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Engineering Notes

Hypersonic Flowfield Analysis of X-33 Model with the Electric Discharge Method

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Introduction

THE flowfield around a model of an X-33 test vehicle has been investigated utilizing the electric discharge method. The electric discharge method has been developed for visualizing almost all important hypersonic flowfield phenomena, such as three-dimensional shock shapes,[1,2] streamlines near the wall surface,[3] streamlines away from the wall surface,[4] three-dimensional temperature fields,[5] and boundary layers.[3] The electric discharge method can also be used to visualize more complicated hypersonic flowfield phenomena, such as the shock/shock interaction, and shock-wave/boundary-layer interaction.[3,6] Visualizations of such three-dimensional flowfield phenomena in hypersonic flow have been very difficult or almost impossible. The present visualized results can be compared with those obtained by theoretical and numerical methods. In this respect, the results shown in this paper will be helpful for understanding the flowfield phenomena around the X-33 test vehicle.

Experimental Equipment

In these experiments, the hypersonic gun tunnel shown in Fig. 1 is used. The test duration is 10 ms. The freestream conditions in these experiments are Mach number, static pressure, density, and velocity of 10, 70 Pa, 4.5×10^{-3} kg/m^3, and 1.5 km/s, respectively, and the test gas is air. To carry out the visualization using this method, it is necessary to generate an electric discharge within the short duration time. The electric discharge circuit shown in Fig. 2 is designed for this purpose. We can generate various kinds of electric discharges suitable for the visualization of flowfield phenomena by just selecting suitable values of the electric resistances R1, R2, R3, and R4 shown in the Fig. 2. In this respect, the experiments can be carried out easily and simply. The dimensions of the model used in these experiments are shown in Fig. 3.

Visualization of Shock Wave and Temperature Field

First, the lateral shock shapes of the model in the hypersonic flow are visualized. The arrangement of a pair of needle cathode and line anode electrodes is shown in Fig. 4. The line electrode is bonded to the model surface, and the needle electrode is installed in the freestream. A sheet-shaped electric discharge is generated between the electrodes applying a high voltage of 2 kV. The experiments are carried out under the condition that the angles of attack of the model are 0, 10, 20, and 30 deg. The visualized results are shown in Figs. 5a–5d. The difference of the shock shapes due to angle of attack is indicated clearly. Moreover, qualitative temperature distributions in the shock layers are visualized by the radiation spectrum from the electric discharges as shown in Figs. 5a–5d.

Second, the cross-sectional shock shapes perpendicular to the freestream are visualized. The positions of the four line electrodes bonded to the model surface are shown in Fig. 6a. The sheet-shaped electric discharges are generated between the needle electrode installed in the freestream and one of the line electrodes. The observing direction of the sheet-shaped electric discharges is shown in Fig. 6b. In these experiments, the visualizations are carried out under the condition that the angle of attack is 30 deg. These experimental results are shown in Figs. 7a–7d. The shock-standoff distance shown in Fig. 7a is read numerically, and the result is shown in Fig. 8.

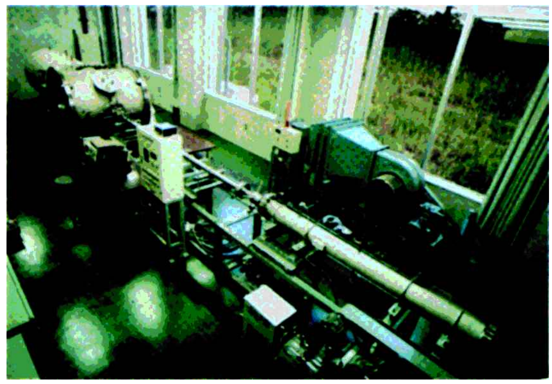

Fig. 1 Hypersonic tunnel.

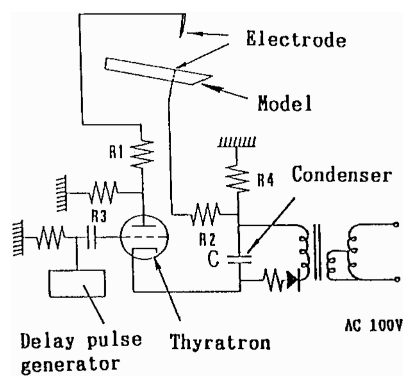

Fig. 2 Electric circuit.

