Numerical Simulation of Air Resistance on the Mars Probe Cabin Separation

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Abstract. In order to verify the separation requirements of Mars probe’s cabins, the Flunet analysis models of the heatshield and the aeroshell of Mars probe are established. The relationships between air resistance and the velocity, deflection angle of the cabins are obtained by numerical calculation method. The relationships between air resistance moment and the velocity, deflection angle of the cabins are also gained. According to simulation and analysis, the air resistance of the cabins obviously with velocity, but has little change with the increase of deflection angle. The air resistance moment of the cabins increases obviously with velocity and deflection angle. The dynamic simulation results of air resistance during the courses of the cabins separations provide effective data support for the simulation and ground validation of Mars probe cabin separation.

1. Introduction

During the exploration of Mars, the EDL (Entry, Descent and Landing) process is fully autonomously controlled, called "black 7 minutes". To verify the separation scheme design of the heatshield, which is facing on the surface of Mars and ablated in the process of falling, and the aeroshell, which is back facing on the surface of Mars and separated by parachute, it is necessary to carry out ground test verification. Mars's atmospheric density is less than 1% of the Earth's atmosphere, which is one of the main factors affecting the ground test of EDL cabin separation. At present, the main research methods of air resistance are numerical simulation [1] [2] [3] [4] and experimental research [5] [6]. In this paper, the Flunet analysis models of the heatshield and the aeroshell are established by numerical calculation. Through numerical simulation, the relationships between air resistance and the velocity, deflection angle and the relationships between air resistance moment and the velocity, deflection angle are obtained.

2. Test technical scheme

The stress realization scheme of the cabins is shown in figure 1. The cabins are subjected to axial force, normal force and torque. The axial force is controlled by servo motor, while the normal force and torque are mainly controlled by springs.
3. Model Building

3.1. Geometric Model
The moving direction of the cabins defined as X axis. The deflection angle is defined as the angle between the deflected X axis and the initial X axis. The maximum diameter of the cabins is 3400mm, so the models of the cabins are carried into the calculation domain of 12000mm*10000mm in the analysis module of ANSYS. In order to simplify the calculations, the symmetrical surfaces are set up and half of the models are taken for analysis. The top surface of the cuboid is an air inlet and the base surface is an outlet. The calculation domains of heatshield and aeroshell are shown in figure 2.

3.2. Mathematical Model and Boundary Conditions
Considering the small volume of the heatshield and the aeroshell, the change of air density surrounding them should be neglected. Make the following assumptions.

a. The isotropic assumption is introduced for turbulent motion. The standard k-ε turbulence model is used to solve the three-dimensional N-S equation, and the standard wall function is used near the shell.

b. The flow is incompressible.

c. There is no heat exchange in the air flow.

The continuum equation and momentum equations are as follows:
\[
\frac{\partial u_i}{\partial x_i} = 0
\]
(1)
\[
\frac{\partial (\mu u_i)}{\partial x_i} + \frac{1}{\rho} \frac{\partial p}{\partial x_i} = \nu \left( \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) - \overline{u_i'u_j'}
\]
(2)

where, \( u_i, u_j \) \((i, j = 1, 2, 3)\) are the average velocity component;
\( x_i \) \((i, j = 1, 2, 3)\) are the coordinate component;
\( \rho \) is the average pressure of fluid;
\( \nu \) is the kinematic viscous coefficient of fluid;
\( \rho \) is the fluid density;
\( \overline{u_i'u_j'} \) are unknown Reynolds stress component.

To simulate the working conditions as accurately as possible, the inlet and outlet channels of air are extended during modeling. The inlet boundary is located at 5000mm away from the center of the heatshield, where the wind speed is given. The outlet boundary is located at 5000mm away from the axle centre of the heatshield, where the pressure is atmospheric pressure. According to the simulation results of ADAMS in previous period, the velocity of the heatshield changes from 3.5m/s to 8.5m/s with 0.5m/s intervals, and the deflection angle is set to 0°, 1°, 2°, 3°, 5°. Meanwhile, the velocity of the aeroshell changes from 3m/s to 8m/s with 0.5m/s intervals, and the deflection angle is set to 0°, 1°, 2°, 3°, 5°.

4. Simulation results

4.1. Heatshield

4.1.1. Resistance. The relationship between the resistance on the heatshield and velocity, deflection angle of the heatshield is shown in table 1 and figure 3.

### Table 1. The relationship between resistance and velocity, deflection angle of heatshield

| Resistance (N) | 3.5 | 4  | 4.5 | 5  | 5.5 | 6  | 6.5 | 7  | 7.5 | 8  | 8.5 |
|---------------|-----|----|-----|----|-----|----|-----|----|-----|----|-----|
| Velocity (ms\(^{-1}\)) |     |    |     |    |     |    |     |    |     |    |     |
| Deflection Angle(°) |     |    |     |    |     |    |     |    |     |    |     |
| 0             | 84  | 102.7 | 123.6 | 146.8 | 172.8 | 200.4 | 230 | 262 | 295.2 | 330.8 | 368.8 |
| 1             | 82.4 | 101.6 | 122.8 | 145.8 | 171.4 | 199.0 | 229.4 | 260.6 | 294.7 | 330.4 | 368.4 |
| 2             | 80.7 | 100.8 | 121.2 | 145.1 | 171.0 | 199.2 | 228.4 | 263.1 | 294 | 332.7 | 368.8 |
| 3             | 79.8 | 99.6 | 120.4 | 146.2 | 170.6 | 200.5 | 229.2 | 264.2 | 295.6 | 333.5 | 371.2 |
| 5             | 78.6 | 98.4 | 120.6 | 145.0 | 171.6 | 200.4 | 231.4 | 264.4 | 300 | 337.4 | 376.0 |
When the heatshield velocity increases from 3.5 m/s to 8.5 m/s and the deflection angle increases from 0° to 5°, the air resistance increases from 78 N to 376 N. The air resistance of the heatshield increases obviously with velocity, but has little change with the increase of deflection angle.

