Flowfield prediction of a probe entering the Martian atmosphere

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Summary The three-dimensional Navier-Stokes equations are solved by a parallel code to analyze the flow field structures, aerodynamic characteristics and their variation patterns of the Mars Science Laboratory entering the Martian atmosphere with and without the chemical reaction models. The analysis shows that the parameters of the thermal dynamics and the transportations have an effect on the position and intensity of the shock wave. As the result of the chemical non-equilibrium effect, the shock layer is strongly compressed, the stagnation pressure decreases and the maximum temperature behind the shock is highly reduced.

INTRODUCTION

As a result of intense future exploration missions to Mars, new and comprehensive studies on the flow dynamics, chemical kinetics, thermal non-equilibrium, and radiation of high-temperature gases present in the shock layer and in the wake of probes entering the Martian atmosphere are necessary in order to evaluate the aerodynamic characteristics precisely. Martian atmosphere mainly consists of 95.7% CO_2, 2.7% N_2 and 1.6% Ar, which is significantly different from the Earth's atmosphere; in addition the density is only one percent of Earth's atmospheric density. The impact of those factors and the variation of aerodynamic characteristics both need to be solved.

PHYSICS MODELING AND NUMERICAL METHODS

To date most Mars probes are designed to enter the atmosphere with a lifting entry, including the latest lunched vehicle - Mars Science Laboratory (MSL), which is used as a research object in this paper. Fig.1 shows the physical model and the grids of MSL.

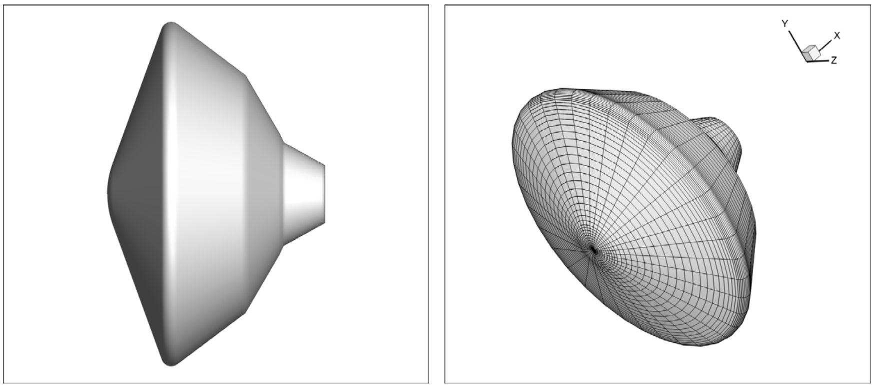

Fig.1 The physical model and the mesh of MSL

RESULTS AND ANALYSIS

The value of specific heat ratio and transport coefficients in the computation of perfect gas will affect the results dramatically. Fig.2 shows that as the specific heat ratio decrease, the pressure behind the shock almost stay the same, but the distance from the surface and the temperature are reduced. When the chemical non-equilibrium is considered, the pressure also doesn't change a lot, however, the position of the shock is much closer to the surface and the temperature is greatly reduced from 12000 K to about 7000 K. Simultaneously Fig.3 shows the change of the shock layer under different computational condition of chemical non-equilibrium and perfect gas.

