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Original Method for Visualizing Streamlines Around Hypersonic Vehicles

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ABSTRACT

This paper described a new visualizing method of streamlines around a body in hypersonic flows. The new visualizing method is based on the following ideas; when an electric discharge is generated across a shock wave and it is continued, the electric discharge column is being drifted because of the flow. In this case, there occurs a radiation contrast along the streamline passing through the intersection of the shock wave and the initial spark discharge. The streamline is made visible by taking the photograph of the drifting discharge column. In this paper, the visualization of a streamline around a wedge has been tried and the visualized result has been compared with the theoretical wedge flow in order to verify the usefulness of the result obtained by the present method. From this comparison, it has been proved that the present visualizing method is available for the visualization of streamlines around hypersonic vehicles. Moreover, the visualization of a streamline around a hypersonic body whose front part is a wedge and back part is a two dimensional rectangular has been performed by the present method, successfully.

1. Introduction

This paper has described a new visualizing method of streamlines around hypersonic vehicles by using an electrical discharge.

The visualization of streamlines around hypersonic vehicles is very important for understanding the characteristics of the flow field. However, the visualization of streamlines is very difficult because the hypersonic flows obtained in laboratories have usually been of considerably low density, high speed, and short duration for the visualization.

Concerning the density ρ of hypersonic flows obtained by hypersonic tunnels, it is expressed as follows[1];

$$\rho = \rho_0 / \{1 + \frac{\gamma - 1}{2} M^2\}^{1/(\gamma - 1)} \qquad (1)$$

Where ρ_0 and M are stagnation density and Mach number, respectively. From the expression described above, it will be known that if the flow is hypersonic and the Mach number M becomes very large, the density ρ becomes very low. If the density ρ is very low, we can not utilize tracer methods which are generally known as typical streamline visualizing techniques. Because it becomes difficult that the tracers exactly follow the streamlines when the density is very low.

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The relation between a hypersonic air velocity U and a Mach number is expressed as follows;

$$U = a \cdot M \tag{2}$$

where a is a velocity of sound. Therefore, if the velocity of sound is constant, and if the Mach number becomes very large, the hypersonic air velocity U becomes also very large, and therefore, the tracer particles used in tracer methods would not coincide with real streamlines.

Furthermore, it costs a great deal to make the duration time of hypersonic flows long. Because, in the hypersonic flows, the total enthalpy must be very large. Therefore, the duration times of ordinary hypersonic tunnels are usually considerably short. Consequently, the measurements of streamlines by using such short duration tunnels would become very difficult in various means.

The result of these problems is that the development of a viable visualizing method of these streamlines has not been found. Therefore, the development of a visualizing method of hypersonic streamlines even in such flow conditions has been desired for a long time. However, recently, a new visualizing method of hypersonic streamlines has been developed by the authors.

The new visualizing method is based on the following ideas; when an electric discharge is generated across a shock wave and it is continued, the electric discharge column is being drifted because of the flow. In this case there occurs a radiation contrast along the streamline passing through the intersection of the shock wave and the initial spark discharge. The streamline is made visible by taking the photograph of the drifting discharge column.

In this paper, the visualization of a streamline around a wedge has been tried and the result has been compared with the theoretical wedge flow in order to verify the usefulness of the result obtained by the present method. From this comparison, it has been proved that the present visualizing method is available for the visualization of streamlines around hypersonic vehicles. Moreover, the visualization of a streamline around a typical and fundamental hypersonic body shape whose front part is a wedge and back part is a two dimensional rectangular is performed by the present method, successfully. The visualized streamline is compared with the one obtained by the method of characteristics2 and it is found that both the results agree quite well. Consequently, it has been confirmed that the present method using the electrical discharge is useful for the visualization of hypersonic streamlines.

