A Braked Tail Cover Separation Concept and Simulation of Separation Process

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Abstract. Large-scale missiles are generally catapulted by the ejector. And a tail cover is used to protect the first stage rocket engine. When the missile reaches the predetermined height, the tail cover should be separated timely so that the engine can work properly. In this paper, a braked tail cover separation concept is proposed. And a new type of tail cover separation device is designed according to the concept. Firstly, the forces analysis and the internal ballistic simulation of ejection are conducted before setting working conditions. And then, the finite element software Abaqus is adopted to achieve the simulation of tail cover separation process. Through analyzing the obtained results, it's concluded that the braked tail cover separation concept is feasible. Moreover, the influence of material changes on the braking effects is also studied.

1 Introduction

At present, large-scale cylindrical missile generally use cold launch to complete the launch process [1]. That is, the high temperature and high pressure gas produced by the gas generator at the bottom of the launcher pushes the missile out of the tube. when the missile reaches the predetermined height, the rocket engine ignites and the missile starts the flight. In order to avoid the damage the gas caused to the equipment and the engine, a tail cover is necessary to protect the missile in the process of ejection. when the ejection is finished, the tail cover should be separated timely so that the engine can work properly. Moreover, the tail cover should be deviated from the launcher to avoid smashing the personnel and equipment [2-3]. Therefore, the tail cover separation device should meet the following requirements: fast, reliable and safe [4].

According to the requirements above, a new tail cover separation scheme is present in this paper and a new type of tail cover separation device is designed.

2 Tail cover separation concept and tail cover separation device

2.1 Tail cover separation concept

Firstly, the braked tail cover separation concept is proposed. Its schematic diagram is shown in Fig. 1. The projectile and the tail cover are connected by a locating pin. When the missile is ejected, the tail cover is arrested in the tube by the tail cover separation device. For the projectile is not screwed with the tail cover, it flight at a natural speed. In this scheme, the tail cover separation device is a vital technology.
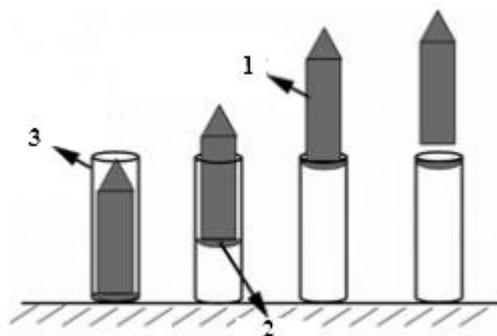

Figure 1. Schematic diagram of the braked tail cover separation concept: 1-projectile; 2-tail cover; 3-launch tube.

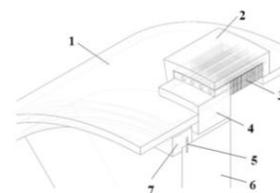### 2.2 Tail cover separation device

Figure 2. Structure of the braked tail cover separation device : 1-launch tube; 2-inner wall; 3-metal slice combination; 4-trasmission device; 5-connecting pin; 6-projectile; 7-tail cover.

Based on the braked tail cover separation concept, a new type of tail cover separation device is designed. It is shown in Fig. 2.
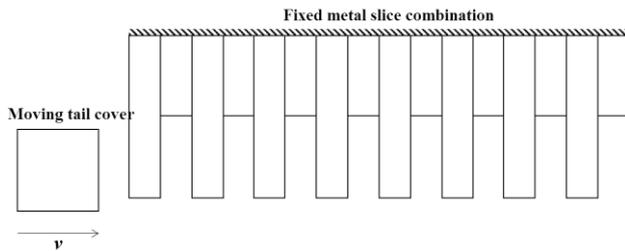

Figure 3. The basic working principle diagram of the device

Fig. 3 shows the basic working principle of the device. when the tail cover with great kinetic energy moves to the mouth of the launch tube, it is arrested by the metal slice combination, and the metal slice combination is cut to realize the deceleration of the tail cover.

