A Test Scheme Design for High Speed Active Cabin Separation

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Abstract. In Mars explorations, the EDL (Entry, Descent and Landing) process is autonomously controlled, called "black 7minutes". In order to verify the EDL process of the Mars probe cabin (the heatshield facing the Mars surface and the aeroshell back to the surface of Mars) high speed separated, this paper proposes an active motor pull separation scheme and controlling method of axial force, normal force and torque multi-coupling, solves the technological problem of the force applied, followed and safe recycling cabin in short time and distance, establishes a test system and completed the separation test of the heatshield and the aeroshell by real product. The results show that the test success criteria are met and the test scheme is successful. This method and experimental system can be used not only in the separation experiment of Mars probe, but also in the separation or servo simulation of other detectors or general mechanisms, can be widely used or used for reference. This paper explains the general scheme and key technology, followed by other papers on ADAMS Simulation, influence on air-resistance and so on.

1. Introduction

In Mars explorations, the EDL (Entry, Descent and Landing) process is autonomously controlled, called "black 7minutes". In order to verify the separation design of the heatshield and the aeroshell in the EDL process of the Mars explorations, and to solve the problems of the deviation and uncertainty of the simulation verification, it is necessary to carry out the test on the ground to fully verify the design and the key technology.

In Flight test, During the development of the US Viking Parachute, 4 times separation tests of heatshield were carried out[1][2]. Before the Curiosity, there was no more high-altitude supersonic flight test[3]. The separation test of the heatshield (including on-orbit flight) of chinese manned spacecraft has been carried out 16 times. European ExoMars conducted a wind tunnel test for the process of separation of heatshield. MER (Mars Exploration Rover, in the US) used the POST2 software system to carry out the simulation analysis of the separation of heatshield[4][5]. EXOMARS(in Europe) carried out simulation of the separation of heatshield and aeroshell and establish the entire EDM model[6]. China Harbin Institute of Technology Deep Space Exploration Basic Research Center carried out Monte Carlo six-free numerical simulation verification of the full error model. According to the requirement of ground test for separation test, combined with simulation verification, this paper carries out the design of ground active separation test scheme.
2. Introduction

The biggest difference between ground test and on-orbit is that the gravity of the earth is 1g and that of Mars is about 0.33g, which requires compensation from ground test system. The weight of test equipment, such as test hangers, which increase the degree of freedom of motion of the specimen, will be added to the specimen, resulting in the difference of mass and moment of inertia. In order to make the ground test as consistent as possible with the on-orbit state, the equivalence of the stress state should be considered. The actual force state of the cabin in the short-term separation process (about 1 s) is shown in figure 1. The force state of the cabin on ground is shown in figure 2.

Before separation:

\[ F_x - G - F_{ab} = G_b \sin \theta - A_b \cdot F_{ab} \]  \hspace{1cm} (1)

\[ F_z = N_b + G_b \cos \theta \]  \hspace{1cm} (2)

\[ M_y = C_{bmg} \]  \hspace{1cm} (3)

After separation:

\[ F_x - G = G_b \sin \theta - A_b \]  \hspace{1cm} (4)

\[ F_z = N_b + G_b \cos \theta \]  \hspace{1cm} (5)
$My = C_{bncg}$

From the formula, when the earth gravity of the aeroshell is compensated by $F_x$, the axial force $F_x - G$, the normal force $F_z$ and the torque $My$ are all consistent with the on-orbit force state.

According to the existing conditions and test requirements, the suspension plan is put forward including Fully passive Test Scheme , Fully passive Test Scheme and Fully passive Test Scheme. Fully passive Test Scheme: Axial acceleration is less than 1g, not a constant value, not applicable to this working condition. The Test Scheme is applicable only when the acceleration accuracy is not strictly required. Hybrid Test Scheme: Detonation time and control time are difficult to synchronize, not applicable to this working condition. It is used when the requirement for accuracy is medium. Fully active Scheme: It is used when the requirement for accuracy is high Recommended, but Servo control system is complicated. Considering fully, only the active scheme can meet the test requirements.