2. Visualizing Principle and Experimental Procedure

The present new visualizing method of hypersonic streamlines is based on the following ideas; as illustrated in Fig.1, when an electric discharge is generated across a shock wave and it is continued, the electric discharge column is being drifted because of the flow. The radiation from the drifting discharge column also continues. In this case, the radiation intensities from the drifting discharge column are not equal along the discharge column. Because an electric field strength changes very strongly at the positions along the streamline passing through the intersection of the shock wave and the initial spark discharge. Because the ion density in the region (A) is different from the one in the region (B). Consequently, the radiation intensity would change abruptly at the position of the air particles which drift along the streamline. The streamline is made visible by taking the photograph of the drifting

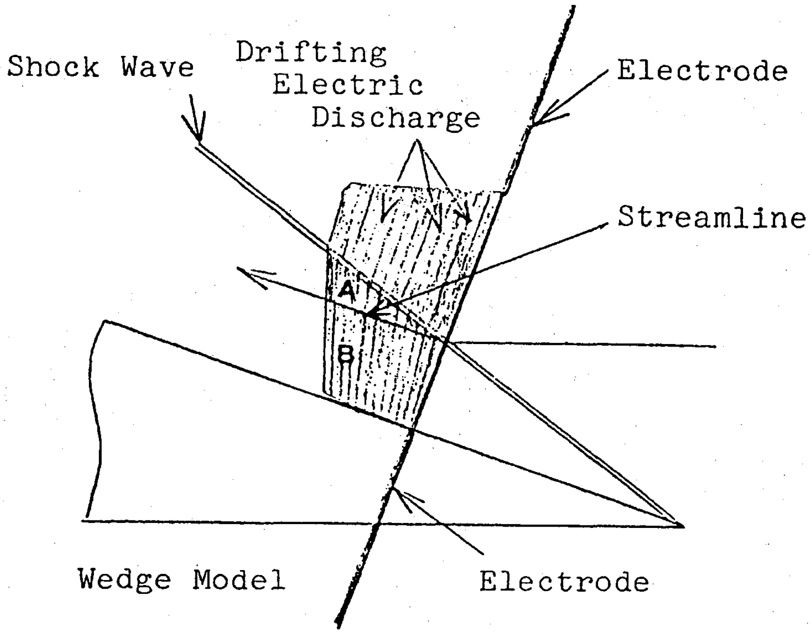

Fig.1 Illustration of visualizing principle.

discharge column.

In these experiments, a hypersonic gun-tunnel has been used. The illustration of the tunnel is shown in Fig.2. The duration time of the tunnel was the order of 10^{-2} sec and the measurements had to be finished in such short duration time. From this reason, the electric circuit was designed as shown in Fig.3. The visualization of hypersonic streamlines were performed in the following procedure. A pressure transducer made of titanic acid barium in the gun barrel of the gun-tunnel received a signal by an incident shock wave in the barrel. This pulse became an input signal of the delay pulse generator(D1). The signal was delayed in this pulse generator so as to generate the electric discharge while the freestream was being obtained. The delayed pulse acted on the thyratron(T1). When the thyratron was operated, the electric circuit was closed, and a high voltage was applied between a pair of

