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VISUALIZATION OF SUPERSONIC GAS FLOWS WITH AN IMPULSIVE SPACE CHARGE*

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Most of the established methods of visualizing gas flows are suited for studying steady and quasisteady processes with characteristic times greater than a millisecond. Rapid interactions of gasdynamic disturbances and discontinuities are visualized primarily by conventional shadow and holographic interference methods, which have serious limitations with respect to sensitivity and range of gas density.

Several investigations [1, 2] have employed an electric discharge to visualize steady gas flows with shock waves. The local intensity of luminescence of the gas in the region of the discharge is related to the gasdynamic parameters of the flow and the parameters of the electric field [3]. This problem is most complex near the front of a shock wave.

Studies of the effect of ionization on the propagation of shock waves have shown that the velocity, amplitude, and structure of the waves change in glow, high-frequency, and superhigh-frequency discharges [4, 5]. These changes are connected both with heating of the gas and with nonequilibrium excitation of its molecules. Thus, significant changes are introduced when a gas flow is visualized by means of a steady discharge. To be precise, we should therefore state that a gas flow ionized by a discharge is being visualized.

Some of the limitations attending the use of an electric discharge to visualize gasdynamic processes can be eliminated if a highly uniform impulsive discharge is created within the test volume and the period of luminescence is much shorter than the characteristic gasdynamic times. Such conditions have been realized on a STDO (shock-tube — discharge — optics) unit, which is a combination of a shock tube and a special discharge chamber [6].

The internal cross section of the tube is 24 × 48 mm. In the tests we conducted, the Mach number of the shock waves $M = 1.1$-6, the period of supersonic flow was 200-400 μsec, and the initial pressure in the slipstream ranged up to 50 kPa. A discharge scheme employing plasma electrodes used in laser technology [7] generated the space charge in the working chamber (which changes into the shock-tube channel). A high degree of spatial uniformity of the discharge was ensured by pre-ionization ultraviolet irradiation from plasma electrodes — plates sliding over the surface of dielectrics located on the top and bottom walls of the chamber flush with the shock-tube channel. The uniformity of the discharge was checked by taking photographs at the ends of the chamber and by continuously observing the discharge visually through the side walls, made of quartz glass. The criterion for uniform luminescence of the air in the region of the discharge was the presence of a uniform gas (stationary or two-dimensional flow) within the density range from 8 g/m^3 to 0.2 kg/m^3. The presence of discontinuities in the air flow led to nonuniform ionization of the test volume. The sliding discharge was initiated unevenly when the discontinuities were adjacent to the plasma electrodes. The ionization coefficient α is a nonlinear function of E/N, and density nonuniformity led to redistribution of the current as a result of the dependence of electron concentration on α. Data on the distribution of the intensity of luminescence of corresponding elements of the flow provided information on instantaneous local profiles of particle density in the discharge region. It must also be taken into account that a level of saturation might have been reached with respect to the concentration of excited particles populating the levels from which radiation was recorded in different regions of the discharge volume.

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Fig. 1

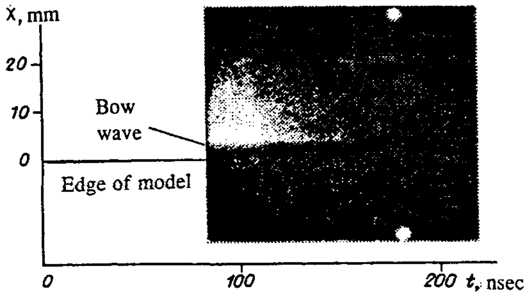

Fig. 2

We used AGAT-SF-3M (scanning speed 50 nsec/cm) and FER-7 (125 and 250 nsec/cm) electrooptic cameras to study the time-dependent characteristics of luminescence of the gas in the discharge region and the dynamics of the spatial distribution of the intensity of luminescence of elements of the flow during the pulse. Analysis of the photographs showed that the period of luminescence of the ionized flow of air was 150-180 nsec. With integral recording of luminescence, the exposure was instantaneous from the viewpoint of the gasdynamic time scale. Scans of the luminescence of elements of the flow showed that no redistribution of the parameters took place during the time of current flow.

Impulsive flow diagnostics, with visualization of the flow field, permits integral recording of luminescence [8]. Initiation of a discharge in the gas flow makes it possible to visualize discontinuities at a prescribed moment in the gasdynamic process. A synchronization system based on piezoelectric gages installed in the channel of the shock tube ensured the requisite delay in the initiation of the discharge.

The setup of the experiment conducted to visualize steady gasdynamic flows (supersonic flow about a model) was as follows: a plane shock wave with $M = 2.5\text{-}5.5$ exited the shock-tube channel and entered the discharge chamber. The wave underwent diffraction on the model (which was secured on the chamber axis), supersonic flow about the model was established for a period of 30-40 μsec, and the discharge was initiated.

Figure 1 shows a photograph of the flow field around a blunt cylinder with a pressure $P = 33$ kPa in the incoming flow. The Mach number of the supersonic flow was 1.5. The voltage in the discharge gap was 30 kV. Figure 2 shows a photographic scan of the luminescence of the region of the shock layer along the symmetry axis X.

We also obtained images of a plane shock wave in the discharge chamber. The discharge was initiated at different moments during the passage of the wave along the discharge gap. Ionization of the gas (and the formation of plasma sheets) occurred only ahead of the shock wave — in the region of low density and pressure. An increase in the energy contribution ahead of the wave was accompanied by a monotonic increase in luminescence intensity in the direction of the front. In the absence of short-circuit elements, the luminescence of the flow lasted no longer than 200 nsec. The minimal effect of ionization-related phenomena on the gas flow was due to the brevity of the current flow and the high degree of spatial uniformity of the discharge region. Comparison of the images we obtained with corresponding shadowgraphs and interference patterns demonstrates the sensitivity of the method to weak disturbances; another advantage of the method is that it can be used in the low-pressure region (from 130 Pa). In contrast to other diagnostic techniques, the method proposed here makes it possible to visualize the flow through one window of the working chamber.

Thus, the method allows density perturbations and discontinuities to be recorded in a wide range of gas flows with a high degree of sensitivity. It also reveals the character of the relative change in density in the perturbation region.

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