Method for Visualizing Gas Temperature Distributions Around Hypersonic Vehicles by Using Electric Discharge

Masatomi Nishio*
Fukuyama University, Fukuyama 729, Japan

I. Introduction

MEASUREMENTS of flowfields around hypersonic vehicles are very important for understanding the characteristics of the flowfields. Recently, methods for visualizing three-dimensional shock shapes around hypersonic vehicles using an electric discharge have been developed by Nishio.[1,2] A method for visualizing streamlines around hypersonic vehicles using an electric discharge has been reported also by Nishio.[3] Moreover, a method for measurement of surface pressure distributions around hypersonic vehicles has been reported by Nishio and Kimura.[4,5] In the case of hypersonic flow, the investigation of gas temperature distributions around hypersonic vehicles is especially important because the hypersonic vehicles are covered with high temperature gas. However, the visualization of gas temperature distributions around hypersonic vehicles in the experiments using hypersonic tunnels is very difficult and few viable visualizing methods have been suggested until now. In this Note, a method for visualizing qualitative gas temperature distributions around hypersonic vehicles is suggested.

II. Experimental Principle and Experiments

The ideas of this method for visualizing gas temperature distributions are as follows. Vibrational conditions, rotational conditions, etc., of excited molecules are changed according to the gas temperature. The excitation functions of the excited gas molecules for an electron collision differ according to the previously excited gas molecules' conditions. Therefore, if an electric discharge is generated in the flowfield where a gas temperature distribution exists and further excitations of the previously excited molecules by the electrons traveling from the cathode to the anode are generated, not only a radiation intensity, but also a radiation spectrum from the electric discharge differs according to the gas temperature. Therefore, the gas temperature distribution is obtainable by taking a photograph of the electric discharge.

As an example of this method, a gas temperature distribution over a slightly blunted wedge is visualized. The arrangement of the wedge and electrodes is shown in Fig. 1. In this experiment, the method of the pair of point-line electrodes[1] is used to generate the electric discharge. The bluntness of the tip of the wedge is about 0.2 mm and the angle of attack of the wedge is 0 deg. In this flowfield, it is predicted that a temperature layer whose gas temperature is different from those of other regions occurs near the surface of the model as illustrated in Fig. 1. The reasons why the temperature layer occurs are explained as follows. One reason is that the gas temperature just after the strongly curved shock wave generated around a slightly blunted nose differs according to the incident shock angle. Another reason is that the gas temperature in the shock layer near the model surface is varied by the re-expansion of the flow.

The characteristics of the hypersonic tunnel used in this experiment are Mach number = 10; duration of the freestream = 10 ms; stagnation temperature of the tunnel barrel = 1000 K; and freestream molecular number density = $10^{17}/cm^3$. The test gas is air.

The visualization was carried out under the following conditions: The duration of the electric discharge was about 2 μs. The applied voltage between the pair of electrodes was 1000 V. The electric current of the electric discharge was very small so as not to increase the gas temperature by the electric discharge. Therefore, the radiation from the electric discharge was so feeble that we had to use very sensitive color film. A Nikon F camera was set open during the experiments. The iris of the camera was $f = 1.4$ and the film speed was ASA 3000.

The result of the visualization is shown in Fig. 2. The photograph shows there exists a radiation spectrum contrast near the model surface. From this spectrum contrast, we can see a layer along the model surface. This layer is the temperature layer. From this visualizing result, it is considered that the present method using the electric discharge is available for visualizing gas temperature distributions around hypersonic vehicles in the experiment using the pulsed hypersonic tunnel.

III. Discussion

Several matters including the temperature difference may be considered as the causes of the radiation spectrum differences. In this flowfield there occur flow velocity change, pressure change, and density change near the model surface. When the electric discharge of very short duration and very small electric current is generated, the pressure change and the flow velocity change have nothing to do with the electron velocity traveling from the cathode to the anode. Even in case of hypersonic flow, the electron velocity is much faster than the flow velocity. The excitation functions of the molecules are not changed because of the pressure change and the flow velocity change. Therefore, the pressure change and the velocity change have little influence on the radiation spectrum from the electric discharge. Concerning density change, there is a possibility