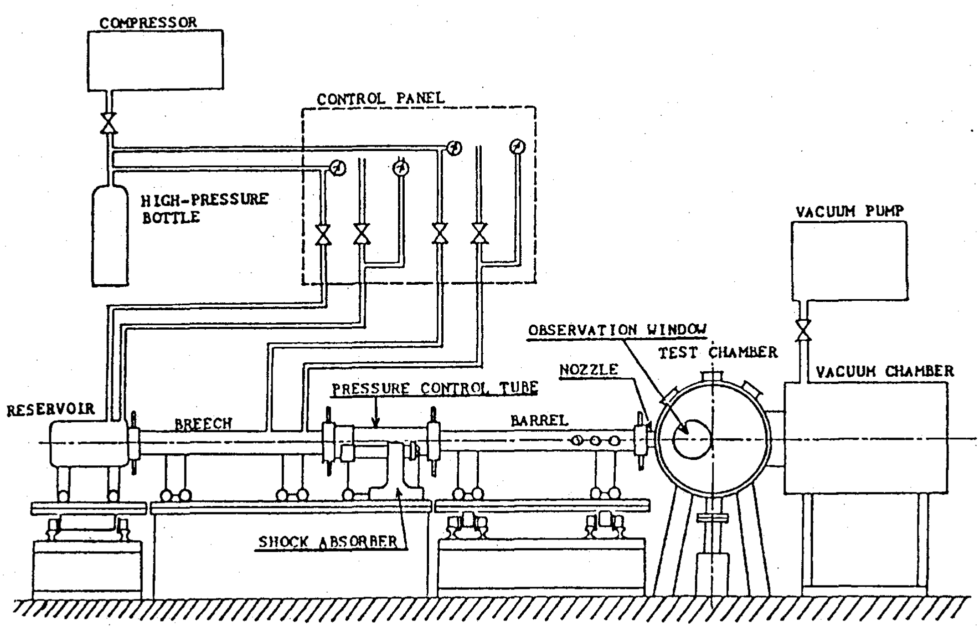

Fig.2 Illustration of a hypersonic gun tunnel.

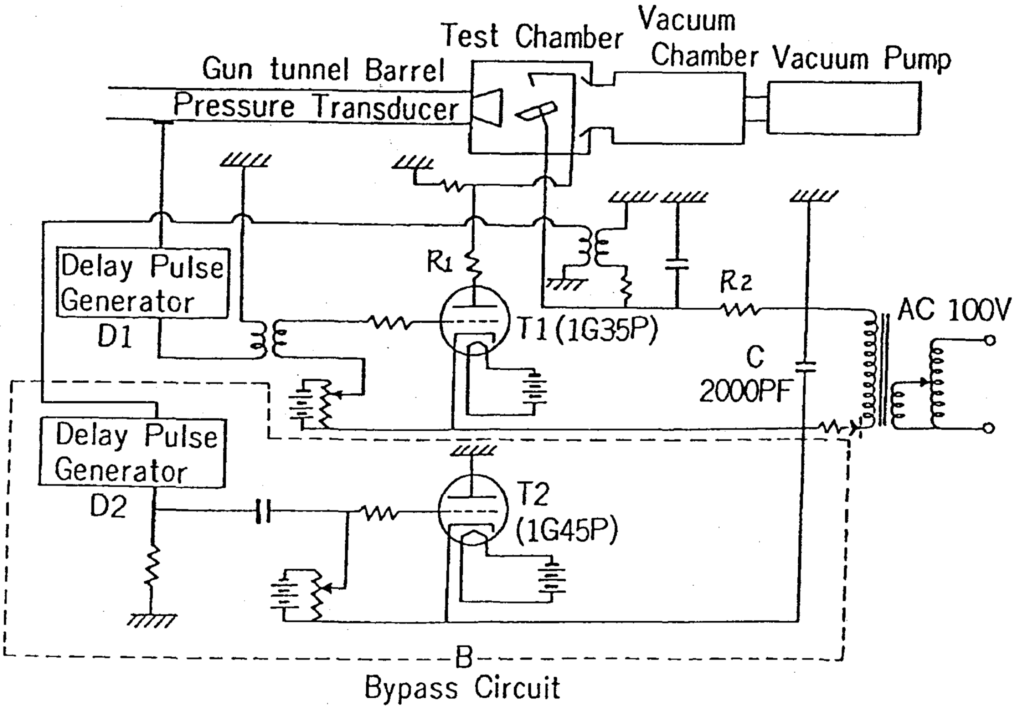

Fig.3 Electric circuit.

electrodes by the electric charges stored in the condencer(C1). After that a spark discharge occurred naturally. The bypass circuit(B) was designed to control the discharge duration time. In the bypass circuit, the signal generated by the electric current of the electric discharge acted on the thyratron(T2). Consequently, the electric charges in the condenser were released to the ground and the electric discharge between the pair of electrodes finished. An electrode was placed in the freestream and an another electrode was installed in a model. The drifting electric discharge generated between the pair of electrodes was photographed with a camera.

