[5]Floryan, J. M., and Dallmann, U., "Flow over a Leading Edge with Distributed Surface Roughness," *Journal of Fluid Mechanics,* Vol. 216, Dec. 1990, pp. 629–656.

[6]Stuart, J. T., "The Viscous Flow near a Stagnation Point When External Stream Has Uniform Vorticity," *Journal of the Aero/Space Sciences,* Vol. 26, No. 2, 1959, pp. 124–125.

[7]Tamada, K., "Two-Dimensional Stagnation-Point Flow Impinging Obliquely on a Plane Wall," *Journal of the Physical Society of Japan,* Vol. 46, No. 1, 1979, pp. 310–311.

[8]Dorrepaal, J. M., "An Exact Solution of the Navier-Stokes Equation Which Describes Nonorthogonal Stagnation Point Flow in Two Dimensions," *Journal of Fluid Mechanics,* Vol. 163, Feb. 1986, pp. 141–147.

[9]Hall, P., Malik, M. R., and Poll, I. A., "On the Stability of Infinite Swept Attachment Line Boundary Layer," *Proceedings of the Royal Society of London,* Series A, Vol. A395, No. 1809, Oct. 1984 pp. 229–245.

Method for Visualizing Streamlines Around Hypersonic Vehicles by Using Electrical Discharge

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I. Introduction

IT is very important to obtain shock shapes, pressure distributions, streamlines, etc. around hypersonic vehicles for understanding the characteristics of the flowfield. Recently, a method for visualizing three-dimensional shock shapes around hypersonic vehicles by using an electrical discharge was reported by Nishio.[1] A method for measurement of surface pressure distribution around hypersonic vehicles was reported by Nishio and Kimura.[2-4] However, it is very difficult to visualize the streamlines because the hypersonic flows obtained by ordinary hypersonic tunnels in laboratories have usually been of considerable low density, high speed, and short duration. The result is that few viable visualizing methods have been reported. Therefore, a useful method for visualizing streamlines of hypersonic flows obtained by ordinary hypersonic tunnels has been required. In this Note, a method for visualizing the streamlines by using an electrical discharge is described.

II. Visualizing Principle and Experiments

The method for visualizing streamlines around hypersonic vehicles is based on the following ideas.

As illustrated in Fig. 1, when a columnar spark discharge is generated across a shock wave by applying high voltage to a pair of point-point electrodes, and the application of voltage between the electrodes is continued after generating the spark discharge, the columnar discharge drifts with the flow. The radiation from the drifting columnar discharge also continues because of the continuous electric current from the cathode to the anode. The radiation intensities from the drifting columnar discharge are not equal throughout the columnar discharge. The radiation intensities change at the position where the streamline passes through the intersection of the shock wave and the initial spark discharge because the electron excitation function,[1] which relates to the radiation intensities, changes abruptly at that position. This abrupt change is the result of a change at the position in the electric field strength and the subsequent change in the energy of electrons drifting from the cathode to the anode. The electric field strength changes at that position because the ion density in region A, where the field is above the streamline, is different from that in region B, where the field is below the streamline. There are two reasons why this difference of ion densities in regions A and B occurs. One reason is that when the initial electrical discharge is generated the ion number density generated in the freestream is different from that in the shock layer because the ionization efficiency[1] in the freestream is different from that in the shock layer. The other reason is that the ion number density generated by the electrical discharge in the freestream changes when the freestream gas, which contains the ions, enters the shock layer because the gas densities in the freestream and the shock layer are different from each other. Consequently, the radiation intensities change abruptly at the position of the streamline. Therefore, the streamline can be seen by taking a photograph of the continuous drifting columnar discharges.

The characteristics of the hypersonic gun tunnel used in these experiments were as follows: test gas was air, Mach number was 10, Reynolds number was 2×10^6/m, freestream velocity was 1000 m/s, freestream density was 4×10^{-3} kg/m^3, and freestream duration was 10^{-2} s. The electric discharge circuit[1] shown in Fig. 2 was used to obtain the continuous drifting columnar discharge.

