Numerical Investigation of Martian Entry Vehicles Aerodynamics for Hypersonic Rarefied Conditions

***†Huang Fei[1], Liu Xiao-wen[1], Jin Xu-hong[1], Lv Jun-ming[1], Cheng Xiao-li[1]**

[1]China Academy of Aerospace Aerodynamics, Beijing 100074, China

***†**Corresponding author: huang05013@163.com

Abstract

Attempt has been made to analyze aerodynamics of Martian entry vehicles for hypersonic rarefied conditions by simulating flows around such like Mars Science Laboratory. The effects of real gas model on hypersonic rarefied aerodynamics are investigated. Solutions of entry capsule aerodynamic characteristics are obtained and presented. The results show that as flight altitude increases, rarefaction enhances, shock standoff distance and shock thickness increases. At the same time, shock intensity weakens, and flow contours are trend to arc shape. Real gas effect results in that compression enhances in windward and expansion also does in leeward. At the same time, axial force coefficient, normal force coefficient and pitch moment coefficient increase. On the other hand, as rarefaction enhances, axial force coefficient, normal force and pitch moment coefficients also increases. At the same angle, pressure center moves forward and static stability is decreased as flight altitude increases.

Key words: Martian; Entry capsule; Rarefied; DSMC; Aerodynamics

Introduction

Viking is the first successful explorer that entered Martian atmosphere in 1976[1]. In 21st century, as the development of aerospace technology and understanding of Mars atmosphere, the probability of success grows a lot. The well-known projects include Phoenix and Mars Science Laboratory, et al. Mars exploration mission[2] has gained more and more attention by many countries, but there are still a lot of challenges in accurately predicting aerodynamics characteristics in Martian atmosphere.

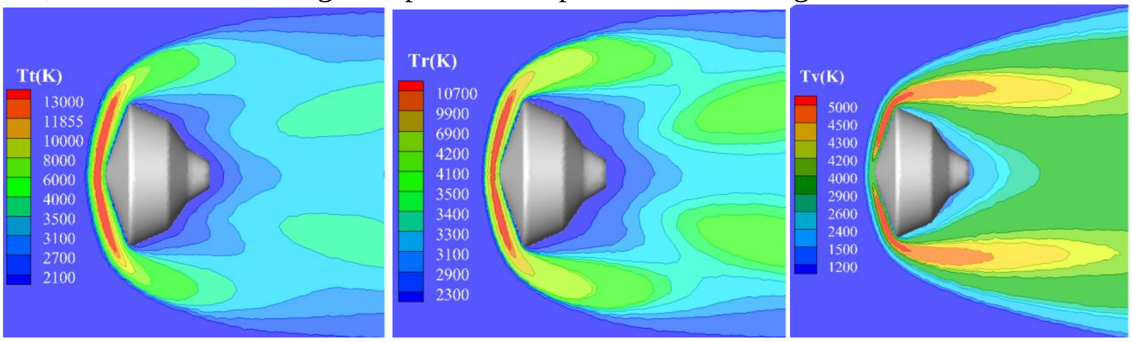
In this paper, aerodynamics of Martians entry vehicle such like Mars Science Laboratory is investigated. Direct Simulation Monte Carlo(DSMC) method is used to simulating flows for hypersonic rarefied conditions. The effects of real gas model on hypersonic rarefied aerodynamics is investigated.

Computational Methods and Physical Models

The basic steps in DSMC simulation[3] are that the position, velocity, and internal energy of each simulated particle which represent real gas particles are stored and can be changed as colliding with each other and reflecting off surfaces. Lastly, the macroscopic quantities of the flow can be obtained by sampling. The variable hard sphere model was used for molecular collisions. The Larsen-Borgnakke model was assumed for energy transfer between translational and internal molecular modes. The rotational and vibrational energy were both considered in the internal modes. Solutions were obtained with and without thermal non-equilibrium for a constant freestream gas composition consisting of 97 percent CO2 and 3 percent N2 by mass. The surface boundary conditions assumed the gas-surface interaction to be diffuse with full thermal accommodation to a specified surface temperature. A virtual sub-cells technique with transient adaptive collision distance is used to insure that collision distance is less than third local mean free path of gas. Code validation can be found in reference[4].

