Plasma Control of Supersonic Body Streamline

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A possibility to control the shock wave configuration by plasma methods is reported. In particular, the effects of nonequilibrium plasma action on the position of a bow shock wave arising due to supersonic streamlining of a half-cylindrical body by ionized xenon flow are considered. A nonequilibrium plasma flow was created by special gas discharge before the body. Discharge parameters were chosen so that to increase electron temperature but to minimize Joule heating of the gas. It has been shown that a change in the bow shock wave position depends on the degree of plasma nonequilibrium that is ratio of the electron temperature to the temperature of heavy component. Flow nonequilibrium degree was changed by means of gas discharge current changes.

This work is a continuation of the series of works [1-2] concerned with possibility to control the shock-wave configuration by non-mechanical methods. A plasma action on supersonic flow structure resulting from features of supersonic flows of highly nonequilibrium plasmas is considered. The aim of this work was to show the possibility of position control of the bow shock-wave arising due to supersonic streamlining of a half-cylindrical body by a highly nonequilibrium plasma flow created by means of gas discharge before the body. The main task of the work was to investigate how the bow shock wave position changes at a change of the nonequilibrium degree of incoming flow, i.e., at a change of the ratio between electron and gas temperatures T_e/T_h.

Experiments were conducted at the setup based on a shock tube. Figure 1 shows a scheme of the gasdynamic range. A working chamber in the form of a supersonic nozzle with the walls inclined at 11^0 to the axis was connected to the butt end of a low-pressure chamber. A set of copper electrodes was mounted into the upper and lower nozzle walls. At a distance of 20 cm from the nozzle entrance, at its axis, a body in the form of a half-cylinder was placed. The radius of the cylindrical part was 1.5 cm and the total length of the body was 3.8 cm. The body was placed in such a manner that the flow passed through the region of three pairs of electrodes before it reached the body. Xenon was used as a working gas. Homogeneous flow of ionized xenon with duration about 600 mks was created in the nozzle. Flow visualization was realized by means of a schlieren system with light source in the form of a semiconductor laser with pulse duration about 20 ns. Schlieren pictures were recorded directly to the digital photo camera Canon EOS 300D matrix. From schlieren pictures of the flow the distance d along the nozzle axis between bow shock wave and the body's nose part was determined. The effect of organized flow conditions on bow shock wave shift from the initial position without any action d_0 was investigated.

To create nonequilibrium ionization during the established stationary flow in the area before the body the gas discharge was switched on by means of a voltage pulse supplied to the top and bottom electrodes of the working chamber from the specially developed thyratron scheme. The primary goal of gas discharge was to increase the electron temperature of the gas, but to minimize gas heating. Duration of the discharge and discharge current were chosen such that gas heating was no more than 5-7 % of the flow kinetic energy. In this case the main task was to show a possibility of the plasma action (not heating) by minimizing the heat effect of the gas discharge. The change in the bow shock position was investigated as a function of nonequilibrium degree. Different temperature regimes of the incoming flow were created by means of different gas discharge currents. The electron temperature was evaluated by the Unsold-Kramers method [3, 4] for which a drop in the xenon luminosity in the ultraviolet region of the continuous spectrum was measured in experiments at different gas discharge intensities [2]. Gas temperature was determined from two dimensions calculation of the flow parameters in nozzle by Euler equations.

Figure 1a,b,c shows schlieren pictures of the flow for different nonequilibrium degrees of the incoming flow. For illustration purposes all pictures in the bottom part are combined with the schlieren photo of the flow in the absence of any action. It is seen that as electron temperature of incoming flow increases, the distance between the bow shock wave and body *d* also increases. The voltage-current characteristics were obtained in experiments that allowed us to determine the effective plasma conductivity. Figure 2a shows the graph of the electron temperature versus plasma conductivity. The electron temperature increases with increasing of plasma conductivity.

