Abstract. The influence of energy excited media on Mach configuration arising at shock wave reflection in air from an inclined plane surface is considered. The experimental results are received in an electro-discharge section of a shock tube. With the help of the shadow device TE - 19 were observed schlieren pictures of process of shock wave reflection from a wedge placed in the discharge section. The pictures of flow were registered by means of the high-speed camera FK-4 or by one frame camera using a spark light source. The features of shock reflection are registered in gas discharge region.

Introduction

The problem of influence of the energy-excited regions on gasdynamical processes, namely a supersonic flow around bodies and flow with high speed reactions in a scramjet, attracts attention of the researchers both theorists [1-4], and experimenters [4-7]. In some cases the energy-excited region is caused by the gas discharge in a limited area. In this case it is plasma formation, namely low-temperature nonequilibrium plasma. The large number of types of the gas discharge causes numerous interactions between plasmas and gas flows. The variability of interaction also follows from a change of parameters of the non-stationary discharges. In turn it expands possible application of the studied phenomenon in perspective technological processes.

In the given work non-stationary irregular reflection of plane shock waves in air from a plane, inclined, non-conducting surface experimentally was investigated at the presence of plasma formation. It was the pulse gas discharge near reflecting surface. The research is carried out in a shock tube.

Experimental installation

Fig.1. shows the experimental arrangement. Here HPC - high pressure chamber (length 1.7m), LPC - low pressure chamber (length 7 m). In contrast with the conventional shock tube the given tube contains a quick-opening pneumatic valve VV, separating LPC from HPC. The opening time of the valve is about 1msec. The chamber of low pressure LPC has variable cross-sections, near the valve it is round by a diameter of 98mm. Length of this part LPC is 4.7m, further it is square (98×98mm) having length 2.3m.

The experiments are carried out in air at initial pressure in LPC in an interval 4.6-13.8Torr. (613-1840Pa). The shock wave velocity is measured by means of a number of piezogauges located along the shock tube. The Mach numbers of incident shock waves were in the interval 1.9-2.2. At the end of the low pressure chamber the electro-discharge experimental section ES from acrylic plastic of the length 400mm and of the cross-section of 72×72mm was placed. The transition from the shock tube cross-section (98×98 mm) to a cross-section of the experimental section was realized with the help of rather long knives at the end of LPC. These knives are cutting out the appropriate part of an incident shock front. The experimental section had on the top and bottom walls 11 copper electrodes parallel to the incident shock front. The dimension of electrodes was of 10×70mm. The lateral walls of the experimental section had windows with optical glasses by a diameter of 180mm in a field of sight of the shadow device TE - 19. In the section the dielectric wedge was mounted with a top angle β=45°. The wedge also had in the central part of a reflecting surface 7 copper electrodes having a diameter of 4mm which were located in a line parallel to a leading edge of a wedge. The block diagram of installation is presented on Fig.2. Here 1 - shock tube, 2 - experimental section, in which three-shock configuration is shown. Piezogauges 3 are used for synchronization of installation with the passage of a shock wave and measurement of shock wave velocity by means of complex 4 (frequency meters, digital oscillographs). The visualization of process of interaction was carried out with the help of the shadow device TE - 19 (5 - collimator, 6 - receiver part) with a diameter of a light beam of 150 mm.
For triggering of the recording equipment, light source of visualization system and gas discharge, the control block 7 was used which was in turn started either from piezogauge, or from a system including the photoreceiver 8 and continuous He-Ne lasers 9. The beam of this laser passed through the glasses of experimental section near to the region of interaction of a shock wave with a reflecting wedge surface. It raised accuracy and reliability of synchronization at small initial pressure in LPC, when piezogauge operation is not stable.

As a light source 10 was used either a spark with duration of a luminescence 0.5 μsec or a pulse lamp with adjustable duration of a luminescence 200-800μsec. In the first case the spark was realized by the discharge of capacity 1.6 nF, charged from the power supply 11 up to a voltage 15 kV. The photoregistration of flow in this case was made with the help of the one frame camera 14 for more detailed consideration of a picture of interaction. In the second case the pulse lamp with the power supply 12 and a block of control of duration of lamp operation 13 was used with the high-speed camera FK-4. This camera 15 allows to receive 50 frames size of 16×22mm with frequency up to 200000 frames/sec or 156 frames (size 7.5×10.5mm) with frequency up to 600000 frames/sec.

The gas discharge in experimental section was realized for 100-500 μsec before arrival of a shock wave with a charge integrator block 16, containing capacity 0.075-0.150μf charged up to a voltage 8-14kV and triggering block 17. A current in a circuit of the gas discharge and gas discharge voltage were registered by oscillograph 18.

Example of schlieren picture of irregular reflection of a shock wave with Mach number $M = 2.1$ from a wedge in absence of the gas discharge is given on Fig.3. The picture is obtained with the spark light source. Here we see a typical picture of reflection of a shock wave of moderate intensity from a wedge with a wedge apex angle $\theta = 45^\circ$. The schematic of triplee-shock configuration and

**Fig.2.** The schematic of experimental installation.

1, 2 - block of a shock tube; 3, 4 - block of measurement of shock wave velocity; 5, 6 - shadow device; 3, 7, 8, 9 - block of synchronization and triggering of a light source, gas discharge and equipment; 10, 11, 12, 13 - block of a light source; 14, 15 - block of photoregistration; 16, 17, 18 - block of the pulse gas discharge.
electrodes position are given on Fig.4. Here OL - bottom wall of experimental section, LOM - wedge with apex angle $\beta=45^\circ$, OM - reflecting surface of a wedge, IS - the nonperturbated part of an incident shock wave propagating from left to right, RS - reflected shock wave, SM - Mach stem, ST - contact surface, OS - trajectory of a triple-point S, $\chi$ - angle of inclination of triple-point trajectory to a reflecting surface.

