The memoirs of Faculty of Engineering
Fukuyama University
The 26th issue, Sep., 2002

Flowfield Around MUSES-C Superorbital Re-entry Capsule

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ABSTRACT

The spatial flow structure around a model of the MUSES-C capsule traveling at a speed of Mach 10 was investigated utilizing the electric discharge method. The shock shape ahead of the capsule was observed utilizing a technique for visualizing shock shapes, then the streamline following the shock wave was observed utilizing the technique for visualizing streamlines crossing a shock wave. Subsequently, the flow pattern including the re-circulation region such as a separation point, free shear layer, and rear stagnation location behind the capsule was observed utilizing a technique of the electric discharge method. These experiments have made clear the spatial flow structure before and behind the capsule, which had been very difficult to visualize.

Keywords: Re-entry, Visualization, Spatial flow structure, Streamline, and Electric discharge method

1. Introduction

In recent years, the mission for bringing back the sample of a celestial body to the earth is planed. At the ISAS (Institute of Space and Astronautical Science), Japan, the asteroid sample return mission is in development. This mission is called MUSES-C. The MUSES-C has been designed to bring back sample of asteroid's surface. In this mission, the MUSES-C capsule re-entries into the earth atmosphere at superorbital speed. Therefore, it is important to make clear the flowfield phenomena around the capsule. The visualization of the flowfield is very useful for making clear the flowfield phenomena. However, there were few techniques for visualizing the spatial flowfield around hypersonic vehicles until now.

In this study, the spatial flowfield around a model of MUSES-C capsule traveling at a speed of Mach 10 was investigated by utilizing the electric discharge method [1]-[5].

2. Experimental Equipment

Figure 1 shows a hypersonic gun tunnel used in these experiments. The freestream conditions are as follows: Mach number was 10, velocity was 1.5km/s, density was 4.5×10^{-3}kg/m^3, duration was 10ms, and unit Reynolds number was 1.7×10^6/m. The test gas was air. Figure.2 shows the electrical circuit for generating electric fields in the hypersonic flowfield. The circuit was designed so as to operate while the hypersonic flow was being obtained. The dimensions of a capsule used in these experiments are shown in Fig.3. This model similar to a MUSES-C capsule. Figure 4 shows the test section of the tunnel, including a capsule model, model supporting system, and hypersonic nozzle.

3. Shock wave Ahead of the Capsule

The shock shape ahead of the model was visualized using one technique of the electrical discharge method. Figure 5 shows the arrangement of the model and a pair of electrodes. The line electrode (anode) was bonded to

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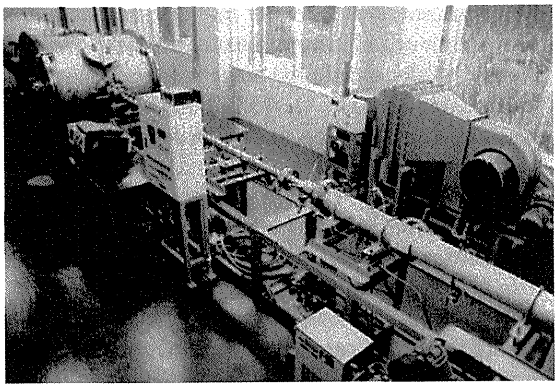


Fig.1 Hypersonic gun tunnel.

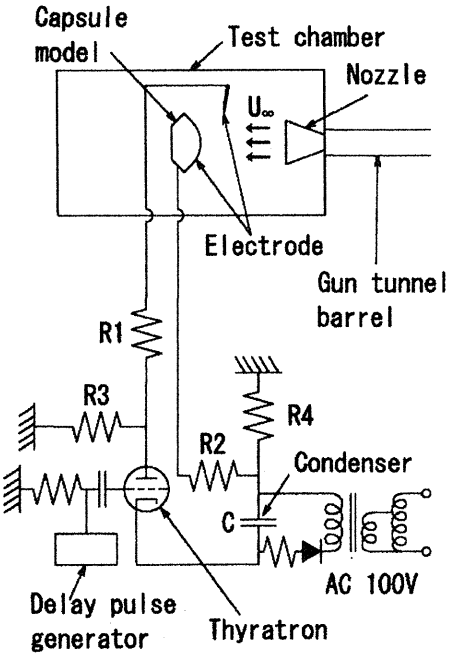


Fig.2 Electric circuit.

