a=\frac{\rho D_0^3}{4\pi^2}T^{5/2} \tag{18}$$

Based on this basic assumption, the air drag force during air-filling varies linearly with time.

$$\frac{\rho}{2}C_D S=\frac{\sigma\rho_0}{2}(C_D S)_{\max}T \tag{19}$$

In this expression, $(C_D S)_{\max}$is the characteristic of the drag force at the moment the parachute is fully open, $\sigma$is the ratio of the air density at the altitude at which the parachute is deployed to the normal air density, and ρ is the air density at the altitude at which the parachute is deployed.

Using these equations, we can obtain a differential equation for the instantaneous velocity of the parachute system during the air gas-filling process.

$$2\left[\frac{W\times10^6}{20g\sigma D_0^3}+11.25T\right]\frac{dv}{\mathrm{dT}}+22.5v=\frac{-120t_f(C_D S)_{\max}Tv^2}{D_0^3}+\frac{W\times10^5 t_f}{\sigma D_0^3} \tag{20}$$

The integral form of Equation (15) is as follows.

$$\int \mathrm{dV}=\frac{D_0^2}{\pi}t_f\int v(1-T)T\left[\left(\frac{2L_s}{2L_s+D_0-D_0T^{1/2}}\right)^2-2C\right]\mathrm{dT} \tag{21}$$

Using these two equations, the inflation time can be found as follows:

1. First, the value t_f is selected, and numerical integration is performed on Equation (20) to obtain the instantaneous velocity v within the range 0–1.
2. By substituting this value into Equations (21) and calculating the integral value on the right-hand side of Equation (21), within the range of 0–1.
3. The integral value on the left-hand side of Equation (21) is equal to Vmax. Based on the basic hypothesis, it can be obtained from the geometry of the parachute.
4. Compare the integral values of the left and right sides of Equation (21), and if not equal, select again t_f to repeat the above process; then, the time of the air-filling is the time of the solution when the two integrals are equal.

The Empirical Formula for Calculating Air-Filling Time

In general, there is no formula for calculating the air-filling time; however, an empirical formula for calculating it is given [7].

$$t_f=\frac{0.65\lambda_g D_0}{v_L} \tag{22}$$

Where, λ_g is the geometric ventilation of the parachute and v_L is the linear tensile velocity.

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For a particular coating, the variation in parameters such as the type of sheeting cupboard and the process of sheeting and parachute (which are difficult to control for these factors) can deviate from the calculation results of this empirical formula.

In fact, this formula is quite different from the actual value because it does not consider the packing method of the parachute, type of coating, and type of parachute. Therefore, the gas-filling time obtained from this empirical formula must be adjusted within a certain range.

For example, when calculating the load, a relatively small air-filling time should be considered, and a slightly larger value should be considered when evaluating the performance.

Calculation of Air-Filling Time

Generally, the whole air-filling process is divided into three stages.

1. *Stage 1: Initial Filling Phase*
   The initial filling stage can be considered the point at which the folded parachute is released by 20% of the total nominal area.
   $$t_{m1} = \lambda_m \, (\mathrm{CA})_{\mathrm{sk}}^{1/2} / v_L \quad (23)$$
   In this expression, $(\mathrm{CA})_{\mathrm{sk}}^{1/2}$ is the characteristic of the drag force at the initial filling stage, and λ_m is the time coefficient.

   The time coefficient of the annular slot parachute is λ_m = 23.5.

2. *Stage 2: Buffering Step*
   This stage is considered to be in an unfilled state because the inlet air continues to enter, but the inlet velocity is equal to the outlet velocity.
   The time is very short and therefore not included in the total filling time.

3. *Stage 3: Complete Divergence Phase*
   $$t_{m3} = \lambda_{m3} \left[(\mathrm{CA})_s^{1/2} - (\mathrm{CA})_2^{1/2} \right] / v \quad (24)$$
   In the equation, v is the falling velocity of the parachute, and $(\mathrm{CA})_s$ is the characteristic resistance of the parachute when the parachute is full, is the characteristic resistance of the fully open case, and (λm^3) is the coefficient, according to equation 24, λ m^3= 4.3 for the annular slot parachute.