First, the author carried out the visualization of a streamline around a wedge in the hypersonic flow to verify the usefulness of the method. The visualization was carried out under the following conditions: the clearance between electrodes was 7

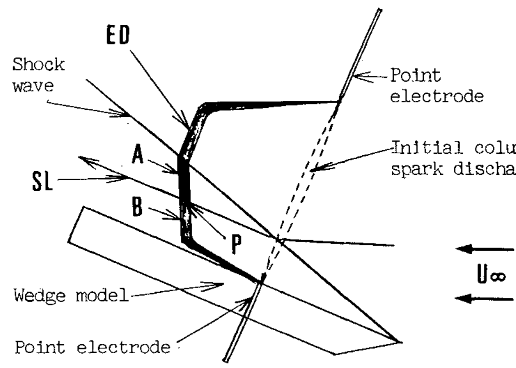

Fig. 1 Illustration of visualizing principle: SL = streamline passing through the intersection of the shock wave and the initial columnar spark discharge; ED = drifting columnar spark discharge generated at a time *T* (*T* is the time elapsed from the start of the initial columnar spark discharge); A = region above the streamline in the shock layer; B = region below the streamline in the shock layer; P = position on the streamline.

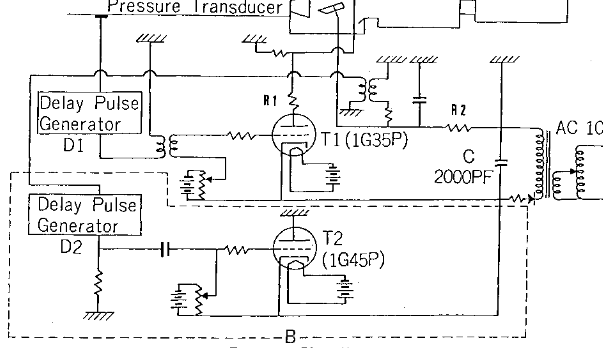

Fig. 2 Electric discharge circuit.

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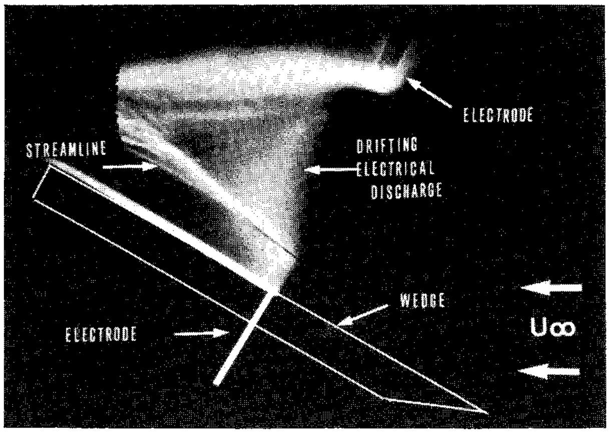
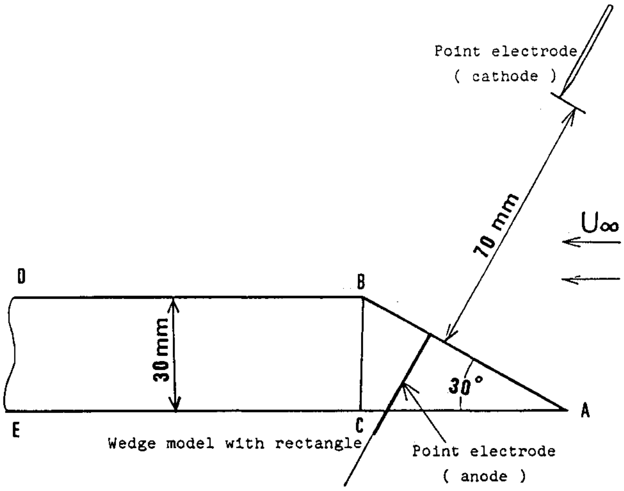
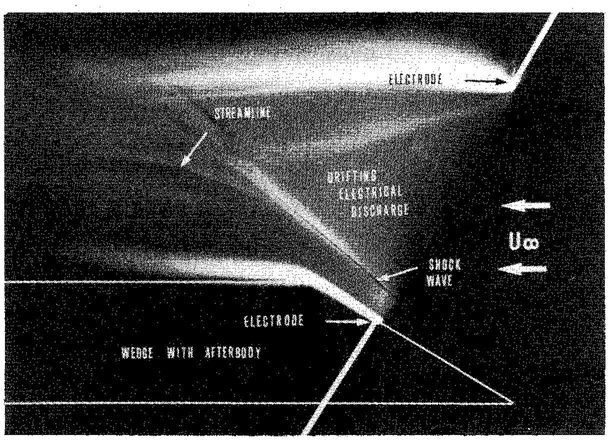


