Magnetic and electric fields actions on supersonic body streamline in ionized flow

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This work is concerned with possibility to control the shock-wave configuration by non-mechanical methods. The three types of action on structure of supersonic flow around semicylindrical body were considered: a plasmogasdynamic (PGD) method coming from features of supersonic flows of highly nonequlibrium plasmas, electrogasdynamic (EGD) realized due to heating of a gas in gas discharges of high intensity, and magnetohydrodynamic (MHD) by action of Lorentz force appeared at organized in gas discharge electric current at transversal magnetic field. In the plasmogasdynamic control method a discharge creates a strongly nonequilibrium plasma in the flow before the body. In the EGD and MHD methods, a discharge was organized in the near surface area of the nose part of the body.

1. Introduction

The aim of this work is to show possibility to control position of the bow shock-wave arising due to supersonic streamlining of a semicylindrical body as by plasmogasdynamic (PGD) method (by creation a highly nonequlibrium plasma flow by gas discharge before the body), as by electrogasdynamic (EGD) method realized due to heating action, and magnetogidrodynemic (MHD) method realized due to Lorentz force action at surface discharge near the front edge of the model. The main task is to investigate how the bow shock-wave position change:

1. At change of nonequliubrium degree of incoming flow, i.e. at changing of a ratio between electron and gas temperatures T_e/T_h;
2. At increase of EGD parameter in surface gas discharge near nose part of the body, i.e. a ratio between heat of a gas in the discharge and kinetic energy of the flow $N = jE\Delta t / \rho u^2$;
3. At increase of MHD interaction in near surface region due to increase Stewart parameter, i.e. a ratio between work of Lorentz force and kinetic energy of the flow $St = jBL / \rho u^2$.

Where j is current density, E is electric field intensity, Δt is interaction time, B is magnetic induction, ρ and u are density and velocity of incoming flow, L is width of interaction zone.

2. Experiment arrangement

Experiments were conducted at the setup based on a shock tube [1,2]. A working chamber in the form of a supersonic nozzle was connected to the end of a low-pressure chamber. The semicylindrical body was placed in such a manner that the flow passed through the region of three pairs of electrodes mounted into the upper and lower walls before it reached the body. The set-up includes the systems of gas discharge and transversal magnetic field creation. Xenon was used as a working gas. It allows us to model PGD, EGD and MHD influence upon supersonic streamline of aircraft head parts without additional energy expenditures on ionization. From schlieren pictures of flow the distance d from bow shock wave to the body's nose part was determined and bow shock wave shift from first position d_0 without any action was investigated depending on organized flow conditions.

3. Plasmagasdynamics (PGD) action.

For creation of nonequilibrium ionization during the stationary flow in area before a body the gas discharge was switched on by an impulse of the voltage supplied to the top and bottom electrodes of the working chamber. The primary goal of gas discharge is to increase electron temperature, but to minimize gas heating. Different temperature regimes of incoming flow were created by different gas discharge intensity. Electron temperature was measured in experiments [2], gas temperature from calculations.

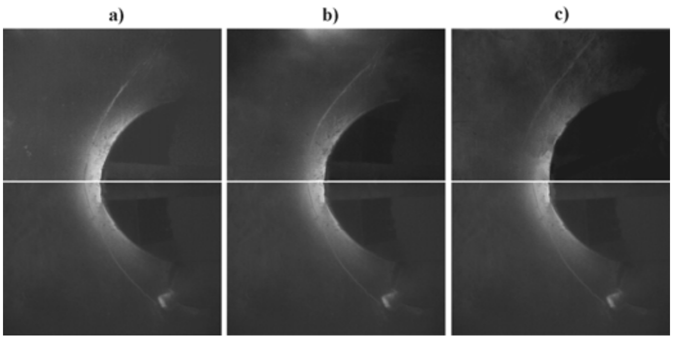

Fig.1.Schlieren flow pictures: a) T_e=6600K, j=2.5·10^{5}A/m^2; b) T_e=7300K, j=3.6·10^{5}A/m^2; c) T_e=7800K, j=4.4·10^5 A/m^2

Fig.1 shows schlieren pictures at different nonequlibrium degree of incoming flow. For illustration at bottom part of the picture a position at absence of gas discharge is shown. At increasing of electron temperature of incoming flow the distance between bow shock wave and body d also increases. On Fig. 2 change of bow shock-wave shift d-d_0 divided by distance without gas discharge d_0 at increase of nonequlibrium degree is shown. Different points correspond to different width of discharge area, which change by changing a number of electrodes to which voltage is applied.

Bow shock-wave shift poorly depends on width of area of the discharge. It means that gas heating slightly influence on shock wave position, and the shock shift occurs under the influence of the PGD effects due to increase of nonequilibrium ionization of plasma of the incoming flow.