3. Visualization of Streamline

First, the authors verified the usefulness of the new method by carrying out the visualization of a streamline around a wedge. As the electrodes used for generating an electric discharge, a pair of point electrodes, the negative electrode in the freestream and the positive electrode in the model surface, were used. The arrangement of the wedge and the pair of electrodes were shown in Fig.4. The gap length of the pair of electrodes was about 7 cm and the wedge angle was 30°. A high voltage of 2500V was applied between the pair of electrodes to generate an initial spark discharge. The electric discharge was continued for about 100 sec. The characteristics of the hypersonic gun-tunnel were a Mach number of 10, a Reynolds number of 2×10^6/m, a freestream velocity of 1000 m/sec, a density of 4×10^{-3} kg/m^3, and a duration time of 10^{-2} sec. In the present visualizing method, the accuracy of the visualization was considered to be effected considerably by the quantity of ions generated during the electric discharge. The reason is that when the discharge energy becomes too large, not only the shock shape but also the streamline itself would be disturbed. Therefore, when the experiments were performed, the values of the applied voltage and the electric current between the pair of electrodes as well as the initial applied voltage were well payed attention during the electric discharge. In order to control the values of the applied voltage

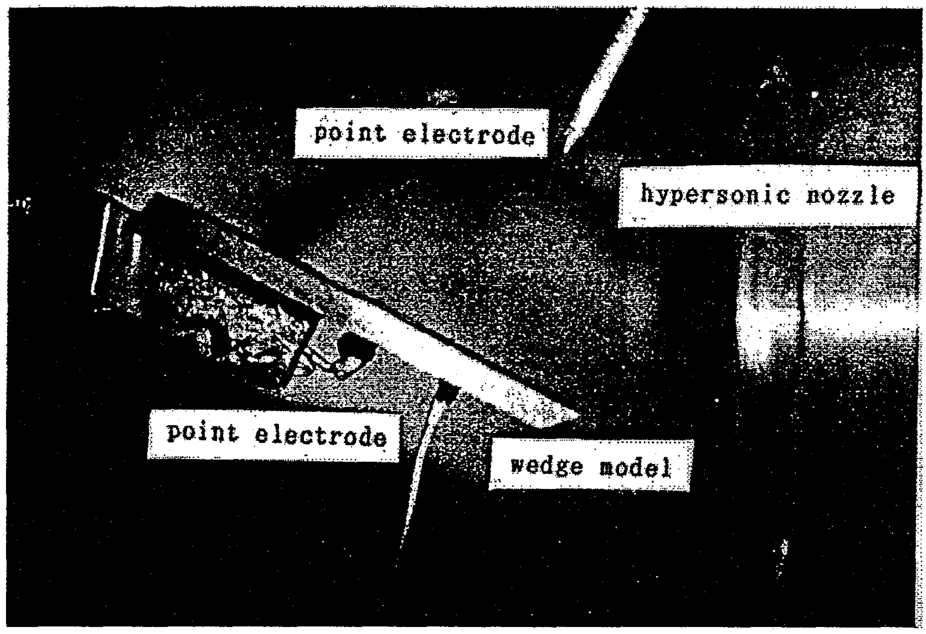

Fig.4 Arrangement of the wedge model and the pair of electrodes.

and the electric current, the suitable electric resistances R1 and R2 which were indicated in the electric circuit shown in Fig.3 should be selected. In these experiments R1 and R2 were decided to be 4 kΩ and 1 kΩ, respectively. When the circuit resistances were such large values, it was considered that the ion number generated in this flow was very small.[3] Therefore, it was confirmed that the disturbance of the streamline in the flowfield was negligible small. However, in the case that the electric circuit resistances were too large, we could not take the discharge photograph even if we used a high sensitive film, since the radiation intensity from the discharge column became too small. Therefore, it was necessary to select the suitable circuit resistances to perform this kind of streamline visualization. A visualization result under the considerations described above, was shown in Fig.5 and the illustration of the photograph was shown in Fig.6. In this visualization, the wedge angle was