Fig. 3 Visualization of a streamline around a wedge in the hypersonic flow.



a) Arrangement of the model and the pair of electrodes



b) Visualization of a streamline

Fig. 4 Visualization of a streamline around a wedge with a two-dimensional rectangular afterbody in the hypersonic flow.

cm and the attack angle of the wedge was 30 deg. A high voltage of 2500 V was applied between the electrodes to generate an initial spark discharge and that application of voltage between the electrodes was continued for about 100 μs after generating the spark discharge. The discharge current should be as small as possible in order not to disturb the flowfield. The type of camera was a Nikon F. The iris of the camera was F = 1.4. The film speed was ASA 1600. The camera shutter was left open while the electrical discharge was being generated. The experimental result is shown in Fig. 3. The figure shows that there exist very bright regions near the electrodes. However, actually, the radiations from the regions were not large. The observation of the electrical discharge had to be carried out by using a very sensitive film because the flowfield between the electrodes was given very small energy in order not to disturb the flowfield. The figure indicates that the streamline in the shock layer is approximately parallel to the wedge surface. The theoretical streamline is considered to be parallel to the wedge surface. From this, it was demonstrated that the method using an electrical discharge is available for the visualization of streamlines around hypersonic vehicles.

Moreover, the author carried out the visualization of a streamline around a more complicated model shape. The model was a wedge with a two-dimensional rectangular afterbody, as shown in Fig. 4a. Such a model shape is not only a typical shape, but also a fundamental one of hypersonic bodies. As shown in the figure, the wedge surface AB was set at the angle of 30 deg and the rectangle's surface BD was set parallel to the freestream. The visualization of a streamline around the body was performed under the same conditions as just described. The result is shown in Fig. 4b. The figure shows that the streamline is curved at the flowfield just after point B because of the expansion wave from the point.

III. Discussion

There is a significant limitation of this method. To visualize a streamline using this method, we have to generate an initial spark discharge that crosses a shock wave. Considering the principle of the visualization, the shock wave should be strong. If the shock wave is weak, the visualization of the streamline would be very difficult. Density, spatial, and test time limitations are important problems for the visualization. However, we will be able to manage to find out suitable experimental conditions under these limitations.

The electric circuit shown in Fig. 2 is designed so as to generate a spark discharge with an accuracy of 10^{-5} s. Therefore, the electric discharge can be generated almost at an arbitrary time. For example, the freestream duration of 10^{-2} s is long enough for generating a spark discharge in the freestream. From this, it is considered that there are no problems for generating a spark discharge in the pulsed facility environment.

This method is suitable for visualizing streamlines around models in the freestream of large Mach numbers because there easily occurs strong shock waves over the models in the case of large Mach numbers.

The visualization of multiple streamlines is possible if we can apply pulsed high voltage several times during the continuous electric discharge. It is a problem of the electric circuit. To visualize multiple streamlines, we have to make a more complicated electric circuit.

References

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

[2]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., Kobe, Japan, 1986, pp. 63–71.

[3]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.

[4]Nishio, M., and Kimura, T., "A New Method for Measuring Surface Pressure by Means of Magnetic Tape," *Transactions of Japan Society of Mechanical Engineering*, Vol. 56, No. 532, 1990, pp. 3799–3804.