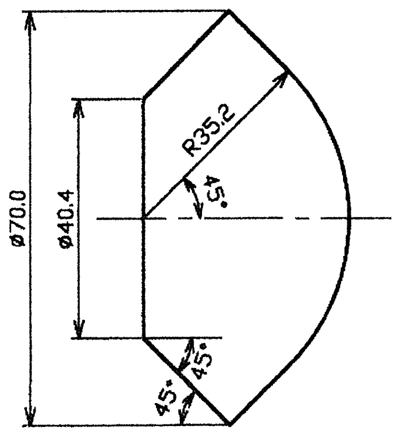


Fig.3 Model dimensions. (Unit: mm)

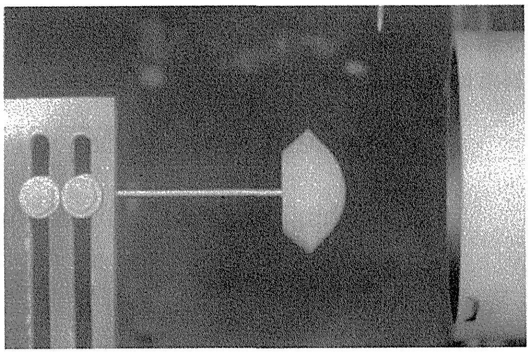


Fig.4 Test section of the tunnel.

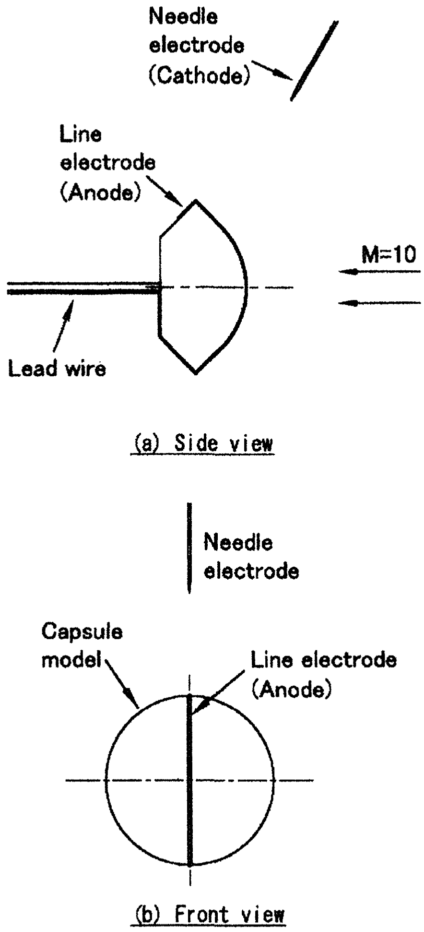


Fig.5 Arrangement of model and pair of electrodes.

the model surface, and another needle electrode (cathode) was installed in the freestream. A sheet shape electrical discharge path was generated between the electrodes applying a high voltage of 2kV. We visualized the shock shape by the radiation contrast at the shock position in the sheet shape electrical discharge path. Figure 6 shows the visualized shock shape ahead of the model. Furthermore, in order to examine the validity of the visualized result by the electrical discharge method, the

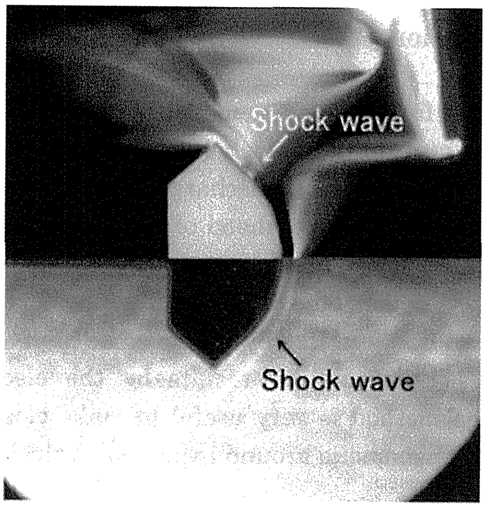


Fig.6 Shock shapes. Upper photograph is electric Discharge. Lower one is schlieren.