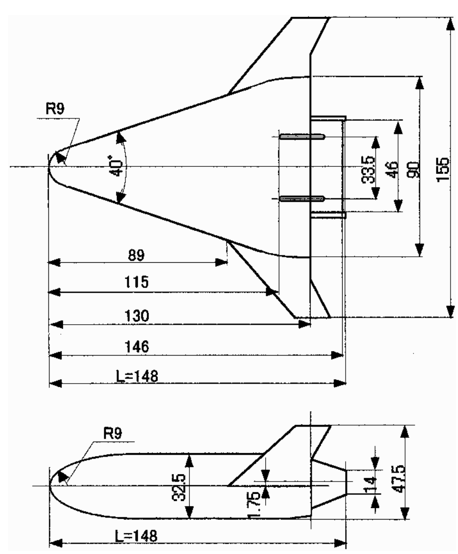

Fig. 3 Model dimensions, millimeters.

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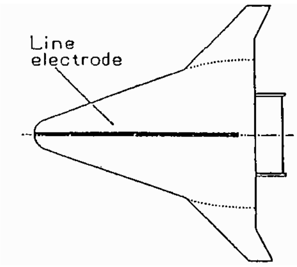
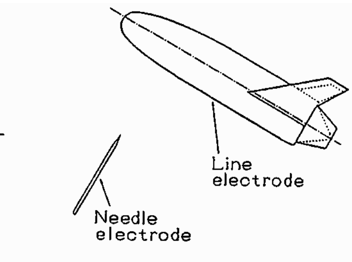
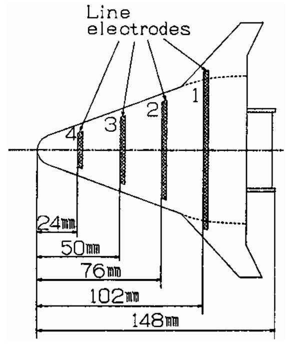


Bottom view

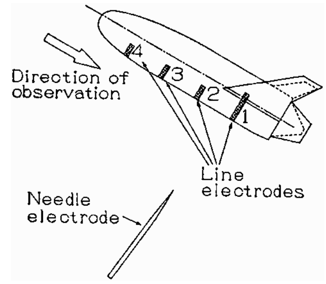


Side view

Fig. 4 Arrangement of a pair of electrodes.

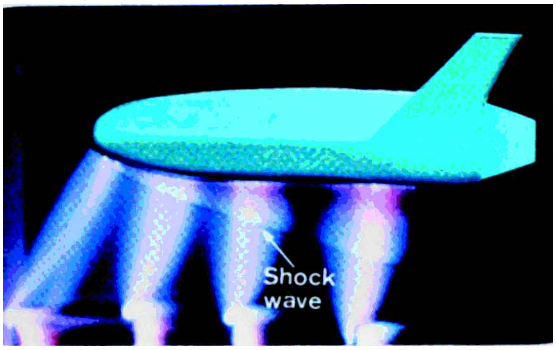


a) Bottom view

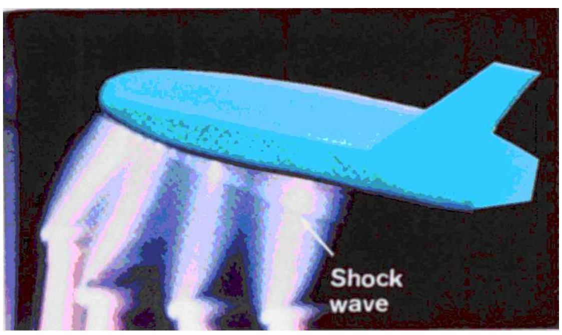


b) Side view

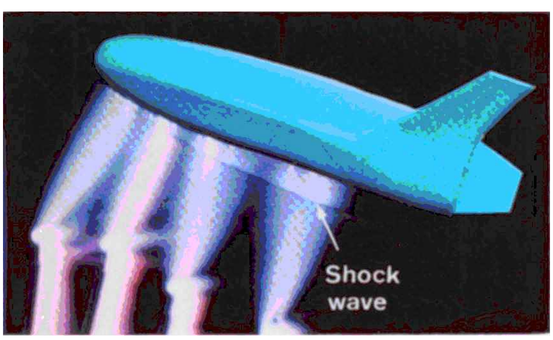
Fig. 6 Arrangement of electrodes and observing direction.



