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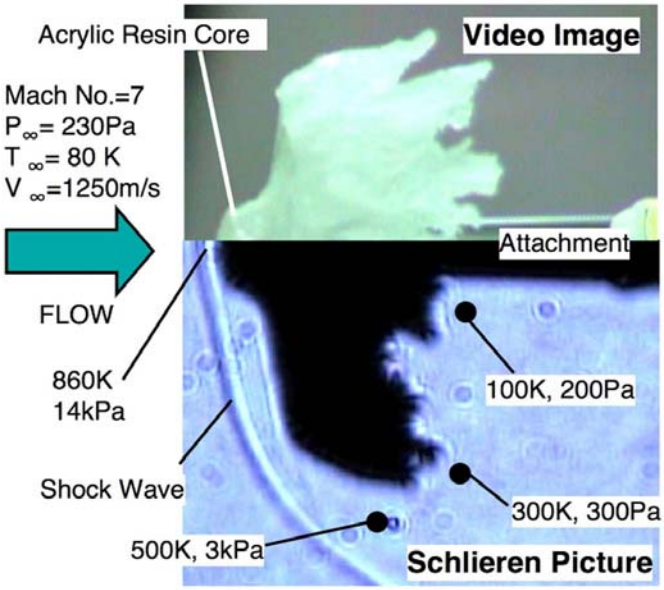
# Experimental study on atmospheric entry simulation of icy object using hypersonic wind tunnel

Kojiro Suzuki[1*], Imamura Osamu[2]

[1]Dept. Advanced Energy, GSFS, Univ. Tokyo, [2]Dept. Aero and Astronautics, Univ. Tokyo




The atmosphere is considered as only one possible window open to the space from the ground. In the field of aerospace engineering, researches on the aerodynamic heating and the thermal protection system have been extensively carried out so far. Their experimental and numerical techniques are expected to be quite useful to the planetary science. In the present study, we focused on the atmospheric entry of an icy object like a comet nucleus, and made the hypersonic wind tunnel experiments to simulate the flow phenomena around such bodies.
The experiments were conducted at the hypersonic and high-enthalpy wind tunnel in Graduate School of Frontier Sciences, The University of Tokyo (http://daedalus.k.u-tokyo.ac.jp/wt/wt_index.htm). The nozzle exit diameter and the Mach number are 200mm and 7.0-7.1, respectively. The maximum test time is about 60s. The test piece is a 40mm-diameter sphere made from ice around the 15mm-diameter spherical core made from acrylic resin. The ice piece is set in the test section by the supporting rod via thermal insulator (bakelite rod). The figure shows the behavior of the ice piece and the flow around it at 40s after the injection into the flow at the total pressure 950kPa and the total temperature 820-900K. The upper part is the snapshot of the video image and the lower part is the Schlieren picture of the flow with the shock wave. The local pressure and temperature indicated in the figure are estimated by the numerical analysis of the Navier-Stokes equations. The pressure and heating rate at the stagnation point of the initial spherical shape are predicted as about 14kPa and 130kW/m$^2$. These numbers are almost the same as those for an entry object of the diameter 100m flying at the altitude 60km and the velocity 8km/s. It is observed that the acrylic resin core has been exposed in the stagnation region due to significant mass loss by the ablation under the severe aerodynamic heating. The liquid water and vapor produced by the ablation are transported by the flow to the downstream region, where the temperature rapidly decreases by the expansion, and are changed into ice again. The columns of the frost stretching out in the radial direction form the brim-like shape around the core. The diameter of the brim is about 1.5 times larger than the initial diameter. The CFD analysis shows that the aerodynamic drag force is estimated to be about three times larger than that of the initial shape. The mass loss of ice is caused by not only the phase change but also the mechanical damage, by which the tips of the frost columns are broken into small ice pieces flying downstream. The increase in the drag force and the mass loss due to the ablation cause the decrease in the

ballistic coefficient of an icy object, and significantly affect its entry trajectory and the probability of impact at the ground.
For investigation on the chemical reactions around the ablating icy object in the flow at higher enthalpy, the numerical analysis is necessary. For example, the viscous shock-layer (VSL) analysis code with nonequilibrium chemistry of 26 C-H-O-N species has been developed to describe the chemical reaction of the air and the ablation gas from the thermal protection of the sample return capsule in HAYABUSA mission (Suzuki, ISAS Rep. SP-17, 2003). This code is easily applied for the analysis on the chemical reactions of the ablation gas ($H_2O$) from the ice surface in the earth's early atmosphere ($CO_2$and $N_2$mixture). In the 26 species model, HCN, which is one of the most important prebiotic molecules, is included. Some test calculations suggest that HCN may be efficiently produced in the vicinity of the ablating surface of an icy entry body.
As explained in the above, the application of research tools in the aerospace engineering to the planetary science will enhance the exchange of knowledge and technologies, and bring benefits to both fields.

Keywords: atmospheric entry, ice, ablation, hypersonic flow, wind tunnel experiment