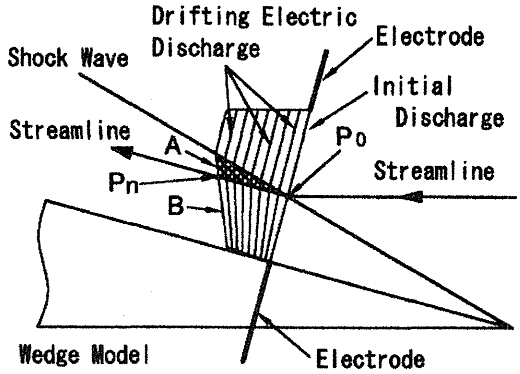


Fig.7 Illustration of visualizing principle for streamline after shock wave.

shock shape ahead of the model was visualized by the shlieren method. In figure 6, upper photograph shows the visualized shock shape by the electrical discharge method and lower one shows the visualized shock shape by the schlieren method in same condition. The comparison of the electrical discharge method and the schlieren method show good agreement for the shock standoff distance.

4. Streamline after Shock Wave

Figure 7 shows the illustration of visualizing principle for streamline after shock wave. The principle of the technique is as follows: 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 radiating light. In this case, the radiation intensities from the drifting columnar discharge are not equal throughout the columnar discharge. The radiation intensities of the drifting electric discharge change at the position Po, as illustrated in Fig.7, on the streamline where the streamline passes through the intersection of the shock wave and initial spark discharge. Thus, the streamline can be seen by taking a photograph of the continuous drifting columnar discharge.

In order to examine the validity of this visualizing method the experiment was carried out. A high-speed camera was used in this experiment. The exposure and delay were 1 μ s and 4 μ s, respectively. Figure 8 shows

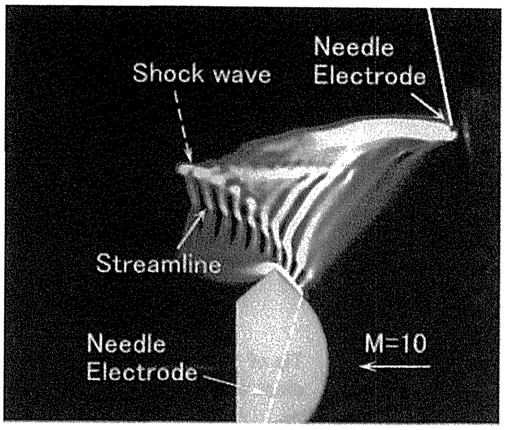
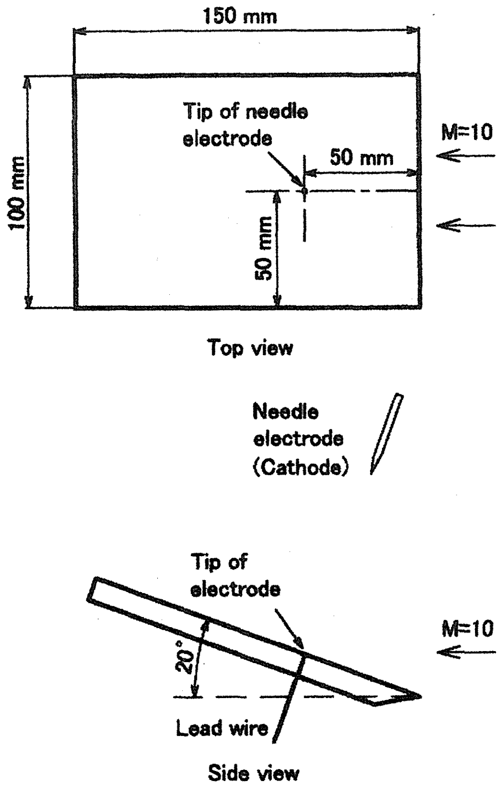
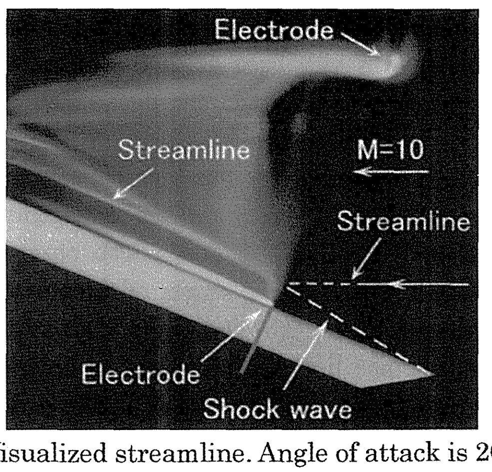