Example of Calculation of Air-Filling Time

i. The air-filling time of a standard C-9 flat circular parachute with a nominal diameter of 8.5344 m was calculated.
ii. The parachute resistance area is 54.4412 m^2, the weight of the parachute system is 90.72 kg, the air-filling rate is 80.772 m/s, the air density ratio at the parachute opening height of 6096 m is 0.533, and the effective air permeability of the parachute is 0.046.
iii. Assuming an initial value of Vmax = 42.0222 m^3 and an air-filling time of zero, the integral value on the right side of Equation (21) is obtained according to the procedure described previously; if it is not equal to Vmax, the air-filling time is calculated again by increasing 0.01.

The calculation results are as follows.

During air-filling, the instantaneous velocity changes with the air-filling time.

As shown in Figure 1, the instantaneous velocity during air-filling decreases with air-filling time, and the area under the curve is the air-filling distance of this umbrella, which is calculated to be 45.7 m.

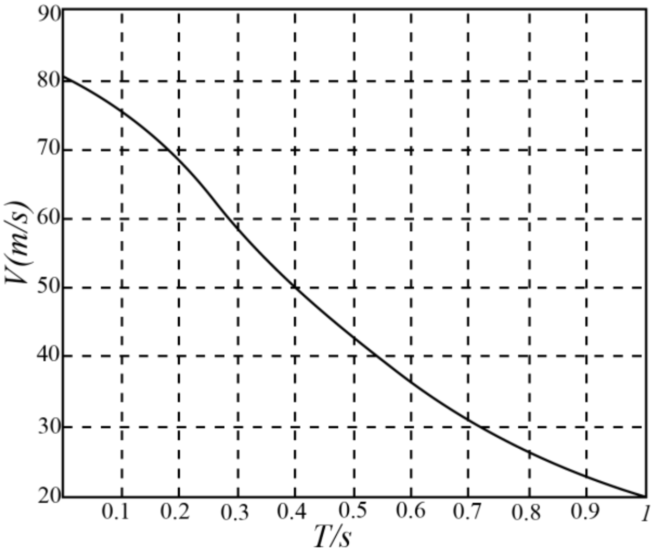

Figure 1. Instantaneous velocity profile of the parachute system versus time.

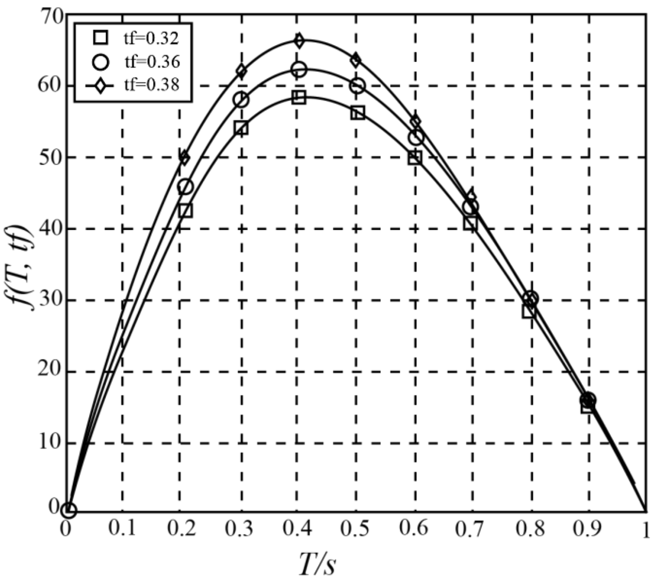

Figure 2. Change of parachute volume versus time.

During air-filling, the curve of the product function on the right-hand side in Equation (21) is shown in Figure 2, where the instantaneous volume of air in the umbrella is 0.32 s, 0.35 s, and 0.38 s, respectively, which is the instantaneous volume of air in the umbrella with the area enclosed by the left at any time and the lower side of each curve.

CONCLUSION

As shown in the simulation results, the volume of the parachute at 0.38 s is 41.9656 m^3, which is very similar to V max, so the air-filling time of this parachute is considered to be 0.38 s. In this study, the air-filling times of various types of parachutes were calculated using a model and empirical formula. Using this method in the design phase of the parachute, calculating the air-filling time can aid in system design.

As can be seen, we have solved two problems through the analysis of the air-filling time calculation model of parachute coatings. The vertical drop velocity of the parachute and the variation in the parachute volume with time were obtained.

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