In the way of 90° ×4, the device is installed at the mouth of the launch tube. The projectile and the tail cover are connected by locating pins. And the two rush to the braked device with great kinetic energy. After the collision with the transmission device, the positioning pin bends first. Then the missile and the tail cover start separation and the tail cover rush to the metal slice combination fixed on the braked device. When contacting with the moving tail cover, the first metal slice is sheared and deformed, and then the metal combination is sheared and deformation one after another until the tail cover decelerates to zero. At the same time, the missile flies out of the launcher. Now, the separation of the tail cover and the projectile has been achieved.

3 Calculation and simulation

Braked device is a key component in the tail cover separation scheme, which needs to withstand the force and thermal environment in the process of ejection. Its braking effects are to studied through numerical simulation. Before the simulation, some calculations are necessary. First, according to the results of internal ballistic simulation during the ejection, the separation process of the tail device is calculated and analyzed. Then, the numerical simulation model is established in Abaqus. Next, set the parameters in conjunction with the calculated results in Abaqus. At last, the simulation is run and the obtained results are processed and analyzed.

3.1. Calculation

3.1.1 Calculation condition

Table 1. Initial design parameters .

Parameters	value
Mass of the tail cover	$80kg$
Radius of the tail cover	$1.49m$
Velocity of the tail cover	$38m/s$

Stroke of ejection	$2m$

Before the simulation is conducted, some calculation is necessary.the initial design paramerers are shown in Table 1.including m the mass of tail cover, r radius of tail cover, v the velocity of tail cover when it hits the device and s the stroke of ejection.

3.1.2 Forces analysis

When the tail cover rushes to the launcher mouth, some forces act on it. including G the gravity, F_r the gas pressure in the launcher tube , F_s the braking force of the braked device , F_a the external atmospheric pressure and F_g the inertia force of the tail cover, ignoring the friction between the sealing ring of tail cover and the tube wall, the pin hole friction, and other smaller forces. Forces analysis is shown in Fig. 4.
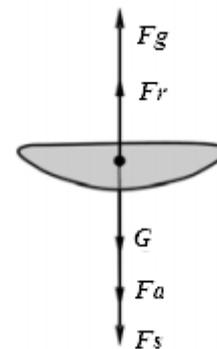

Figure 4. The forces analysis of the tail cover separation device

Where, the gravity of the tail cover is shown in (1).

$$G = mg = 784\,N \qquad (1)$$

And the external atmospheric pressure is shown in (2)

$$F_a = P_o \cdot \pi r^2 = 176543\,N \qquad (2)$$

3.1.3 The initial forces

According to the calculation conditions, the velocity of the tail cover decelerates from 38 m / s down to 0 m / s in the 2m stroke, assuming the it decreases evenly, it can be conclude in (3):

$$F_g = \frac{mv^2}{2s} = 28880\,N \qquad (3)$$

3.1.4 the maximum gas pressure in the launch tube

Take the calculation conditions above into internal ballistic program, the curve of internal ballistic simulation during the ejection is shown in Fig. 5.

During the ejection process, the pressure of launch tube increases rapidly at first and then drops slowly.

From Figure5, it can be seen that the final pressure when the tail cover hits the braked device is about 0.5MPa (absolute pressure). So we can get the value of F_r .
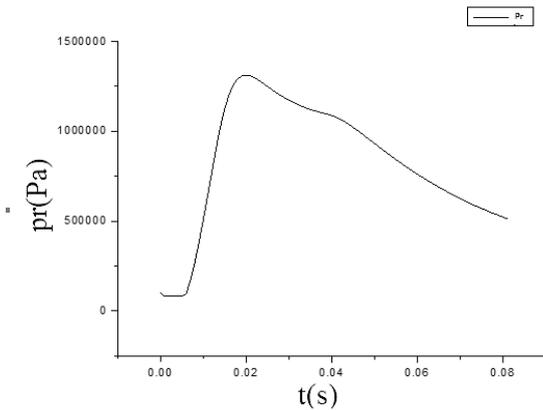