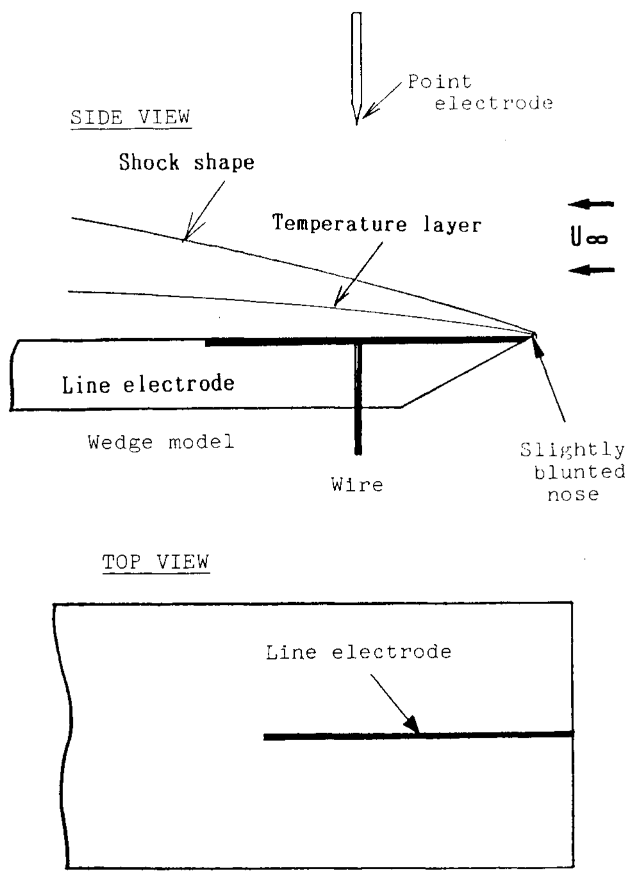

Fig. 1 Flowfield over the model and arrangement of a pair of point-line electrodes.

Received Sept. 9, 1992; revision received Nov. 2, 1992; accepted for publication Nov. 5, 1992.

*Associate Professor, Department of Mechanical Engineering. Member AIAA.

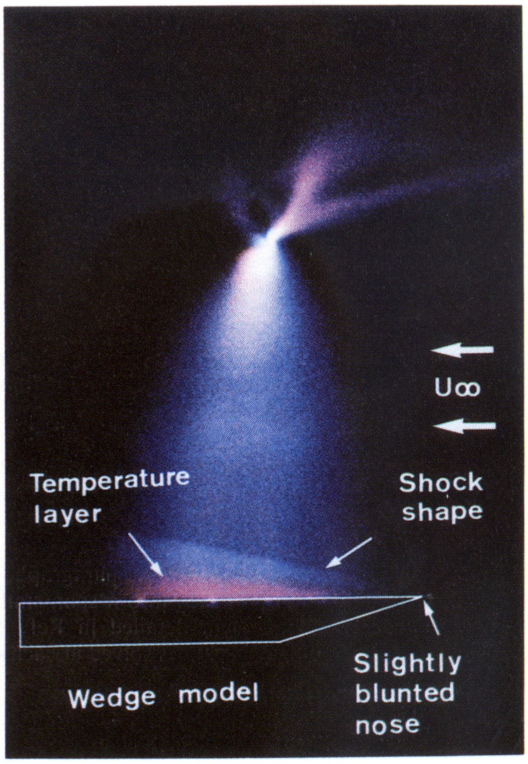

Fig. 2 Visualization of temperature layer.

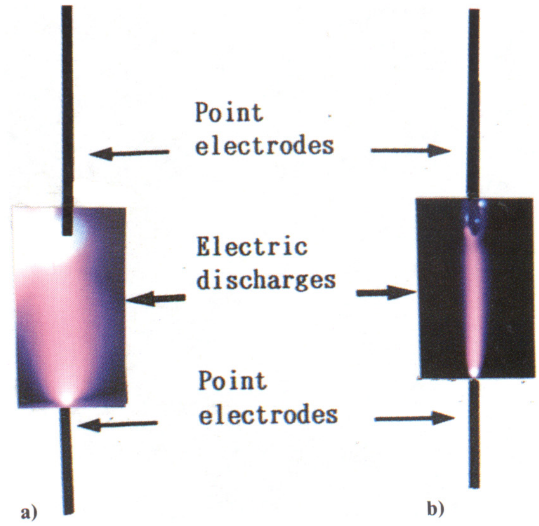

Fig. 3 Investigation of color of electric discharges under condition of different gas molecular number densities: a) $3 \times 10^{16}/cm^3$ and b) $3 \times 10^{17}/cm^3$.

