Development and Application of the Design, Simulation & Calculation Module for the Martian Atmosphere Simulation Environment Box

Gao-tong LIU¹*, Lei ZHANG¹ and Yu SUN¹

¹Beijing Institute of Spacecraft Environment Engineering, Beijing 100094, China

*Corresponding author

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Abstract. The characteristics of Martian atmosphere are studied, by choosing appropriate calculation method combined with FLUENT fluid finite element calculation software to set up a simulation calculation module of the Martian atmosphere simulation environment box, which module realizes steady and unsteady calculation simulation of interior flow field under multiple working conditions of the cylindrical and square Martian atmosphere environment simulation box, and analyzes and discusses the calculation results, obtains the conclusion that the square environment box is superior to the cylindrical environment box in the stabilities of interior flow field, so as to provide technical support and reference for design of the Martian atmosphere simulation box.

Introduction

Frequent Mars exploration program and Mars sample return, landing with human and Mars base construction, as well as subsequent tasks may put strict requirements for the accurate prediction of the aerodynamic characteristics of detectors in the Martian atmosphere. A simulation calculation module is established herein, by choosing appropriate process simulation calculation method for the Martian atmosphere environment box in combination with the characteristics of the Martian atmosphere, and calculation simulation is done for the interior flow field of the environment box, the performance of the environment box with different configurations under the design conditions are discussed, which has an important guiding significance to design a simulation environment box of the Mars atmosphere.

The Simulation Calculation Method for the Martian Atmosphere Environment Box

Because the Martian atmosphere is much rarefied than the earth's atmosphere, the rarefaction characteristics of the Martian atmosphere must be taken into account during the choose of process simulation calculation method, and the Knudsen number is generally employed to characterize rarefaction degree of a meteorological flow in the rarefied gas dynamics theory, the Knudsen number being the ratio of the average free path $\lambda$ of the gas molecules to flow characteristic length $L$, which is in particular expressed by

$$K_n = \frac{\lambda}{L}$$  \hspace{1cm} (1)

The average free path of the gas molecules inside the environment box being calculated according to the given temperature and pressure ranges is a maximum of $8.357 \times 10^{-5}$ m, and a minimum of $2.235 \times 10^{-6}$ m, with the Knudsen number range of $2.235 \times 10^{-6}$~$8.357 \times 10^{-5}$, assuming that the scale length of the gas flow macroscopic gradient is 1 m. According to the gas flow area division by Tsien-Hsueshen, the flow field inside the environment box belongs to a continuous flow field range, and the N-S equation is applicable in the range of gas conditions under which the environment box is situated.
Simulation Calculation of the Martian Atmosphere Simulation Environment Box

According to the related developed modules, cylindrical test box and square test box are analyzed, so as to ensure that the average wind speed of the region under various operating conditions meets the requirements on calculated operating conditions in the process of analysis by means of monitoring the wind velocity of the test section, and adjusting the amplitude of the fan momentum source.

Physical Model and Geometric Model

The geometry sizes of the environment boxes are as following: The cylindrical environment box has a diameter of 3m, a length of 6m, and a diameter of the ducted fan of 0.8m; The Square environment box has a length of 6m, a width of 3m, a height of 3m and a diameter of the ducted fan of 0.8m; The mixed gas component content of the environment box includes carbon dioxide of 95%, nitrogen of 3% and AR of 2%.

The simulation calculation model of the environment box shown in Figure 1 considers the symmetry of the environment box, and we have established half of two environment box models and set the symmetric boundary conditions in the symmetric plane in order to reduce the amount of calculation, the flow field calculation meshes of the cylindrical environment box and the square environment box respectively shown in Figure 2 and Figure 3, wherein the yellow part represents the momentum source applied area, for simulating the ducted fan, and the red area represents the test section, the wind velocity of the test section being monitored in the process of calculation, so as to ensure that the average wind speed in this region meets the requirements for the calculation operating conditions.

![Figure 1. The simulation calculation model of the environment box.](image)

![Figure 2. The fluid calculation grid of the cylindrical environment box.](image)
![Figure 3. The fluid calculation grid of the square environment box.](image)

Steady Calculation of Multi-operating Conditions

With comprehensive consideration of various parameters of operating conditions, we have selected several typical operating conditions to calculate for simulation of the interior gas circulation of the cylindrical environment box and the square environment box, the specific operating parameters being shown in table 1.
Table 1. The operating parameters of calculation.