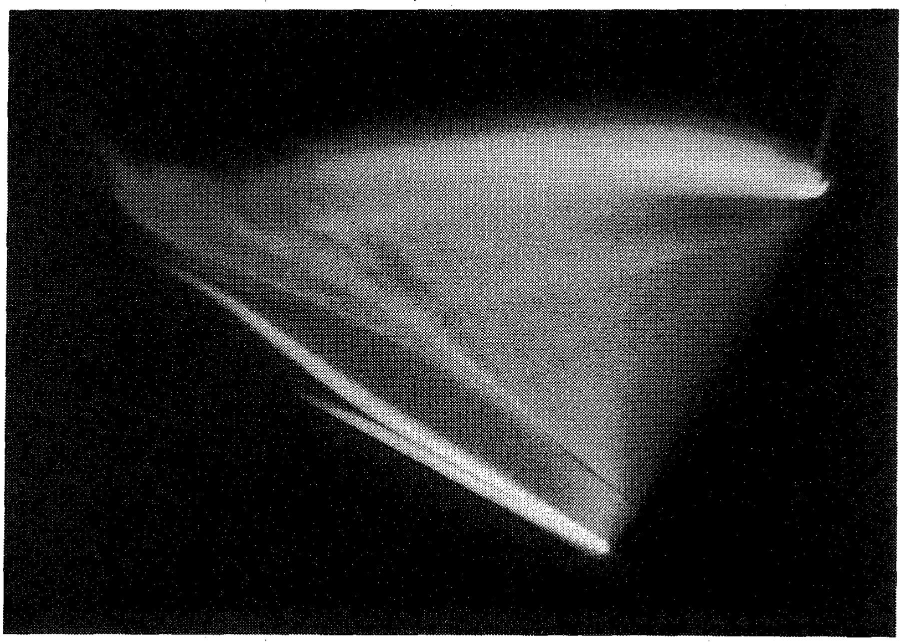

Fig.5 Visualized streamline over the wedge model.

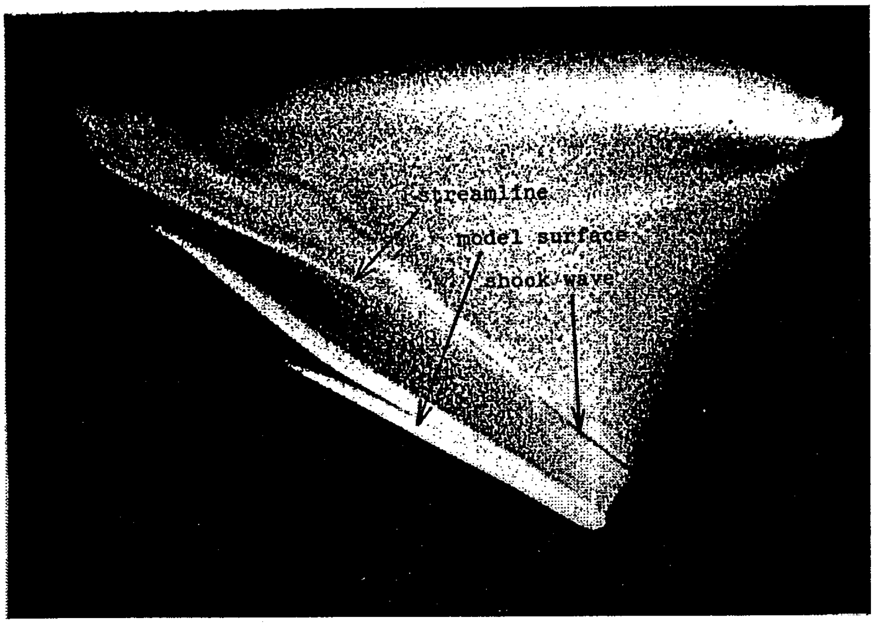

Fig.6 Illustration of the visualized streamline.

30°. Therefore, the streamline was expected to be deflected 30° from its straight course at the shock position by the oblique relation described below.

$$\tan\theta = 2\cot\frac{M^2\sin^2\beta - 1}{M^2(\gamma + \cos 2\beta) + 2} \tag{3}$$

where θ was the deflection angle of a streamline at the shock position and β was the shock angle against the freestream as shown in Fig.7. The experimental streamline also showed that it was deflected about 30° at the shock position and that after entering the shock layer, the streamline was approximately parallel to the wedge surface. Therefore, it was confirmed that the present visualizing method using the electric discharge was available for the hypersonic streamline.