**Fig.3.** Schlieren picture of shock wave Mach reflection at $\beta=45^\circ$ wedge without the gas discharge. (plasma off)

From the moment of arrival of an incident shock wave to the wedge apex the Mach configuration grows self-similarly [8], and the triple point S goes within the limits of a window of visualization on a rectilinear trajectory OS.

**Fig.4.** The schematic of a triple-shock configuration and electrodes position

The pulse gas discharge in experimental section was realized with various arrangements of electrodes. The position of electrodes, used in experiments, also is shown on Fig.4:

a) Discharge between electrode A (anode) on the central part of the wedge surface and B (cathode) on the top wall of the channel;
b) The discharge along the bottom half of the wedge surface from the center of the reflecting wedge surface (A – anode) to the wedge apex (O - cathode);
c) Discharge along all reflecting wedge surface. Anode is on the top wall of the chamber near to wedge (C), cathode is on the bottom wall of the chamber close to the wedge apex (O - cathode).

**Results**

The study have been carried out at three various configurations of a discharge interval. The experiments have shown the following.

New characteristic parameters of Mach configuration at the discharge and electrode position such as: a) are not revealed, schlieren pictures of shock wave reflection in this case have shown that the character of reflection does not differ from a picture of shock reflection at absence of the gas discharge, shown on Fig.3.

For arrangement of electrodes such as b) and c) with the discharge along the wedge surface was observed a change of character of reflection of a shock wave at initial pressure in LPC 13.8Torr.

On Fig.5 the picture of reflection of a shock wave with Mach number $M=2.2$ is given at initial pressure 13.8Torr, voltage 12kV and capacity 0.075 $\mu$F. Here we see that before the shock wave on the surface of the wedge the perturbation propagates with velocity corresponding to Mach number $M=5$. The wave - precursor proceeds from this perturbation. The inclination of this wave to its direction of propagation corresponds to pressure close to this behind the incident shock wave.

**Fig.5.** A schlieren-photo of a shock wave reflection at the presence of a gas discharge plasma along the wedge surface. Before the shock wave the precursor is seen.
Such wave close to a surface is possible either at a separation of a boundary layer in a gas flow or at presence of a jet along a surface in immovable gas in our case. This character of flow results in replacement of pressure jump on Mach stem on smoother rise of pressure from initial value up to pressure behind the reflected shock wave. As it is visible from Toepler-pictures the wave-precursor interacts with the incident shock wave by a regular mode and is ahead of the reflected shock wave. Character of flow in a vicinity of interaction of the precursor and the incident wave is difficult to reveal because of the presence of Mach configuration. It is caused by the fact that the discharge does not cover all surface of the wedge. The limitation of the discharge along the direction of shock propagation (variant $AO$ arrangements of electrodes) is accompanied by deceleration of the front point of the precursor at an exit from area of the discharge.

However behind the incident wave the precursor is still ahead of the reflected wave. It is visible on the schlieren picture of the shock wave reflection at the presence of the discharge on Fig.6. Later the reflected wave and the precursor should merge, and the character of reflection in this case should be the same, as well as in the absence of the discharge.

![Fig.6. Mach reflection of shock wave M=2.4 at the presence of the gas discharge on the bottom half of the wedge surface, $p=13.9$Torr, $V=12kV$, time of the discharge – 100 μsec.](image)

However such character of flow was observed not in all experiences with the discharge. It is caused by the fact that the discharge is reproduced not always by the same mode. Sometimes, it represents a type of the glow discharge, but however occupies only a part of the wedge surface or even is turned to filamentary discharge. It complicates an estimation of the energy input on the unit of volume or the unit of gas mass. In some cases the fast transition from one type of discharge to another and backwards is observed. It corresponds to a change of a voltage on a discharge interval from 125V up to 250V and backwards (at a capacitor voltage - 12kV). On Fig.7 the change in time of a current (top oscillogram) in the gas discharge and voltage on a discharge interval (bottom oscillogram) is shown.

![Fig.7. Oscillograms of the discharge in air at pressure 13.8Torr, the initial capacitor voltage - 12kV, display - 50μsec/div, top - electrical current in the discharge (625μA/div), bottom - voltage on a discharge interval (180V/div).](image)

The first 50μsec are excluded from data processing. It is seen on the oscillogram of the voltage the spasmodic short-time pulses of the voltage, almost two times exceeding the general courses of the voltage. These jumps further become more long-time, the value of the voltage then is close to a voltage in the normal glow discharge. Such change of the voltage apparently is connected to instability of the discharge and transition from a filamentary discharge to the normal glow one and backwards.

**Conclusion**

Thus it is possible to make a conclusion that environment(Wednesday) (in this case created by the pulse gas discharge) is capable to change character of influence of a shock wave to a reflecting surface realization of experiments with independent visualization of the discharge, diagnostics of the discharge by spectral methods and change of a configuration of a digit interval. Subsequently is planned, with the purpose of exception possible(probable) breakdown for a metal-design of a shock pipe.

From here it is possible to make a conclusion, that the energy-excited media (in this case created by the pulse gas discharge) is capable to change the character of influence of a shock
wave to a reflecting surface. The realization of experiments with independent visualization of the discharge, diagnostics of the discharge by spectral methods and change of a configuration of the discharge interval is planned.

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References