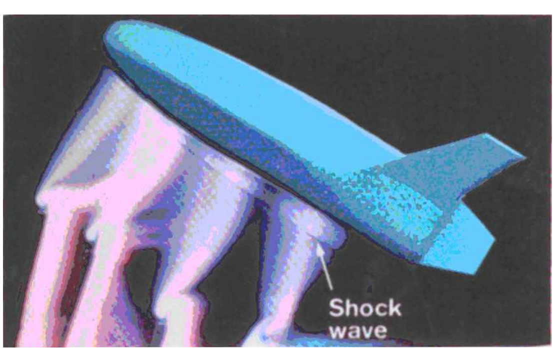
a) 0-deg angle of attack



b) 10-deg angle of attack

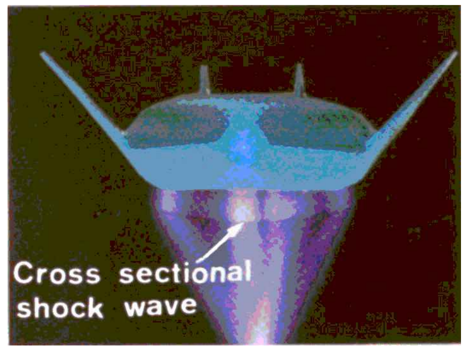


c) 20-deg angle of attack



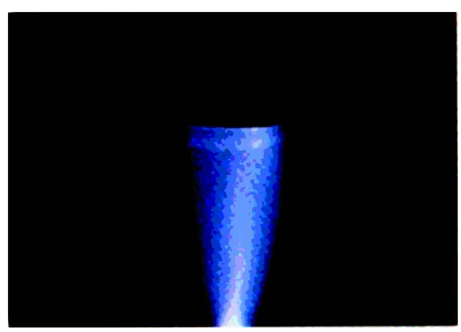
d) 30-deg angle of attack

Fig. 5 Visualized shock shapes and temperature fields (from side).

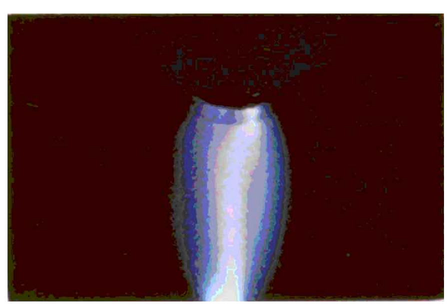


a) Position 1

b) Position 2



c) Position 3



d) Position 4

Fig. 7 Visualized cross-sectional shock shapes, 30-deg angle of attack.

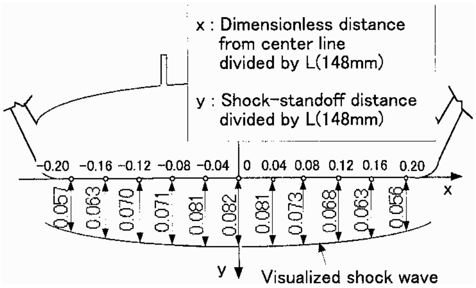
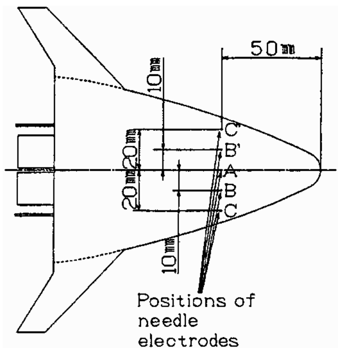
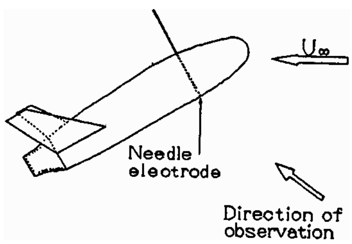


Fig. 8 Shock-standoff distance of Fig. 7a.