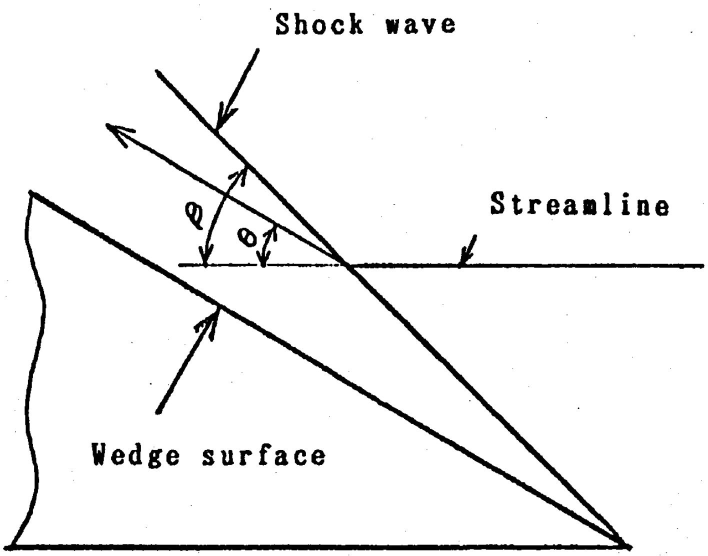

Fig.7 Relation between the oblique shock and the deflection angle.

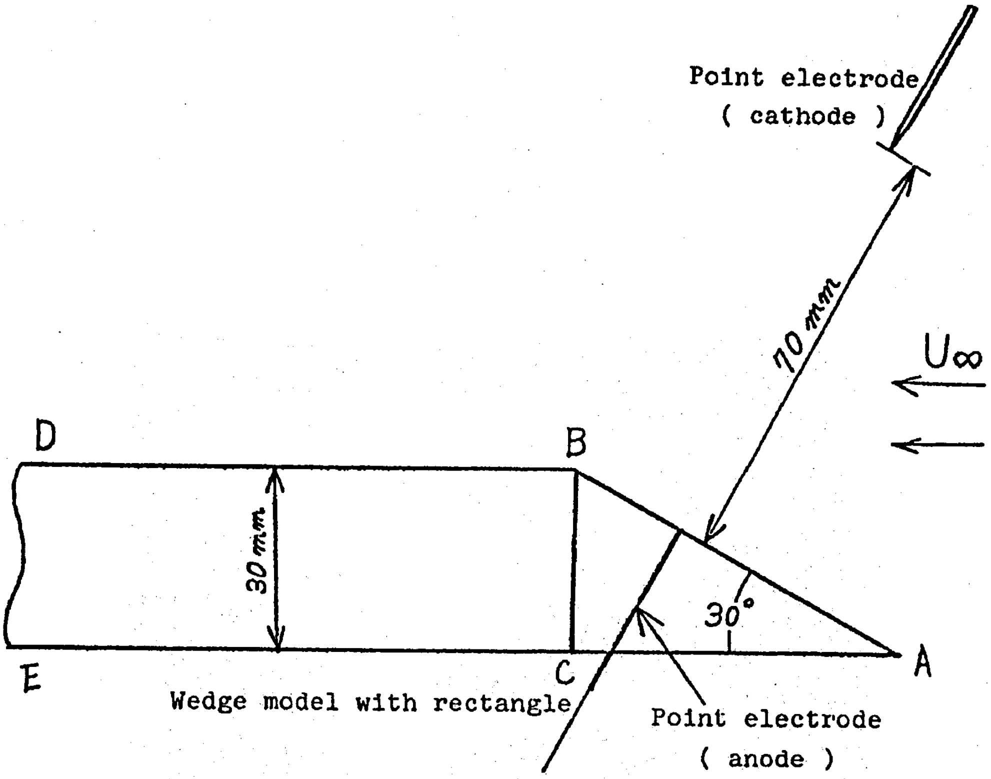

Fig.8 Arrangement of the hypersonic model and the pair of electrodes.