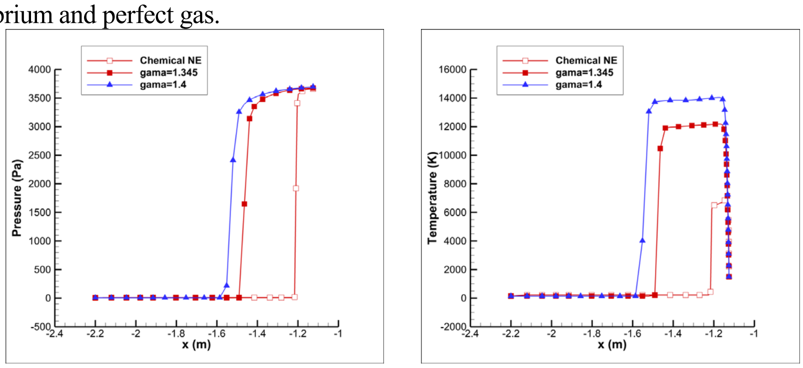

Fig.2 The pressure and temperature along the symmetry axis

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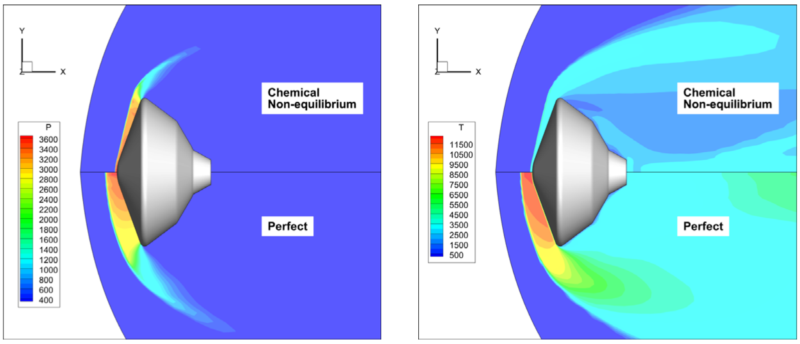

Fig.3 The contour of the pressure and temperature on the symmetric plane

After the shock the increased gas temperature enhanced the chemical reactions. A lot of CO_2 were decomposed to CO and other species, which is showed in Fig.4.

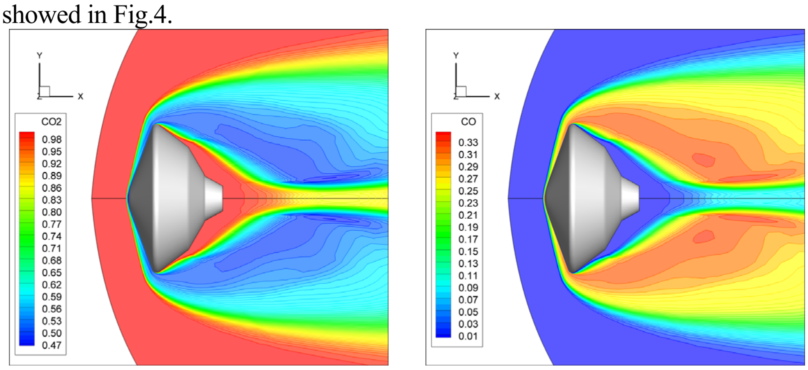

Fig.4 The contour of the mass fraction of CO_2 and CO on the symmetric plane

The space streamlines in Fig.5 shows the complex vortex motion in the wake of the vehicle.

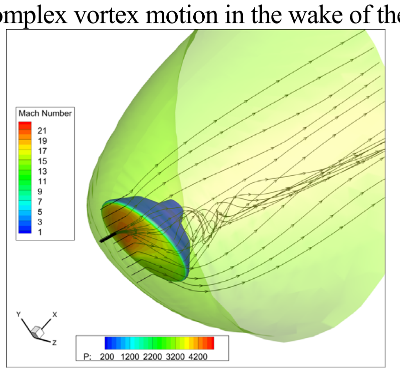

Fig.5 The pressure on surface, the iso-surface of Mach number equals 16 and the space streamlines

As the angle of attack increases, the lift-drag ratio and the coefficient of the pitching moment become lager, shown in Fig.6.

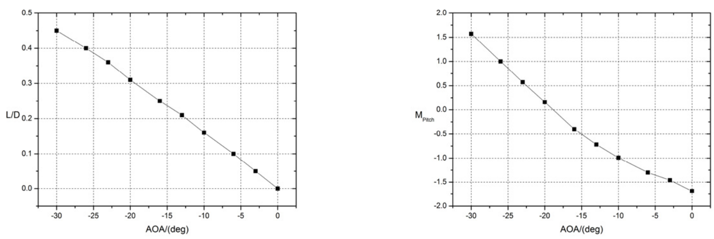

Fig.6 The lift-drag ratio and the coefficient of the pitching moment

CONCLUSIONS

Through the three-dimensional numerical simulation of the Mars Science Laboratory entering the Martian atmosphere, results show that the chemical reactions are more intense behind the shock, where the pressure changes a little, the distance detached from the surface and the temperature are severely reduced, the CO_2 were decomposed to CO and other species; there are complex vortex motion and flow separation in the wake; the lift-drag ratio and the coefficient of the pitching moment change linearly as the angle of attack increases.

References

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