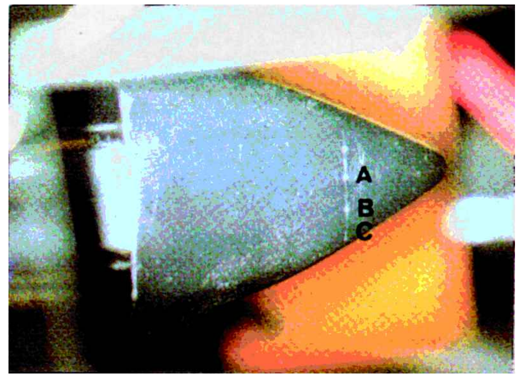


Bottom view

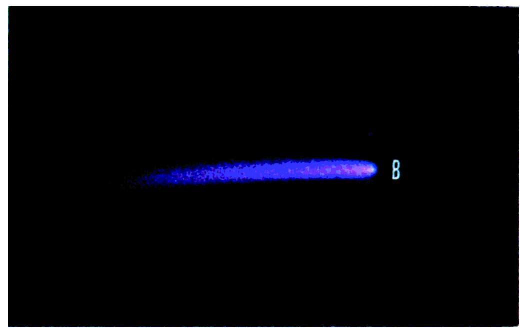


Side view

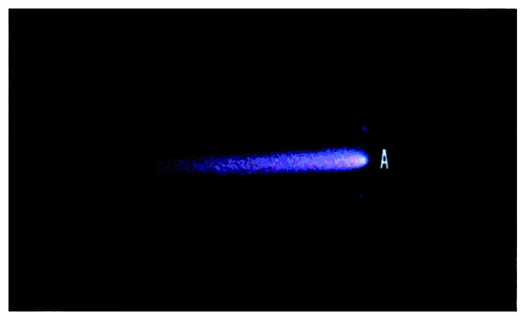
Fig. 9 Arrangement of needle electrodes.



a) Model observed from bottom side



b) Stream pattern starting from point A



c) Stream pattern starting from point B

Fig. 10 Visualized stream pattern near model surface, 10-deg angle of attack.

Visualization of Flow Pattern near Wall Surface

The flow patterns near the model surface are visualized utilizing the method for visualizing stream patterns near wall surfaces in hypersonic flow. The arrangement of the body and the needle anode electrode is shown in Fig. 9. The observing direction is also shown. Points A, B, and C indicate the positions of the tips of needle electrodes.

First, the experiments were conducted at 10-deg angle of attack. Figure 10a is the photograph of the model observed from the bottom side using a mirror. The visualized results are shown in Figs. 10b and 10c. The experimental results show that the two stream patterns starting from points A and B are almost parallel.

Second, the experiments were conducted at 30-deg angle of attack. The visualized results are shown in Figs. 11b–11d. Another experimental result observed from the side direction is shown in Fig. 12. The visualized results show that little crossflows are generated.

Discussion

The electric discharge method is one where the energy of an applied electric field is transformed into photons by generating inelastic collisions between the molecules and electrons. Therefore, very little temperature increase of the gas occurs by applying the electric field. The shock wave over a wedge visualized by the electric discharge method is shown in Fig. 13a. Figure 13b shows the shock wave over the wedge obtained by the schlieren method under the same conditions. The two shock shapes show very good agreement. From this result it is apparent that the disturbance of the flow by applying the electric field is negligible.

However, the intensity of radiation from the flowfield utilizing the electric discharge method is quite weak. Therefore, to observe the radiation using a camera, high-speed film is required. (Film speed used in these experiments was ASA 3200, and the aperture of the camera was *f*1.4.)

Conclusion

The flowfield around a model of the X-33 test vehicle in hypersonic flow was investigated by visualizing three-dimensional shock shapes around the body and stream patterns near the wall surface. These visualizations were carried out utilizing the electric discharge method. These visualized results can be useful in comparing and verifying the results obtained by theoretical and numerical methods.