Moreover, the authors carried out the visualization of a streamline around a more complicated model shape. The arrangement of the model and a pair of electrodes was shown in Fig.8. As shown in Fig.8, the front part of the model was a two dimensional wedge △ABC and the back part of it was a two dimensional rectangular □BDEC. Such kind of model shape is a typical shape as well as a fundamental one as hypersonic bodies. However, a visualization result has not been reported since there had been no available visualizing method. As shown in Fig.8, the wedge surface AB was settled at the angel of 30° and the rectangular surface BD was settled parallel to the freestream. The visualization of streamline performed under the same conditions as before was shown in Fig.9. And the illustration of

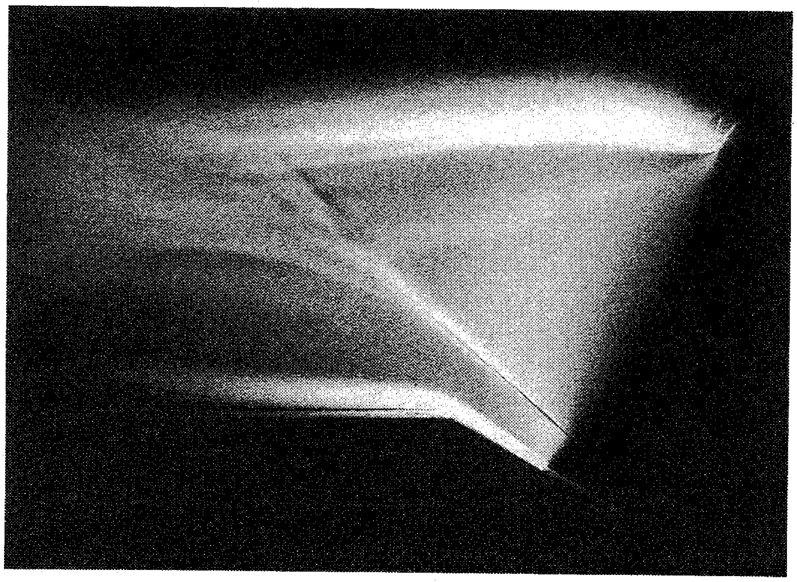

Fig.9 Visualized streamline over the hypersonic model.

the photograph was shown in Fig.10. Furthermore, the authors tried to compare the experimental streamline with the theoretical one obtained by the method of characteristics. The theoretical streamline was shown in Fig.11 and the experimental one was also shown in the same figure. In this body shape, the streamline is carved to the body side at around point B since there occurs the expansion wave from the point B. It is considered that both the results, the experimental and the theoretical streamlines, agreed sufficiently well. From this, it has been proved that the present method is suitable for the visualization of streamlines around hypersonic vehicles.

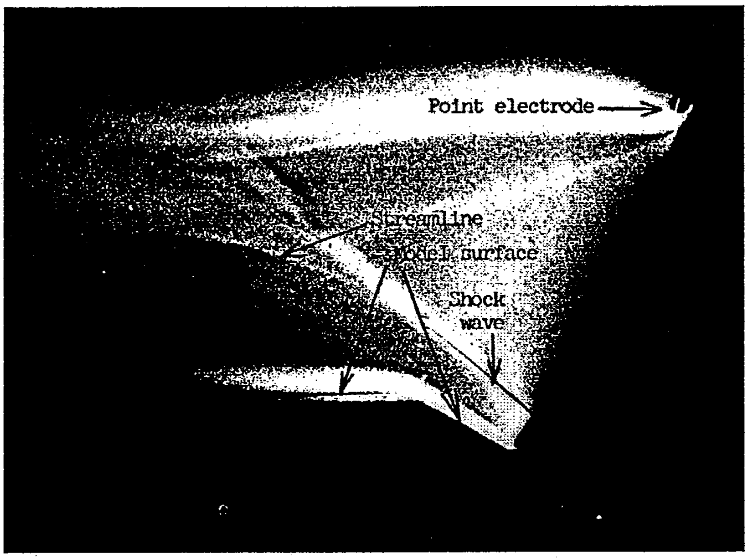

Fig.10 Illustration of the visualized streamline.