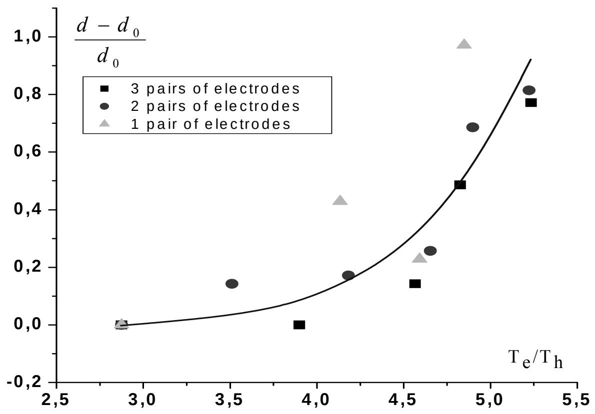

Fig.2. Relative bow shock wave shift vs nonequilibrium parameter.

4. Surface discharge near the front part of the model.

Gas discharge current embraces the nose part of the body by half-circle trajectory as shown on Fig.3. When orthogonal magnetic field is switched on Lorentz force acts on gas in direction from body (Connection 1).

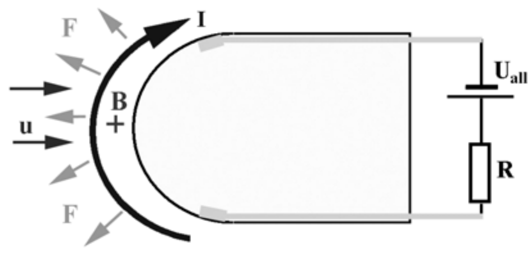

Fig. 3. Lorentz force action at near surface gas discharge.

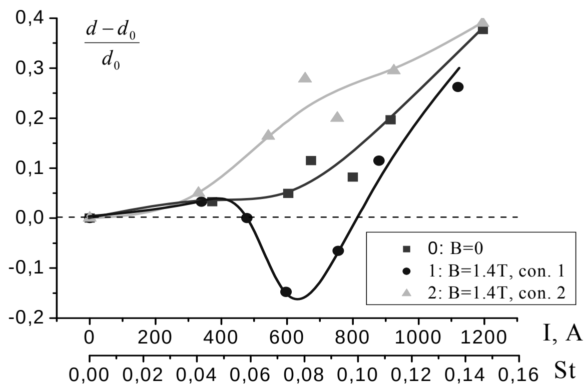

Figure 4. Relative bow shock wave shift at EGD and MHD action.

If current changes its direction to opposite one Lorentz force action has direction to body (Connection 2). If we change discharge current value and its direction we change intensity and direction of EGD and MHD action compressed or expensed the gas behind bow shock wave. In that way we can control bow shock wave position used the near surface discharge and external magnetic field.

On Fig. 4 there are changing curves of bow shock wave shift $d\text{-}d_0$ with EGD and MHD action in dependence from discharge current value and Stewart parameter. All data is normalized on bow shock wave position without any actions d_0. Curve 0 (squares) is obtained without magnetic field, only at EGD action. You can see increasing of distance from body to shock wave with current increasing. Curve 1 (circles) is obtained with magnetic field 1.4 T at near surface current from bottom to top (Connaction 1). At small current there is shock wave approaching to model, wave shift is negative. Then there is wave moving away from body with current increasing because the EGD action starts to dominate. Curve 2 (triangles) is MHD interaction at connection 2.

There is increasing of bow shock wave shift from body in compare with EGD action. At large-scale current value curves 0, 1 and 2 are near resemblance practically.

5. Conclusions

1. Plasmogasdynamic method of action on a bow shock wave is possible at creation of highly nonequlibrium ionized incoming flow. The nonequlibrium flow was created by gas discharge with minimum heat action on the gas in the area before the body. Shift of the bow shock wave depends on degree of plasma nonequlibrity and become substantial at $T_e/T_h=5$. By changing degree of nonequlibrity of the incoming flow it is possible to change shock-waves position.

2. The bow shock wave shifts is realized at electrogasdynamic method due to heat action of the gas discharge in near surface region in the nose part of the body behind bow shock wave. An increase of the distance between the shock wave and the body is the result of pressure increase behind shock due to strong heat of a gas in the discharge. By changing gas heating degree or parameter of EGD action N it is possible to change the bow shock-wave position.

3. At switching-on of external magnetic field orthogonal to the flow and near surface gas discharge it is possible to make magnetohydrodynamic control of the bow shock wave position. Lorentz force removes gas from model or presses gas to model, i.e. increase or decrease pressure behind bow shock wave in depends of current direction. By changing direction of Lorentz force and MHD interaction parameter St it is possible to change the bow shock-wave position as to move wave away from body as to approach it to body.

Acknowledgements

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