Figure 5. Cure of the gas pressure P_r in launch tube.

$$F_r = P_r \cdot \pi r^2 = 871389\,N \qquad (4)$$

3.1.5 The braking force

According to the force balance conditions, the braking force is calculated in (5):

$$F_s = F_g + F_r - G - F_a = 722942\,N \quad (5)$$

3.2 Working condition setting

Based on the working principles and calculation conditions above, the numerical simulation model is established in Abaqus. The braking effect of the tail cover is studied. Moreover, the influence of material change on the braking effect is also studied.

In the structure of the tail cover separation device, the metal slice combination is made of aluminum while the other parts are made of steel. Thus, three working conditions have been designed by changing the material property of different structures.

Table 2. Material property of working condition 1.

Material	Aluminum	Steel
Density(kg/m3)	2.8×10^3	7.87×10^3
Young's modulus(MPa)	72400	210000
Poisson's ratio	0.33	0.3
Yield stress(MPa)	395	1220

Compared to the working condition 1 shown in Table 2, working condition 2 increases the yield stress of the aluminum. And the material parameters of the working condition 2 are shown in Table 3.

Table 3. Material property of working condition 2.

Material	Aluminum	Steel
Density(kg/m3)	2.8×10^3	7.87×10^3
Young's modulus(MPa)	72400	210000
Poisson's ratio	0.33	0.3
Yield stress(MPa)	758.291	1220

Compared to the working condition 1, working condition 3 reduces the yield stress of the steel. The material parameters are shown in Table 3.

Table 4. Material property of working condition 3.

Material	Aluminum	Steel
Density(kg/m3)	2.8×10^3	7.87×10^3
Young's modulus(MPa)	72400	210000
Poisson's ratio	0.33	0.3
Yield stress(MPa)	395	785

Compared to the working condition 1, working condition 3 changes the yield stress of the steel.

3.3 Simulaton and results analysis

3.3.1 Simulation

Three dimensional model of the tail cover separation device is established in Creo, which is imported into Abaqus. Then we give the material properties, apply boundary constraints and loads, mesh the model and submit file for calculation. Abaqus software is uesd to simulate the process of tail cover separation by using finite element method.

3.3.2 Results and discussion

The obtained simulation results are compared under different working conditions . At first, a point in the tail cover is selected to measure the velocity, the braking distance, and the whole kinetic energy of the tail cover. Besides, the deformation of the device is also measured. Curves of different variable in the three working condition are shown in Fig. 7 to Fig. 10.
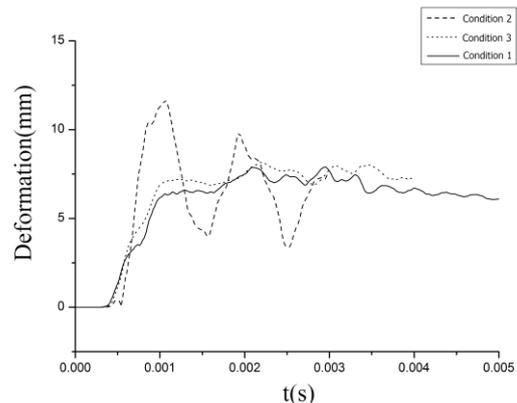

Figure 6. Deformation of the device in the three conditions.