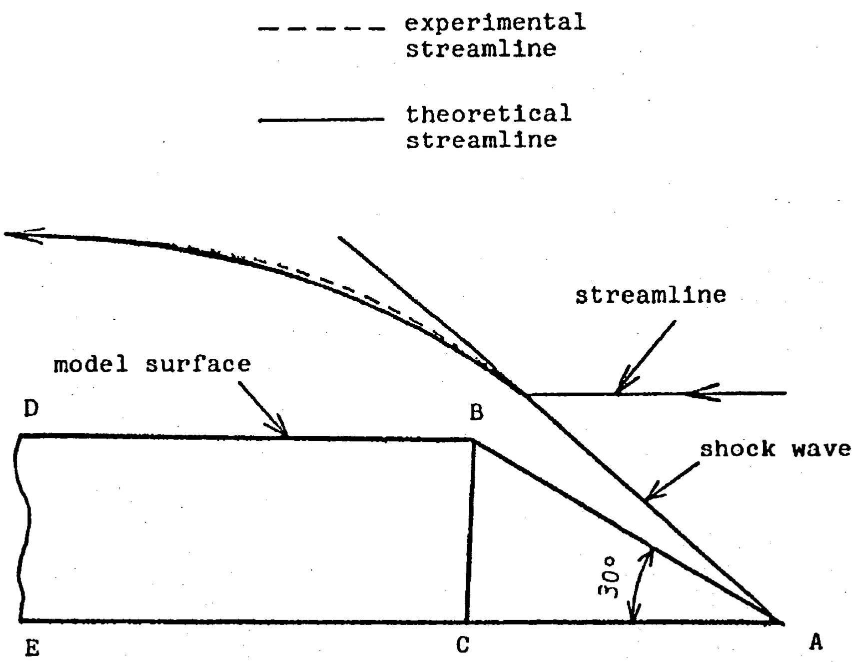

Fig.11 Theoretical streamline obtained by the method of characteristics and the experimental streamline.

4. Conclusions

The new visualizing method of hypersonic streamlines was presented. The visualization of streamlines around hypersonic vehicles is very important for understanding the characteristics of the flow field. However, the visualization of hypersonic streamlines is very difficult because the hypersonic flows obtained in laboratories have usually been of considerably low density, high speed, and short duration for the visualization.

The new visualizing method is based on the following ideas; when an electric discharge is generated across a shock wave and it is continued, the electric discharge column is being drifted because of the flow, and there occurs a radiation contrast along the streamline passing through the intersection of the shock wave and the initial spark discharge. The streamline is made visible by taking the photograph of the drifting discharge column.

In this paper, the visualization of a streamline around a wedge was tried and the result was compared with the theoretical wedge flow in order to verify the usefulness of the result obtained by the present method. From this comparison, it was proved that the present visualizing method was available for the visualization of streamlines around hypersonic vehicles.

Moreover, the authors carried out the visualization of a streamline around a more complicated model. The model shape was that the front part of the model was a two dimensional wedge and the back part of it was a two dimensional rectangular. Such kind of model shape is a typical shape as well as a fundamental one as hypersonic vehicles. However, the visualization result has not been reported since there had been no available visualizing method. The visualization of a streamline for such a model was performed by the present method by using an electrical discharge, successfully. Furthermore, the experimental result was compared with the one obtained by the method of characteristics. The results of both agreed sufficiently well with each other. From this, it has been proved that the present method is suitable for the visualization of streamlines around hypersonic vehicles.

The characteristics of the hypersonic gun-tunnel used in these experiments were a Mach number of 10, a Reynolds number of 2×10^6/m, a freestream velocity of 1000 m/sec, a density of 4×10^{-3} kg/m^3, and a duration time of 10^{-2} sec.

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