The experimental data are summarized in Figure 2b. Here a change in the relative bow shock-wave shift from the initial position (without any action) at increasing ratio between electron and gas temperature in the incoming flow is shown. The distance from the shock wave to the body increases with increasing nonequilibrium degree. Different colors and shapes of the points correspond to different widths of the discharge area in the flow. The width of discharge area is changed by changing the number of electrodes pairs connected to a power supply. It is interesting that the bow shock-wave shift depends only slightly on the discharge width. Irrespective of the number of connected electrodes, experimental points have no large scatter. From here it is possible to suppose that at such organization of the discharge, gas heating slightly affects the bow shock wave position, which strongly depends on nonequilibrium degree. The position of the bow shock-wave strongly changes at nonequilibrium degree T_e/T_h~5, and an increase in distance *d* in two times takes place as nonequilibrium degree increases in 1.8 times. Gas heating in this case does not exceed 4%. In streamlining by nonequilibrium plasma parameters of the body streamlining are defined by plasma parameters of incoming flow, which allows one to realize plasmadynamic control of the flow. The plasma method of action on a bow shock wave position is possible by creating the highly nonequilibrium ionization in an incoming flow. The shock wave position can be changed in a given value by changing nonequilibrium degree of the incoming flow.

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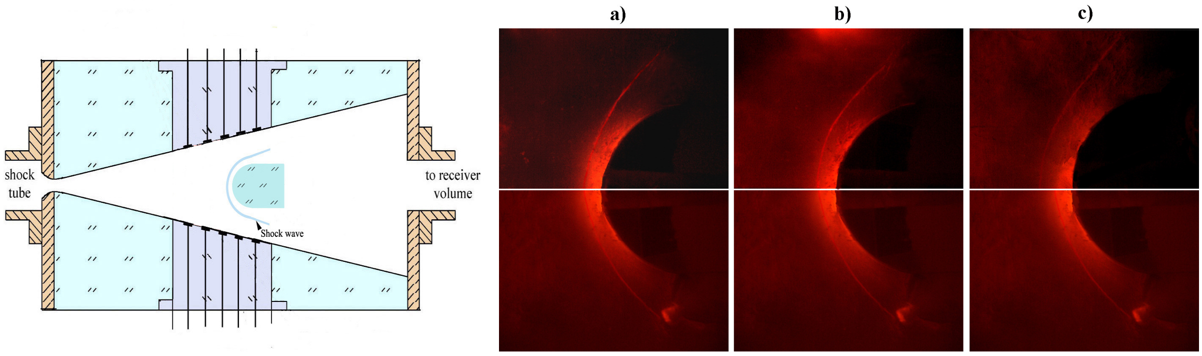

Fig. 1: Setup scheme. Schlieren flow pictures with different incoming flow parameters.
a) T_e=6600K, *d*=4 mm; b) T_e=7300K, *d*=4.3mm; c) T_e=7800K, *d*=6.9 mm.

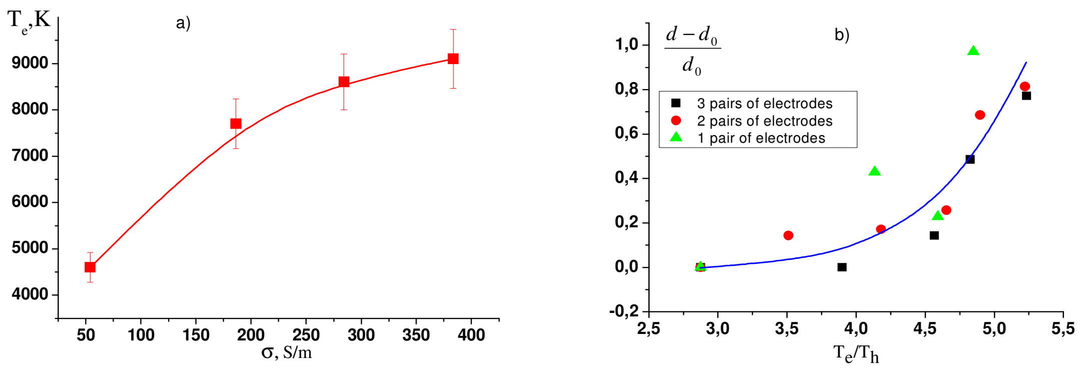

Fig. 2: a) Electron temperature vs plasma conductivity at gas discharge current increase.
b) Relative shift of bow shock wave from first position vs nonequilibrium parameter.

References

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