3. Technical Scheme

3.1. Test technical scheme

According to the stress analysis, the stress realization scheme of the specimens is shown in the figure 3. The specimens are subjected to axial force, normal force and torque, in which the axial force is controlled by servo motor, and the normal force and torque are mainly controlled by springs. The test technical scheme is shown in Figure 3.

![Figure 3. Test technical scheme](image)

3.2. Difficulties and solutions

According to the above test characteristics, the main design difficulties of ground test system lie in force servo and cabin safety at high speed.

The normal force and the rotational moment of the aeroshell are applied at high speed conditions. There is no simple linear coupling between the normal force, the rotational moment and the axial force of the back cover. The normal force pulling spring assembly is used for the application of the normal force (horizontal direction) of the heatshield (the aeroshell), and the normal force under spring is shown in Figure 4. The torque force pulling spring assembly is used for the application of the torque (horizontal direction) of the heatshield (the aeroshell), and the torque normal force under spring is shown in Figure 5.
Safe recycling of the cabin: After the test data is measured, the high-speed moving cabin needs to be decelerated to a standstill for recycling and retesting.

- A safety net is placed 8m from the ground.
- In the case of separation, to avoid the product bumping into the test stand, connect the calculated length of the protective rope at the connection part of the spreader and the product.
- Use balancing weight design to prevent malfunctioning products such as motors from falling off the ground.

4. Test verification

4.1. Components of Test System

The test system consists of six parts: the test platform, the test spreader system, the shock test system, the high-speed photogrammetry system, the product simulation part and the test auxiliary system.

Test platform: providing axial force application, normal force and rotational moment application for the separation process of the hanging cabin, and measuring the force applied in all directions. The stand size can be matched with the size of the test piece. Test spreader system: the separation and lifting of the hanging cabin under two kinds of separation conditions, the spreader and the hanging cabin connecting, the lifting point passes through the center of mass; the test spreader is connected to the test platform through the lifting interface. Impact measurement system: Measuring the shock response of the separation surface of the hanging cabin and the fixed cabin and other measuring points, and carrying out data processing; the strain measuring system measures the strain of key parts of the system. High-speed photogrammetry system: Measuring the separation speed, angular velocity and attitude angle of the suspended cabin; recording separation process. Test Auxiliary System: The auxiliary tooling and equipment used in the test process, which should meet flip requirement of the product as shown in the figure. Test Product Simulation Part: simulation parts with similar quality characteristics and force characteristics with real products, used to test the system.

4.2. Simulation

Through ADAMS simulation analysis, the following conclusions are given:

- Under the test conditions, no collision occurred within 0.1s of the heatshield and 0.5s of the aeroshell;
- Axial tension, air resistance compensation and spring axial component compensation value;
The simulation results show that when the normal tension is along the -Z direction, and the torque is applied along the +Y, it is the limit condition, and the axial force of the heatshield of the motor system under this condition is given.

4.3. Experiment results
The test data of the main axial cable force, the upper torque force, the lower torque force, and the normal force are obtained by sensors under the aeroshell nominal conditions, and the curves are shown in figure 6, figure 7, figure 8 and figure 9.

The analysis of the results of the nominal condition test of the aeroshell meets the requirements. The comparison of actual and theoretical data is shown in Table 1.

Table 1. Result of nominal working condition of the aeroshell

|          | upper torque | Lower torque | normal   | main cable |
|----------|--------------|--------------|----------|------------|
| Theory   | 1672         | 1672         | 852      |            |
| Measured | 1708         | 1674         | 933      | 6.46%      |

5. Conclusions
According to the EDL Process of the Mars probe cabin separated index, this paper proposes an active motor pull separation scheme. The test system is established, the Adams simulation analysis is carried out, and the ground validation test is completed. The following results are obtained:
An overall scheme of active high-speed separation based on servo system and air spring is proposed.

Adams simulation analysis is carried out to provide compensation values for axial tension, air resistance compensation and spring axial component.

An experimental system has been established. The experimental results show that the experimental data meet the criterion of success and the experiment is successful.

This method and experimental system can be used not only in the separation experiment of Mars probe, but also in the separation or servo simulation of other detectors or general mechanisms, can be widely used or used for reference.

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