Topic 4

Anomalous nonlinear effects in a weakly ionized gas exposed to a strong shock wave

J.V. Triaskin[1], V.A. Pavlov[1]

[1] *Physics Department, St. Petersburg State University, 1, Ulyanovskaya str., Petrodvorets, 198504, St. Petersburg, Russia*

The patterns of exposure of the charged components to a strong shock wave in weakly ionized non-isothermal gas have been studied. The assumption of the ion sound is used for the plasma component. Computer simulation is based on the hypothesis of neglecting the action of the charged component perturbations upon the neutral gas component. The strong anomalous nonlinear effects are taking place. Joint competitive action of nonlinearity, dispersion, and dissipation is shown in formation of specific plasma «condensations» and «rarefactions». In a narrow range of shock wave speeds, the anomalous relaxation of plasma oscillations occurs behind the front. Essentially, it appears in the total ambipolar entrainment of charged components by a shock wave. This effect is the possible a result of strong nonlinear resonant (with the respect to shock wave speed) perturbation in the region ahead of the front.

1. Introduction

The interaction of neutral and charged gas components is in a high interest. This attention is caused mostly by aerospace applications as well as for exploring the nonlinear wave processes in the near-Earth space. In this work, the interaction of strong shock waves and supersonic bodies with low-ionized plasma is presented and discussed.

A motivation to the study is the discovery of the effect of anomalous supersonic flow of low-ionized plasma around a body in the absence of energy release ahead of the body [1]. Later, anomalous relaxation and instability of shock waves in gases were found in [2]. Generation of low-ionized gas-discharge non-isothermal plasma ahead of a body, streamlined by a supersonic flow, allows lowering the intensity of a strong shock wave [3]; this effect reduces the aerodynamic drag.

The essence of the phenomenon is the formation of a region with elevated concentration of charged particles ahead of the front of a shock wave at certain speed of the latter. This critical speed is defined by the electron temperature and ion mass. Laboratory experiments show the flow around a body by weakly ionized air to differ markedly from that by heated neutral air. The ‘plasma effect’ is manifested in distancing of the head shock wave from the body and lowering of its intensity.

2. Results

Under certain conditions, total ‘destruction’ of a shock wave is possible due to the presence of gas ionization ahead of the body. Analytical studies assumed rather far-reaching idealizations. Based on computer simulation [4], formation of a plasma precursor was shown to be possible ahead of the shock wave front – a soliton with a critical property: a non-monotonic resonant dependence of the soliton amplitude on the shock wave speed. The maximum perturbations develop at values of the shock wave speed in the range $c \approx (1.6 \div 2) \cdot u_s$, ($u_s$ is the ion sound speed).

In such situation, a sole, densest possible, local condensation of charged particles is formed in the precursor. The gas in the ‘condensation’ is not weakly ionized anymore, and charged particles can exert a reciprocal effect upon the neutral component and the shock wave. The ‘competition’ between strong nonlinearity and strong dispersion causes appearing of a sharp decrease of the soliton amplitude with the shock wave speed growing beyond critical value c. Previously similar effect have been found in [5] in hydrodynamic and called ‘Houston’s horse’ effect.

3. References

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