

A new technique for visualization of shock shapes in hypersonic shock tunnel

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Based on the principle of dependence of the intensity and the spectrum of the spontaneous light emitted in an electrical discharge on the density and the temperature of the gas along the discharge path, a technique for flow visualization around the bodies flying at hypersonic Mach number is developed. The shock shapes over a flat plate with sharp leading edge at different angles of attack are visualized using this technique in IISc hypersonic shock tunnel HST1 at flow Mach number of 5.75. The visualized shock wave angles match very well with the theoretical values. The details of this new technique along with a few sample results are presented here.

THE flowfields around hypersonic vehicles are very complex and measurement of these flowfields is important for their understanding. The flow visualization is

conventionally achieved by employing optical systems, such as the schlieren method, interferometry, shadowgraphs and holography. Except holography, none of the other systems is useful for three-dimensional shock wave visualization because the visualization in these systems is achieved by passing the light along the optical axes perpendicular to the direction of the gradient of the gas density. On the other hand, the holographic technique is very sensitive to mechanical vibrations and hence is very difficult to use for the flow visualization in the wind tunnel tests.

A simpler technique based on the electrical discharge for the visualization of three-dimensional shock shapes around hypersonic vehicles has been reported recently. This technique is based on the principle that the intensity of spontaneous radiation emitted by the ion recombination in an electrical discharge depends on the gas density along the discharge path². In this method when an electrical discharge is generated across a shock wave, the light emitted from the shock wave region will be very weak compared to that from the freestream and the shock layer. As a result, the shock shape appears as a dark line in the intensity field. However, the electrical discharge technique has been developed for the flow visualization in a hypersonic wind tunnel where the test time is above 10 milliseconds. In this paper we report a

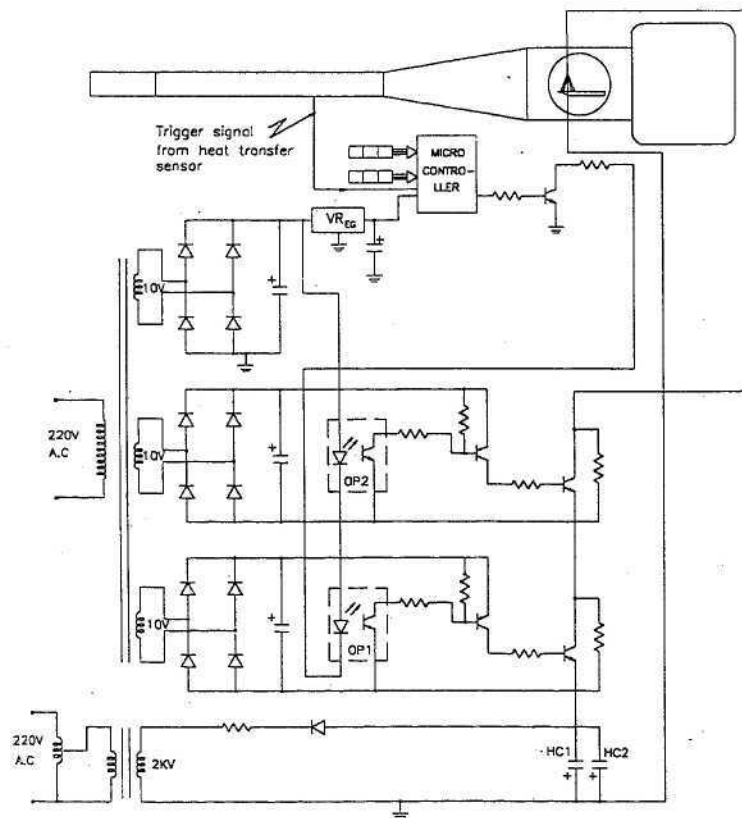


Figure 1. Schematic diagram of a hypersonic shock tunnel with the circuit diagram for the generation of electrical discharge of 2 μ s duration across the pair of electrodes inside the test section.