Fig. 7 shows that the trend of structural deformation of the working condition 1 and the working condition 3 is almost the same and they are relatively stable after a sharp rise. The curve of the working condition 2 fluctuates violently.
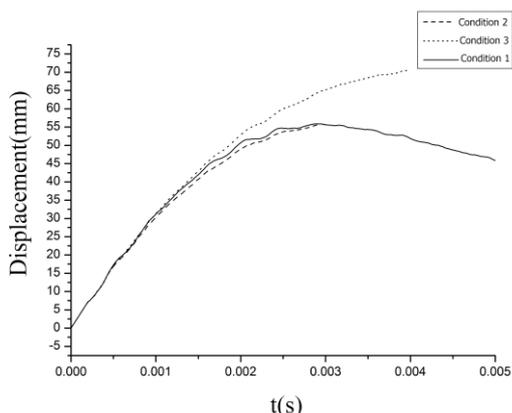
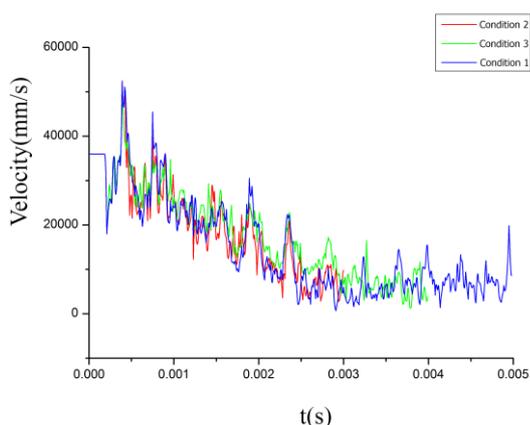**Figure 7.** Braking distance in the three conditions.

Figure 8. Velocity of the device in the three conditions.

Fig. 8 shows that the curves of braking distance in the working condition 1 and 2 almost coincide, and the maximum amplitude is 55mm. While the curve in the working condition 3 is increasing with time and its maximum is 68mm.
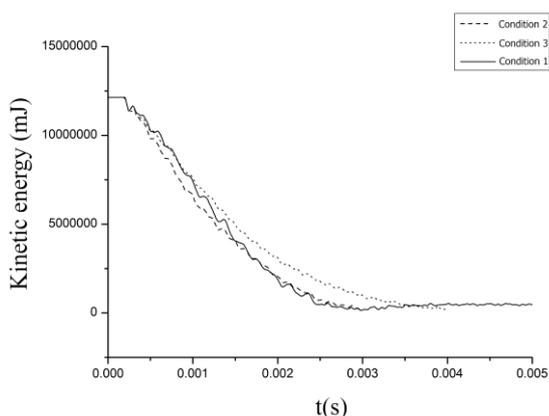

Figure 9. Kinetic energy in the three conditions.

From the Fig. 10, we can see that the trend of the whole kinetic energy in the working condition 1 is closer to that in the working condition 3, and then the difference is larger. For the condition 2, there is a big difference compared to the first two in the beginning. In the later stages, the two trends have become closer. After a while, the overall kinetic energy of the three tend to zero.

We define that the tail cover separation has finished when the velocity of the tail cover tends to 0. From figures above, it can be seen that the braking time of the three working conditions is 0.05s, 0.03s, 0.04s respectively.

Considering that the metal slice combination is made of aluminum while the other parts are made of steel, the influence of material change on the braking effect of the device can be summarized in Table 5.

Table 3. the influence of material change on the braking effect.

Braking effects Material change	Increasing yield stress of the shear slice combination	Increasing yield stress of other parts of the device
deformation	greater	not significant
braking distance	not significant	smaller
deceleration effects	tendency is not significant	tendency is not significant
the absorbing capacity of kinetic energy	Absorb faster during high-speed stage	Absorb faster during low-speed stage

4 Conclusion

In this paper, a braked tail cover separation concept is proposed. Based on this, a new type of tail cover separation device is designed. The numerical simulation model is established in Abaqus. By comparing different working conditions, the braking effects of this device are studied. The obtained results show that the braked tail cover separation scheme is feasible. And the device can separate the tail cover from the projectile quickly and reliably. Furthermore, we can enhance the braking effects by increasing yield stress of the shear slice combination or lowing yield stress of other parts of the device appropriately.

References

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