<table>
<thead>
<tr>
<th>Operating conditions</th>
<th>Pressure [Pa]</th>
<th>Temperatures [℃]</th>
<th>Wind velocity of the test section [m/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating conditions 1</td>
<td>100</td>
<td>-60</td>
<td>20</td>
</tr>
<tr>
<td>Operating conditions 2</td>
<td>600</td>
<td>-100</td>
<td>20</td>
</tr>
<tr>
<td>Operating conditions 3</td>
<td>600</td>
<td>-20</td>
<td>20</td>
</tr>
<tr>
<td>Operating conditions 4</td>
<td>900</td>
<td>-60</td>
<td>20</td>
</tr>
<tr>
<td>Operating conditions 5</td>
<td>1500</td>
<td>-60</td>
<td>20</td>
</tr>
</tbody>
</table>

The velocity vector distribution and the pressure distribution of the cylindrical and square environment boxes under typical operating conditions are shown Figure 4 and Figure 5. From the figures it can be seen that the test section is substantially in a constant velocity laminar flow area, the gas flows back from periphery of the box body to one side of the fan, and forms vortex in the periphery of the intermediate laminar flow area, a negative pressure region will be formed near the air inlet of the fan rotor disk, because of the fan suction, while a positive pressure area will appear where the fan accelerated air flow meets with the box wall, which is resulted from the fact that the air flow in the region is blocked to reduce speed and thus increase pressure, the pressure of the rest, especially of the test section being maintained in the comparative uniform levels.

(a) The cylindrical environment box   (b) The square environment box

Figure 4. The velocity vector distribution of the cylindrical and square environment boxes under typical operating conditions.

(a) The cylindrical environment box   (b) The square environment box

Figure 5. The pressure distribution of the cylindrical and square environment boxes under typical operating conditions.
Non-steady Calculation of Typical Operating Conditions

It is needed to test some electronic devices in the course of experiments of the actual environment box, these electronic devices will generate amount of heat which causes their temperatures to be increased in the testing process. In order to research the influence on heat dissipation of these heat produced devices by the interior airflow of the environment box, a test heat source is included in the model based on the steady analysis. The law of the heat source and the flow field temperature changing with time under certain heating power will be obtained through non-steady calculation simulation of the gas circulation of the environment box.

The calculation in this chapter is carried out based on a typical operating conditions, the specific parameters of which operating conditions include: a temperature of -60 °C; a pressure of 600Pa; and a wind speed of 20m/s.

The specific parameters of the test heat include: a mass of 4kg; heating power of 100w; and specific heat and thermal conductivity referring to the material properties of metal aluminum.

The initial temperature of the test heat source is the same as the environment temperature, the interior flow field circulation of the environment box maintains the stability under the function of the fan, wherein the front velocity of the test source is maintained at around 20m/s, the test heat source begins at the initial time with 100W power to generate heat and remains unchanged during the whole calculation, a part of the heat generated by the heat source being used for heating the heat source itself, and another part of the heat being exchanged with the environment box wall through interior airflow of the environment box and its radiation, wherein the environmental box wall remains constant temperature during the whole calculation.

The finally temperature distribution and the history graph of the heat source temperature change with time of the cylindrical and square environment boxes are shown in Figure 6 and Figure 7, from which it can be seen by comparing the two graphs that under the same heating power of the heat source and the external environmental conditions, the amplitude of temperature increase of the heat source inside the square environment box is slightly less than that of the cylindrical environment box. With the results of the steady analysis, under the same conditions, the interior laminar flow stability and coverage of the square environment box are better than those of the cylindrical environment box with the same size, so that the solution of the square environment box obtains better results.

![Figure 6: The finally temperature distribution of the cylindrical and square environment boxes.](image)
Conclusion

A calculation method and a calculation model are selected herein for the simulation calculation module of the Martian atmosphere simulation environment box, a simulation method and its technology implementation scheme suitable for the rarefied gas simulation of this project are proposed, the key technical problems of calculating physical parameters of the mixed gases and simulating the ducted fan are resolved by research in combination with the development of existing commercial finite element software “FLUENT” for the rarefied gas flow simulation calculation modules, so as to realize running the steady and non-steady simulation calculation of the environment boxes with low temperature in the specified range. At the same time, the steady and non-steady simulation calculation are carried out for two kinds of the environment box schemes under multi-operating conditions, and it can be seen from the analysis and comparison of the results that the square environment box is slightly better than the cylindrical environment box in view of the stability of airflow in the test section.

References