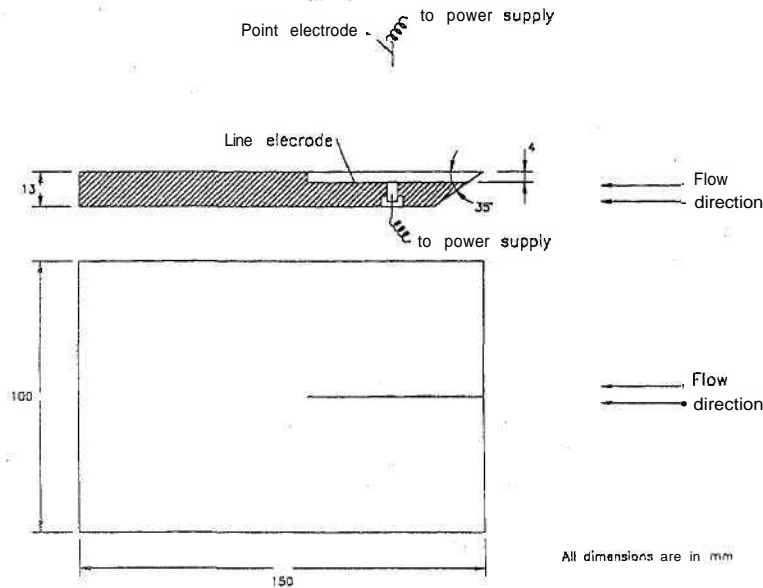


Figure 2. Arrangement of point and line electrodes for the visualization of shock shapes around the flat plate model.

new electrical discharge technique for the visualization of flow in hypersonic shock tunnel where the test time is less than a millisecond. The shock shapes around a flat plate with a sharp leading edge at flow Mach number 5.75 are visualized using this technique in IISc hypersonic shock tunnel HST1. The measured shock angles match very well with the predicted values at various angles of attack.

A schematic diagram of the IISc hypersonic shock tunnel HST1 along with the electrical circuit for the generation of the electrical discharge across the test model is shown in Figure 1. Freestream Mach numbers up to 13 can be generated in this tunnel using a nozzle with appropriate area ratio. A conical nozzle with an exit diameter of 30 cm expands the flow into a 45 cm long test section of 30 cm x 30 cm area. Two optically clean windows are provided for photographing the discharge phenomenon in the test section.

The electrical discharge is generated across a point electrode and a line electrode. The point electrode of 1 mm dia is suspended in the freestream inside the test section while the line electrode made out of a 0.5 mm thick copper strip is embedded in the test model such that one of its edges is flush with the top surface of the model. The electrodes are kept about 60 mm apart. The test model is made out of bakelite material to ensure insulation of the rest of the tunnel from high voltages and also to avoid multiple reflections from the model surface. The details of the flat plate and the electrode arrangement are shown in Figure 2.

The details of the electrical discharge circuit developed for the purpose of generating discharge between

the electrodes are shown in Figure 1. Since it is critical to ensure the occurrence of the discharge after the flow attains steady state in the test section, a circuit is built for delaying the occurrence of the discharge after receiving the trigger signal with a facility to limit the discharge duration. The trigger signal for the circuit is obtained from a platinum thin film sensor located towards the end of the shock tube mounted flush with the inner surface of the driven section. The sensor generates an electrical pulse corresponding to the rise in temperature due to the arrival of the shock wave. This pulse becomes an input signal to the microcontroller encompassing an 8 bit 8031 microprocessor, a 2764 EPROM and a couple of digital switches. This controller has facility for adjusting a delay and the pulse duration. The delay is carefully adjusted such that the electrical discharge is generated after the nozzle starting process is complete and a steady flow is established in the test section. The delayed signal acts on two optical couplers OP_1 and OP_2 , which have an integrated LED and a phototransistor. When activated, the light from the LEDs is sensed by the phototransistors and the photocurrent generated from these diodes will switch on the high voltage transistors BU 205s connected in parallel. This closes the electrical circuit and the high voltage is applied between the pair of electrodes by electrical charge stored in the condensers HC_1 and HC_2 which generates the discharge. After the time lapse set by the pulse duration the microcontroller sends an interrupt signal which will turn off the high power transistors and break the continuity of the electrical circuit terminating the electrical discharge.