Fig.8 Visualized streamline used high-speed camera. (Exposure: 1 μ s, Delay: 4 μ s)

the visualized result. In Fig.8 the photograph of a drifting electric discharge was taken. The exceptionally light part exists in the drifting electric discharge as shown in Fig.8. We considered this part indicates the position of the streamline described at the visualizing principle. The streamline was visualized according to the visualizing principle. From this result, the distribution of velocity vector can be visualized. Furthermore, the validity of visualized streamline by this visualizing principle was examined. Figure 9(a) shows the arrangement of the model and a pair of electrodes. The observation was performed by leaving the shutter of camera open in this experiment. Figure 9(b) shows the visualized result. In the figure, one line was visualized as described at the visualizing principle. This line is almost parallel to the model surface. From this result, we considered the line in the electric discharge indicates a streamline. The streamline after shock wave around the capsule was visualized by applying the above technique. Figure 10 shows the arrangement of capsule model and a pair of electrodes. In order to visualize several streamlines after shock wave the two electrodes are moved to the suitable positions. Figures 11(a)-(d) show the visualized streamline, respectively. We drew a sketch of flowfield around the MUSES-C capsule traveling at Mach 10 obtained by the results of Fig.6 and Fig.11(a)-(d). The illustration is shown in Fig.12.



(a) The arrangement of wedge model and a pair of electrodes.



(b) Visualized streamline. Angle of attack is 20° .

Fig.9 Visualization of streamline over wedge.

5. Conclusion

The flowfield around a model of the MUSES-C traveling at a speed of Mach 10 was investigated by utilizing the electrical discharge method. In this study, the shock shape ahead of the model and the streamline after shock wave were visualized spatially. Furthermore, the distribution of velocity vector can be visualized by utilizing the high- speed camera. The visualized results by the electrical discharge method is very useful to make clear the flowfield phenomena around hypersonic vehicles.

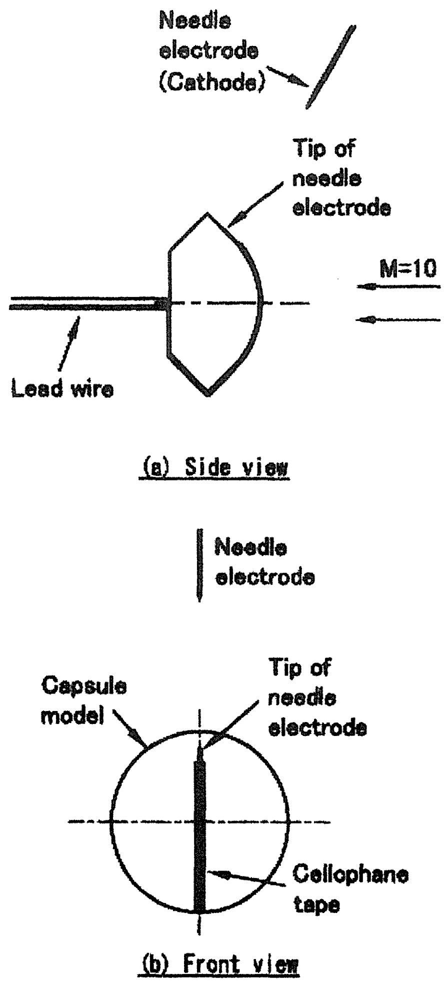
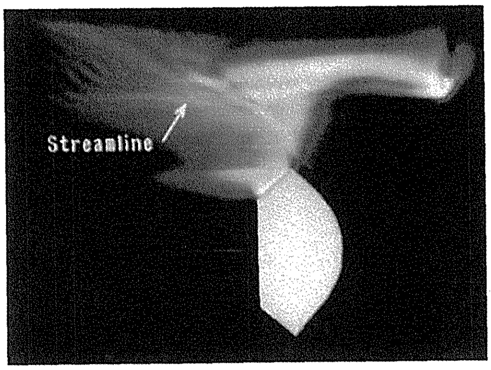
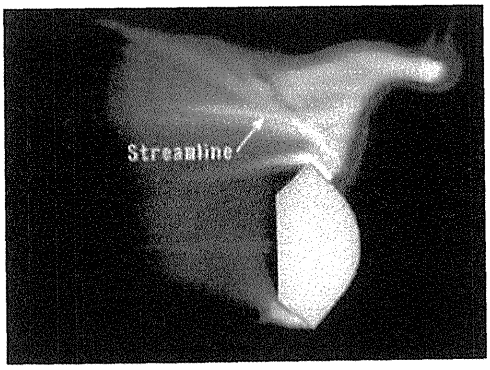