References

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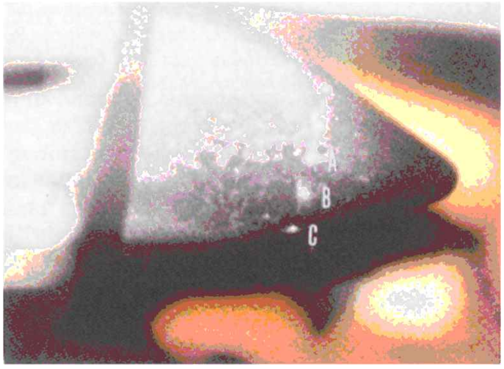
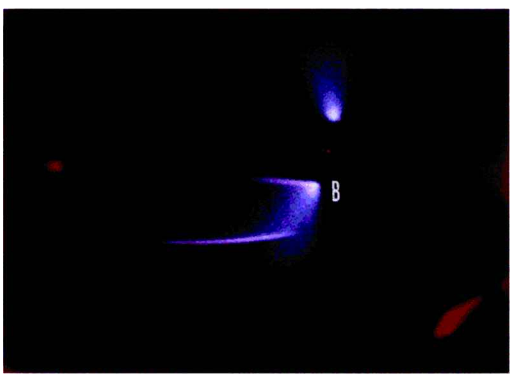
[4]Nishio, M., "Method for Visualizing Streamlines Around Hypersonic Vehicles by Using Electrical Discharge," *AIAA Journal*, Vol. 30, No. 6, 1992, pp. 1662, 1663.

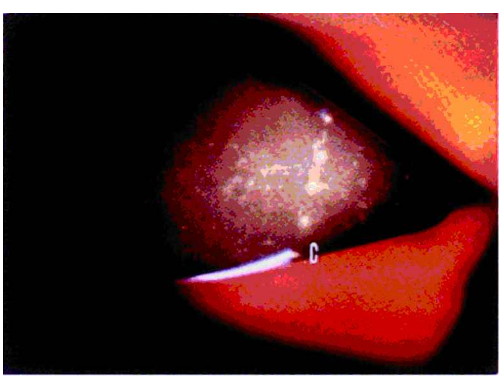


a) Model observed from bottom side

b) Stream pattern starting from point A



c) Stream pattern starting from point B



d) Stream pattern starting from point C

Fig. 11 Visualized stream pattern near model surface, 30-deg angle of attack.

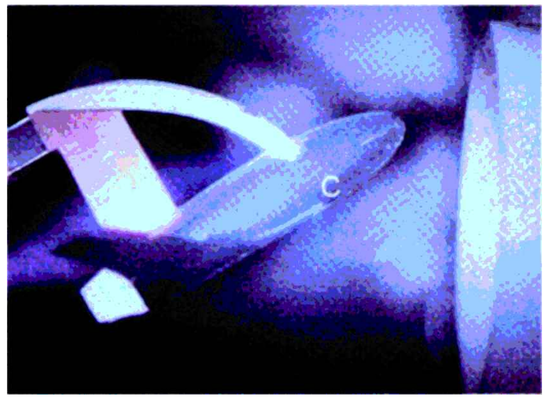
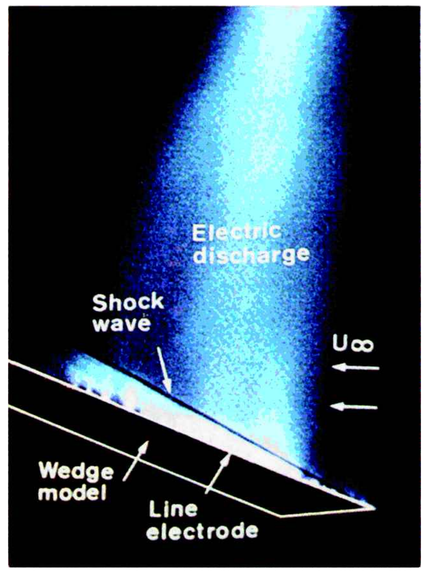
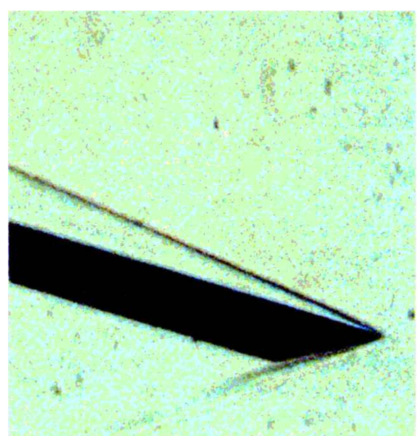


Fig. 12 Visualized stream pattern (from side), 30-deg angle of attack.



a) Shock shape obtained by electric discharge method



b) Shock shape obtained by schlieren method

Fig. 13 Shock shapes over wedge.

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