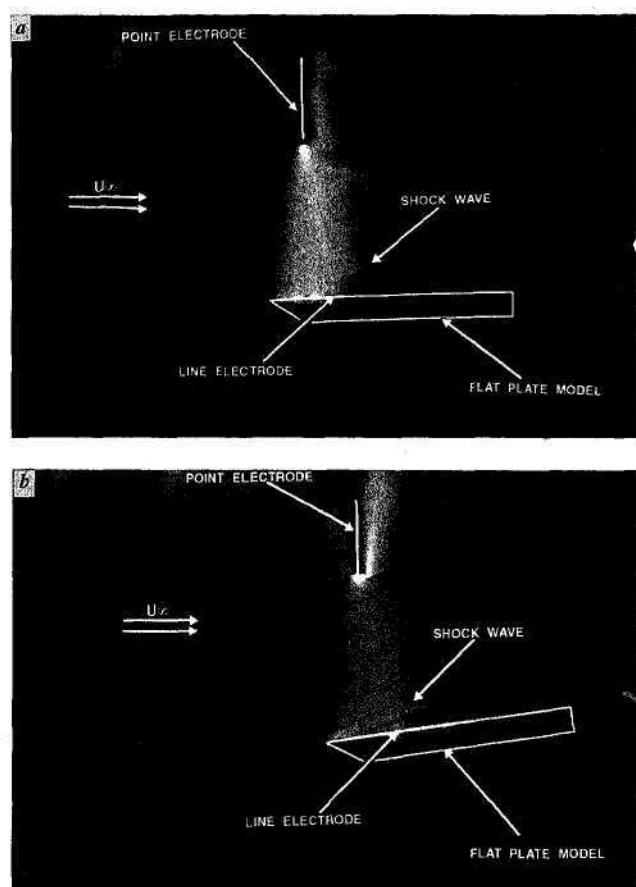


Figure 3a, b. The shock waves over a flat plate with a sharp leading edge inclined at (a) 5° and (b) 6° to the flow direction inside the test section of the HST1 tunnel at Mach number 5.75.

The experiments were conducted with the following test conditions: flow Mach number = 5.75, Reynolds number = $1 \times 10^5 \text{ m}^{-1}$, freestream density = $1 \times 10^{-2} \text{ kg/m}^3$, duration of the steady flow $\sim 800 \mu\text{s}$, freestream temperature = 173 K and freestream static pressure = $9.9 \times 10^{-3} \text{ mbar}$. In these experiments the point electrode was used as the anode and the line electrode was used as cathode. The voltage applied across the electrodes was about 1500 V and the electric current was set at 1 A. The discharge in the test section was photographed from outside the side window using a Nikon FM 2.8 camera with B exposure. A film with ASA 1600 speed was used for recording the weak light emitted from the discharge field. Some of the photographs were taken at film speeds of ASA 3200 and ASA 6400 by using the push processing technique in order to record the spectral variation of the light emitted from the temperature layer. However these preliminary experiments did not reveal the temperature layer because the temperature in this layer will be very low for the flat plate with a sharp lead-

ing edge. Currently the efforts are being made to study the temperature layer with a blunt nose cone model.

Typical results of the shock shape visualization are shown in Figure 3a and b for the flat plate at 5 and 6 degrees angle of attack, respectively. Unlike the dark line representing the position of the shock wave in the long-duration tunnels¹, the shock position in these figures is indicated by the bright line. The bright portion at the shock wave occurs in this case because the experimental conditions are suitable to make the electron energy at the shock wave equal to about 20 eV (ref. 3). The measured shock wave angles of 13° and 14° match very well with those theoretically estimated using oblique shock relationship⁴ for both the cases.

In conclusion, we have demonstrated a new technique for the visualization of the shock shapes around the hypersonic vehicles tested in hypersonic shock tunnel. This method is novel as it suits application in the shock tunnel where the typical test times are less than a millisecond. The measured shock angles for a flat plate with sharp leading edge at an angle of attack tested at flow Mach number 5.75 in IISc shock tunnel HST1 match very well with the theoretical results. This technique can be utilized for visualizing the three-dimensional shock shapes by taking the photograph of the electrical discharge either in the downstream or upstream direction of the flow.

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Received 13 June 1996; accepted 2 July 1996.

Steric enhancement of resonance: An electron localization perspective

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Steric enhancement of resonance (SER) has earlier been characterized in terms of molecular properties such as dipole moment, bathochromic shift, mesomeric moment, spin-spin coupling constant or by monitoring the kinetics of a reaction. The present work provides a unified picture of SER in terms of the electron localization patterns in a molecule.

THE phenomenon of steric hindrance of resonance (SHR) has been well documented¹ in the organic chem-