4.1.2. Resistance moment. The relationship between resistance moment on the heatshield and velocity, deflection angle of the heatshield is shown in Table 2 and Figure 4.

Table 2. The relationship between resistance moment and velocity, deflection angle of heatshield

| Deflection Angle(°) | 0  | 1  | 2  | 3  | 5  |
|---------------------|----|----|----|----|----|
| Moment (N.m)        |    |    |    |    |    |
| Velocity (ms⁻¹)     | 3.5| 4  | 4.5| 5  | 5.5| 6  | 6.5| 7  | 7.5| 8  | 8.5|
| 0                   | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| 1                   | 0.08| 0.29| 0.58| 0.95| 1.24| 1.54| 1.82| 2.12| 2.46| 2.82| 3.2 |
| 2                   | 0.26| 0.58| 1.16| 1.56| 2.16| 2.59| 3.2 | 3.8 | 4.2 | 4.8 | 5.38|
| 3                   | 0.56| 1.21| 1.9 | 2.78| 3.26| 3.51| 4.72| 5.21| 6.4 | 7.2 | 8.38|
| 5                   | 1.4 | 2.28| 3.12| 3.99| 4.92| 5.9 | 7.16| 8.38| 9.72| 11.12| 12.6|

Figure 3. Graph of the relationship between resistance and velocity, deflection angle of heatshield

Figure 4. Graph of the relationship between resistance moment and velocity, deflection angle of heatshield
When the heatshield velocity increases from 3.5 m/s to 8.5 m/s and the deflection angle increases from 0° to 5°, the air resistance moment increases from 0 to 12.6 N.m. The air resistance moment of the heatshield increases obviously with velocity and deflection angle.

4.2. Aeroshell

4.2.1. Resistance. The relationship between the resistance on the aeroshell and velocity, deflection angle of the aeroshell is obtained by simulation calculation, as shown in table 3 and figure 5.

| Velocity (m/s) | 3   | 3.5 | 4   | 4.5 | 5   | 5.5 | 6   | 6.5 | 7   | 7.5 | 8   |
|---------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Resistance (N) | 46.2| 53.2| 67  | 83.5| 94.3| 107.9| 125 | 140.1| 164.2| 185.1| 209.8|
|               | 47.4| 53.8| 67.4| 83.8| 94.9| 108.1| 125.8| 141.8| 165.6| 181.7| 210.2|
|               | 45.2| 52.2| 66.8| 84.4| 93.6| 106.9| 124.7| 140.2| 163.1| 182.1| 208.1|
|               | 46.8| 54.2| 67.5| 85.5| 95.3| 108.6| 127.9| 143.1| 165.2| 181.3| 207.9|
|               | 46.9| 51.3| 67.7| 87.1| 94.8| 108.3| 128.5| 141.1| 167.2| 184.1| 209.2|

Figure 5. Graph of the relationship between resistance and velocity, deflection angle of aeroshell

When the aeroshell velocity increases from 3 m/s to 8 m/s and the deflection angle increases from 0° to 5°, the air resistance increases from 45 N to 210 N. The air resistance of the aeroshell increases obviously with velocity, but has little change with the increase of deflection angle.

4.2.2. Resistance moment. The relationship between resistance moment on the aeroshell and velocity, deflection angle of the aeroshell is obtained by simulation calculation, as shown in table 4 and figure 6.
Table 4. The relation between resistance moment and velocity, deflection angle of aeroshell

| Moment (Nm) | Velocity (ms^-1) | 3   | 3.5 | 4   | 4.5 | 5   | 5.5 | 6   | 6.5 | 7   | 7.5 | 8   |
|------------|------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 0          |                  | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 1          |                  | 0.04| 0.15| 0.29| 0.47| 0.62| 0.77| 0.91| 1.06| 1.23| 1.41| 1.6 |
| 2          |                  | 0.13| 0.29| 0.58| 0.78| 1.08| 1.29| 1.6 | 1.9 | 2.1 | 2.4 | 2.69|
| 3          |                  | 0.28| 0.61| 0.95| 1.39| 1.63| 1.75| 2.36| 2.61| 3.2 | 3.6 | 4.19|
| 5          |                  | 0.7 | 1.14| 1.56| 1.99| 2.46| 2.95| 3.58| 4.19| 4.86| 5.56| 6.3 |

Figure 6. Graph of the relationship between resistance moment and velocity, deflection angle of aeroshell

When the aeroshell velocity increases from 3m/s to 8m/s and the deflection angle increases from 0° to 5°, the air resistance moment increases from 0 to 6.3 N.m. The air resistance moment of the aeroshell increases obviously with velocity and deflection angle.

5. Conclusion
In this paper, the Flunet analysis models of the cabins (heatshield and aeroshell) are established by numerical calculation. According to simulation and analysis, the air resistance of the cabins obviously with velocity, but has little change with the increase of deflection angle. The air resistance moment of the cabins increases obviously with velocity and deflection angle. The results of this paper have been used as input conditions for system simulation and ground test.

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