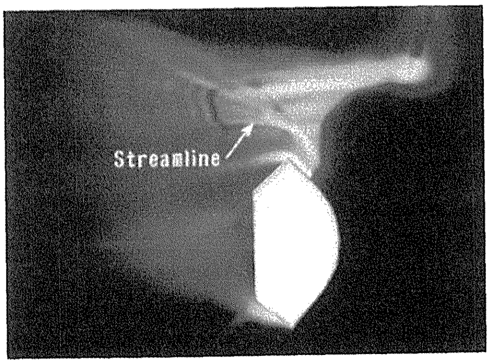
Fig.10 Arrangement of model and a pair of electrodes.



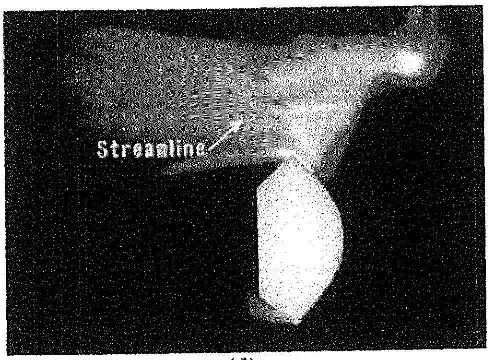
(a)



(b)



(c)



(d)

Fig.11 Visualized streamline after shock waves. The locations of streamline are different, respectively.

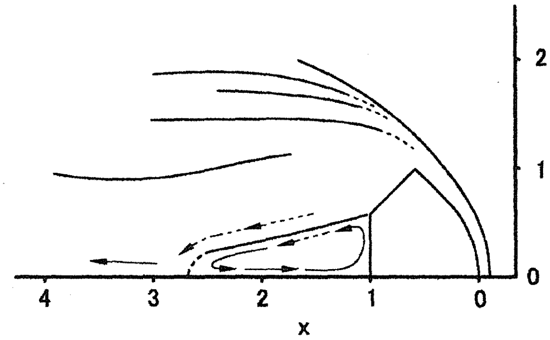


Fig.12 Sketch of streamline around capsule obtained by the results.

References

[1] Nishio, M., "New method for Visualizing Three-Dimensional Shock Shapes Around Hypersonic Vehicles Using an Electric Discharges," 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.2246-2248.

[3] Nishio, M., "Methods for Visualizing Hypersonic Shock-Wave/Boundary-Layer Interaction Using Electric Discharges," AIAA Journal, Vol.34, No.7, 1996, pp.1464-1467.

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

[5] Nishio, M., and Hagiwara, T., "Hypersonic Flowfield Analysis of X-33 Model with the Electric Discharge Method," Journal of Spacecraft and Rockets, Vol.36, No.6, 1999, pp.784-787.