Numerical Analysis on Hypersonic Flow around Icy Body

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1. Introduction

It is known that planetesimals and satellitesimals that are mainly made from water ice entered the earth's early atmosphere frequently. The aerothermodynamics of the hypersonic flow around an ablating body is expected to play an important role in considering the evolution of the planetary atmosphere and the formation of prebiotic materials. The objectives of the present paper are: 1) To review the results of the hypersonic wind tunnel experiments on the shape change of an icy object, 2) To conduct the Navier-Stokes analyses around various instantaneous shapes obtained by the experiments and to reproduce the process of change in the aero- and aerothermodynamic characteristics, 3) To investigate the possibility of the production of prebiotic materials and their related gaseous species by the chemical nonequilibrium VSL analysis around an icy body with ablation injection at the surface, and 4) To present a new paradigm of "hypersonic astrobiology" to consider the origin of life from a viewpoint of the hypersonic flow around extraterrestrial objects entering the earth's early atmosphere.

2. Review of Hypersonic Wind Tunnel Experiments

We briefly review the results of the hypersonic wind tunnel experiments at Mach number 7 on the behavior of an ice piece in Kashiwa campus, The University of Tokyo. Various ablation-induced shape change from initial spherical shape is observed as shown in Fig. 1.

3. Navier-Stokes Analysis around Icy Body

To deepen our understanding about the phenomena of the ice piece in the hypersonic flow, the axisymmetric Navier-Stokes analyses have been conducted. The overset grid method and the implicit time integration with the Matrix-Free Gauss-Seidel method[(1)] are used. The no-slip condition is assumed at the surface and the normal velocity due to the ablation injection is ignored. Figure 2 shows the pressure and temperature contours around the ice shape of Fig. 1.

4. Chemical Nonequilibrium VSL Analysis

Some gaseous chemical species related to the production of prebiotic materials, such as amino acids that are major components of life, may have been produced by the chemical reactions in the high-temperature hypersonic shock layer. We use the chemical nonequilibirum viscous shock-layer (VSL) analysis code[(2)] with 26 species (N_2, O_2, N, O, NO, NO^+, e^-, N^+, O^+, N_2^+, O_2^+, C, C_2, C_3, CO_2, CO, CN, CO^+, C^+, H, H_2, HCN, HCO, C_2H_2, C_2H, CH). The results show that the mass of HCN, which is an important species for formation of prebiotic materials, produced in the hypersonic shock layer is not negligible. It suggests that the biomolecule formation in the inorganic environment of the early earth may have been accelerated by the chemical reaction in the hypersonic shock layer with ablation injection of water from icy entry objects.

5. Concluding Remarks

As seen in this paper, the hypersonic aerothermodynamics in the aerospace engineering will be quite useful for the astrobiology. We present a new paradigm of "hypersonic astrobiology", in which the origin of life is considered from a viewpoint of hypersonic aerothermodynamics of extraterrestrial entry objects.

Bibliography

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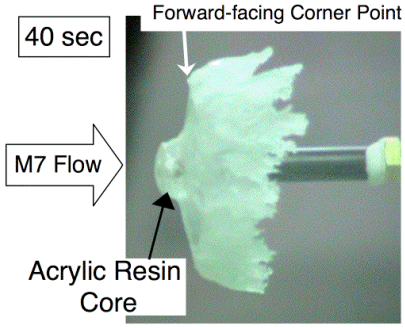

Fig. 1 Shape of ice piece (40 sec after injection into flow)

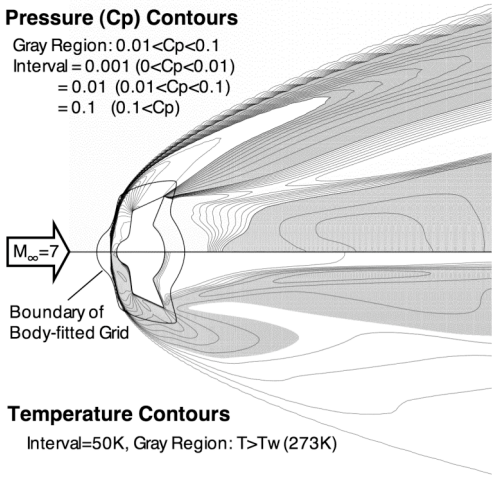

Fig. 2 Pressure and Temperature Contours