NON-STATIONARY SHOCK WAVE INTERACTION WITH SURFACE NANOSECOND DISCHARGES IN THE CHANNEL

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Abstract

Shock wave interaction with surface pulse discharge area was experimentally studied in shock tube. Nanosecond near wall discharges (plasma sheet, sliding on dielectric surface) were switched in test camera channel while shock wave was moving along the electrodes.

1 Introduction

A thin thermal layer near the channel wall influence on the plane shock is well studied (see, for example: Mirels 1988; Nemchinov et al. 1994). The thermal layer effect was discovered in the middle 50's in the course of nuclear tests. The effect shows itself as a growing precursor formation ahead of the blast wave, which causes a global change of the flow behind the shock. The precursor arises in the process of shock wave interaction with a thin layer of low density (thermal layer). The shock wave moves faster along the thermal layer and a large-scale vortex develops behind the oblique shock wave.

Nanosecond surface discharge interaction with plane shock wave in rectangular channel is complex non-stationary process. It includes shock interaction with

- shock waves initiated by surface discharge;
- non-stationary relaxing plasma heating layer.

2 Experimental setup.

The experiments were conducted in a shock tube with special discharge chamber. Shock tube channel and discharge section were of 48x24mm cross section. Gas pressures, electric current, shock wave velocity in the channel were measured. Two walls of the test chamber were quartz windows; the top and bottom walls were flat plasma surface discharges 100 mm long Areas of channel surface 100x32 mm were ionized by system of narrow channels (sliding surface discharges), forming plasma sheets. Discharge current time interval was 80-150ns. The initiation of the pulse discharge in a supersonic flow in the rectangular shock tube channel allows ionizing gas flow in short time interval The ionization time \( \tau \) (100 ns) is much less than characteristic times \( T \) of non-stationary gas dynamics interactions in a shock tube flow:

\[ \tau \ll T. \]

In time interval \( \tau \) changes in configuration of flow discontinuities and non-homogeneities do not occur. Initiating of the plasma sheets discharge in front of plane shock wave in a shock tube channel can be considered as instant surface ionization of a high speed gas flow.
Pressure and density in a homogeneous gas flow of air behind a plane shock wave was calculated using Rankine - Hugoniot relations:

\[
\frac{P_1}{P_0} = \frac{2M_0^2\gamma + \gamma + 1}{\gamma} + 1
\]

\[
\frac{\rho_1}{\rho_0} = \frac{M_0^2(\gamma + 1)}{(\gamma - 1)\gamma^2 + 2}
\]

Pulse surface discharges were switched through synchronization system at the time \(T=0\) when plane shock wave was moving in discharge gap. Image of ionized flow was recorded through quarts window (Fig.2).

**3 Results and discussion.**

The pulse discharge was initiated when shock wave was at distance \(x\) from the beginning of plasma surface discharge gap. Redistribution of plasma occurred in flow with plane shock wave. Discharge burned in low density area in front of shock wave (Fig.2). Zones of low pressure in front of shock wave on opposite walls wave were ionized (Fig. 1,2). At \(x=0,5\); \(M=3\) pressure jump on shock wave surface calculated using Rankine-Hugonio ratio was 10. Energy deposition in every surface was \(\sim 0.25\) J. Discharge plasma energy was transformed into radiation, disturbances, gas heating, and surfaces heating.

Shock wave at \(T>0\) moved through non-stationary, non-homogeneous area of disturbed near wall gas.

Let’s consider flow with a shock wave moving along a surface, to which the layer of the heated gas adjoins. It is known, that if temperature of a layer is not too great, the stationary flow with the curved front is formed. While a plane shock wave propagates near the channel wall over a heated layer of gas, the shock wave will refract and its velocity will increase. If temperature of a layer exceeds threshold, global reorganization of flow occurs: in front of shock wave precursor is formed. A precursor shock wave will form which goes before the original plane shock wave along the surface. A complicated vortex flow region develops under the precursor shock wave which can result in greatly enhanced dynamic pressure conditions. In the zone of interaction the vortex separation layer is formed, and the current becomes non-stationary.

Non-stationary gas flow structure was simulated with CFD. Numerical simulations of the flow were based on two-dimensional unsteady Navie-Stokes equations. High-resolution TVD (total variation diminishing) upwind, finite volume scheme [2] was used for numerical solution governing compressible Euler equations in conservation law form on structured 2D adaptive grids. The non-slip boundary conditions were used for solid wall boundaries and “non-reflecting” ones were used on open boundaries. Initial conditions for case \(M=3\) \(X=5\) cm are on Fig 3. Shock wave is in the middle of discharge gap. Low pressure gas zone and high pressure zone (pulse plasma layer is near wall) are in front of it.

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**Fig.2** Surface discharges switching in front of shock wave. Integral image.

**Fig.3** Initial conditions.

**Fig.4** Scheme of discontinuities interaction.
The conditions in the flow are the same as those in experiments. Evolution and stability of shock wave after pulse ionization of channel walls surface was studied.

Shock wave interaction with pulse surface discharge includes shock-shock interaction (with transversal shock wave caused by quick energy surface input); and shock interaction with non-equilibrium non-stationary nearwall layer. On shock interaction with transversal shock wave Mach configuration appears, later it is transformed to double Mach reflection (1, 2 on Fig.4).

Contact discontinuity curves and vortex is formed. Plane shock surface is deformed; in nearwall rarefied area it spreads quickly forward.

Fig. 5. Calculation of flow after instant energy deposition on channel wall in front of shock wave.

On Fig. 5 results of CFD simulations are presented. Temperature and pressure flowfield after shock interaction with expanding instantly ionized narrow layer near channel surface (at X=5cm; M=2). On calculated temperature and pressure profiles on wall there is significant nearwall gas heating in narrow zone of shock-shock interaction. Shock wave evolution depends on relative amount of energy deposition and enthalpy of flow behind shock wave (or Mach number). From this point of view two regimes of shock wave movement can be distinguished: along heated layer (small Mach numbers) and along rarefaction layer (big Mach numbers).

Conclusions.

Instant (nanosecond) homogeneous energy deposition in front of shock wave in thin layer on channel wall was realized experimentally. CFD simulation was made. Plasma sheet discharge (system of plasma discharges sliding on dielectric surface) burn in front of moving shock surface. Resulting shock configuration depends on relative amount of energy deposition and shock Mach number.

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References.