Results and Discussion

Unstructured tetrahedron cell is used in simulation. Simulated molecules are about 80 million for 80km and 50 million for other altitudes. Heat non-equilibrium effect for Martian rarefied atmosphere at 80km altitude is shown in Fig.1.The contours of the translational temperature, rotational temperature and vibrational temperature are very different. The transitional energy is firstly excited as a result of lower relaxation collision number, then the rotational energy is done. The vibrational temperature distribution is evidently different, and the high temperature strip locates at shoulder region. The vibrational energy exchange is with a long relaxation time and distance, so the vibrational high temperature strip locates at the stagnation downstream.

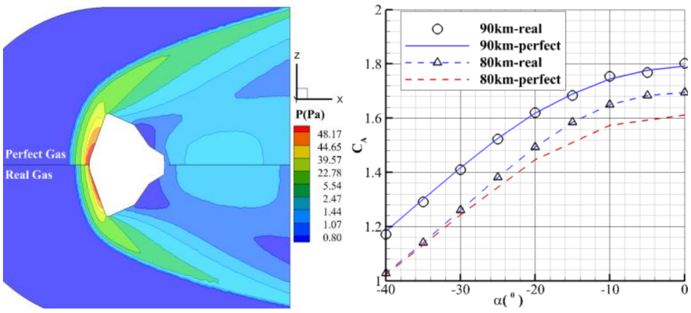


Translational Temperature　　Rotational Temperature　　Vibrational Temperature

Fig.1 Heat non-equilibrium effect for Martian rarefied atmosphere(80km, α=0^0)

The results predicted by real gas model and perfect gas model are shown in Fig.2. It can be found from pressure contours at 80km altitude that real gas model predicts a smaller shock standoff distance than perfect gas model. The axial force coefficient, the absolute value of the normal force and pitching moment coefficients predicted by real gas model is larger at 80km than that by perfect gas model, which are respectively from 1.4924,0.2209,0.0852 to 1.4467,0.1921,0.0831 at -200 incidence angle. As altitude increases to 90km, aerodynamics predicted by different gas model keep an excellent agreement.

Pitching moment coefficient about center of gravity and pressure center variation with angle of attack at different altitude is shown in Fig.3. The increasing rarefaction makes pressure center moves forward, static stability of entry capsule becomes worse, and at incidence angle ranging from 00　to 200, static instability region appears over the 100km altitude. At a lower altitude, pressure center change much more along with incidence angle change than at a higher altitude.



Pressure contours(80km, α=0^0) **Axial force coefficients**

Fig.2 Comparison of aerodynamics predicted by different gas model

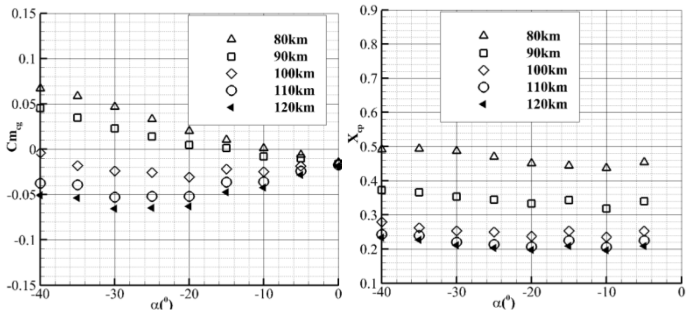


Fig.3 Pitching moment coefficient about center of gravity and pressure center variation with angle of attack

References

[1] Ingoldby R N,Michel F C,Flaherty T M, et al. Entry Data Analysis for Viking Landers 1 and 2 Final Report[R].NASA CR-159388,1976.

[2] Wright M J,Tang C Y,Edquist K T, et al. A review of aerothermal modeling for Mars entry missions[C].AIAA 2010-443,2010.

[3] Bird G A. molecular Gas Dynamics and Direct Simulation of Gas Flow Clarendon[M].Oxford,1994.

[4] Huang Fei，Jin Xu-hong，Lv Jun-ming, Cheng Xiao-li.Impact of Martian Atmosphere Parameters Uncertainties on Entry Vehicles Aerodynamics for Hypersonic Rarefied Conditions. The 30th International Symposium on Rarefied Gas Dynamics. July 11-15,2016.British Columbia,Canada.