that the gas density is influential for the radiation from the electric discharge even if the duration of the electric discharge is very short and the electric current of the electric discharge is very small because the electron energy in the electric discharge changes according to the gas density.[2] Therefore, the relation between the gas density and the radiation spectrum is investigated experimentally. The electric discharges are generated under conditions of different molecular number densities. The relation between the molecular number density and the color of the electric discharge is shown in Figs. 3a and 3b. In this experiment, the molecular number densities of Figs. 3a and 3b are $3 \times 10^{16}/cm^3$ and $3 \times 10^{17}/cm^3$, respectively. The experiment is carried out under the condition of a gas temperature of 300 K. The discharge shapes are different from one another because of the different gas densities. The radiation intensities

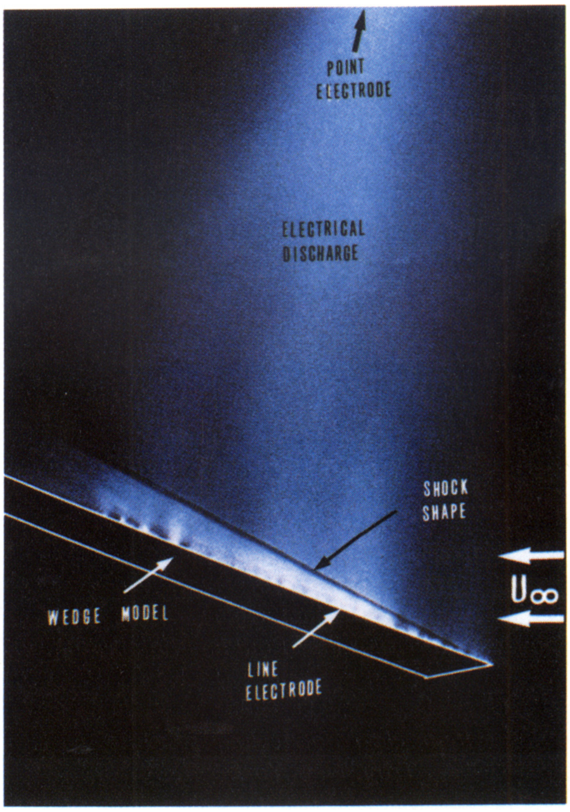

Fig. 4 Visualizing result of flowfield over wedge model whose angle of attack is 20 deg.

change according to the gas densities. However, the colors of these discharge photographs are not very different from one another, although the molecular number densities are considerably different. Judging from these discharge photographs, it is considered that the influence of the gas density change is negligibly small in the present visualization of the gas temperature distribution.

One may think that the layer shown in Fig. 2 indicates the boundary layer. Figure 4 shows the visualizing result of the flowfield over the wedge by the same electric discharge. In this experiment, the angle of attack of the wedge is 20 deg. The temperature layer in this case may be too thin to visualize. In this flowfield, although there exists a boundary layer over this model, the boundary layer cannot be visualized by the radiation spectrum difference. Therefore, it is considered that the layer shown in Fig. 2 does not indicate the boundary layer.

From the preceding discussions, it is considered that the layer shown in Fig. 2 indicates the temperature layer.

Acknowledgment

This work is supported by the Grant-in-Aid for General Scientific Research (C) of the Japanese Ministry of Education, Science and Culture.

References

[1]Nishio, M., "New Method for Visualizing Three-Dimensional Shock Shapes Around Hypersonic Vehicles Using an Electric Discharge," *AIAA Journal,* Vol. 28, No. 12, 1990, pp. 2085–2091.

[2]Nishio, M., "Qualitative Model for Visualizing Shock Shapes," *AIAA Journal,* Vol. 30, No. 9, 1992, pp. 2346–2348.

[3]Nishio, M., "Method for Visualizing Streamlines Around Hypersonic Vehicles by Using Electrical Discharge," *AIAA Journal,* Vol. 30, No. 6, 1992, pp. 1662–1663.

[4]Nishio, M., and Kimura, T., "Measuring Method of Pressure Distribution on Surface of Hypersonic Vehicles by Using Magnetic Tape," *Memoirs of Faculty of Engineering,* Kobe Univ., Japan, 1986, pp. 63–71.

[5]Kimura, T., and Nishio, M., "New Method for Measurement of Surface Pressure Using Magnetic Tape," *AIAA Journal,* Vol. 27, No. 11, 1989, pp. 1579–1583.