DENSITY DISTRIBUTION IN RAREFACTION WAVE PRODUCED BY RUPTURE OF DIAPHRAGM IN A SHOCK TUBE

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The effect of the finite time of opening of the diaphragm in a shock tube on the formation of the rarefaction wave was investigated experimentally. The density distribution in the rarefaction wave was measured in relation to the coordinate and time and was compared with the known self-similar solution.

The flow in a shock tube depends on the rarefaction wave produced by rupture of the diaphragm [1]. The rarefaction wave is used in devices employing the gradient acceleration of the shock wave [2] and in some types of high-speed valves for admission of gas into an evacuated space [3].

A diagram of the apparatus is shown in Fig. 1, where 1 is the expansion section with optical glass windows (vacuum 10^{-2} torr), 2 is the compression section, 3 is an opaque diaphragm made of 12-μ thick coated Lavsan film, 4 is a LG-55 laser, 5 is the outer mirror of the interferometer, 6 is a filter, 7 is a radiation receiver (photomultiplier), 8 is a photomultiplier for synchronization, and 9 is a light source for synchronization.

The flow cross section is $a^2 = 10 \times 10$ mm. The system consists of an expansion section 110 mm long and a compression section 40 mm long. The diaphragm rests on a square frame with smooth edges. When the pressure in the section 2 is increased to 6 atm, one or several cracks appear in the center of the diaphragm, and it splits along these cracks. The light flux from the source 9 is received by the receiver 8 and triggers an oscilloscope through an amplifier and multivibrator. The time of opening of the diaphragm $\tau = 50 \pm 5$ μsec.

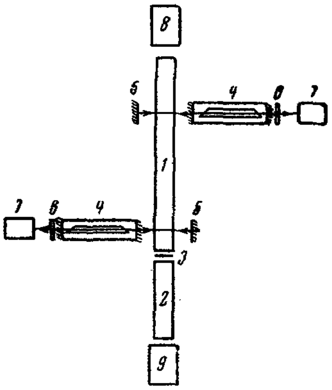

Fig. 1

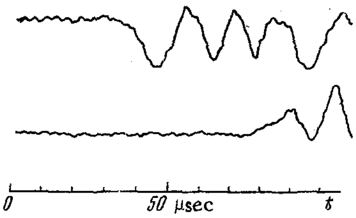

Fig. 2

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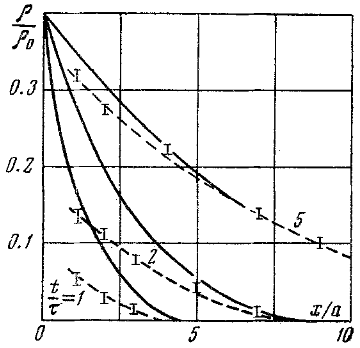

Fig. 3

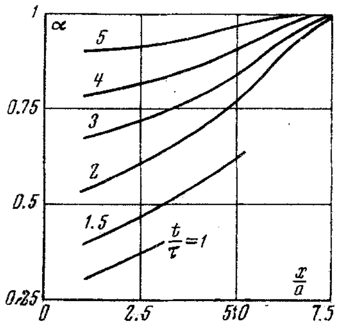

Fig. 4

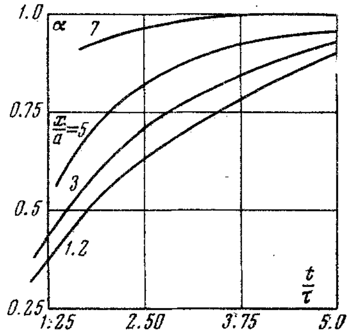

Fig. 5

The density was measured by means of a three-mirror laser interferometer with close coupling of the optical resonators [4, 5]. A helium-neon laser with a wavelength of 0.63 μ was used. The sensitivity of the interferometer for measurement of the density of neutral air was

$$N = nl / 2.8 \cdot 10^{18}$$

where N is the number of fringes, n is the number of particles per cm^3, and L is the beam path length in one pass of the system. In the present case L = 1 cm, so that a particle number of $2.8 \cdot 10^{18}$ cm^{-3} corresponds to one fringe. The dimensions of the probing beam were 0.2 mm in the direction of gas flow and 2 mm in the transverse direction. The presence of two interferometers in the system was due to the need to control the reproducibility of the gas flow when the diaphragm bursts. The results of simultaneous measurement of the density at two points in the flow are shown in Fig. 2. The upper curve is the interferogram at the point $x/a = 3$, and the lower curve is the interferogram at the point $x/a = 7$. The appearance of the signal on the interferometer corresponds to a velocity of 1 km/sec. The time is measured from the appearance of the light signal on the receiver 8 due to the start of rupture of the diaphragm. The irregular nature of the resonance peaks is presumably due to perturbations of the gas flow after rupture of the diaphragm. The density curves obtained in different experiments agreed to within ~10%.

The self-similar solution, obtained on the assumption of instantaneous removal of the diaphragm and unidimensionality of the flow [6], gives an expression for the density:

$$\frac{\rho}{\rho_0} = \left(\frac{2}{\gamma+1}\right)^{2/(\gamma-1)} \left(1 - \frac{\gamma-1}{2} \frac{x}{c_0 t}\right)^{2/(\gamma-1)}$$

Here ρ_0 and c_0 are the density and velocity of the sound in the stationary gas before rupture of the diaphragm; γ is the adiabatic exponent; x is the coordinate measured from the diaphragm into the vacuum; t is the time after rupture of the diaphragm.

The results of the measurements and a comparison of them with the calculated density distribution are given in Figs. 3, 4, and 5. A dimensionless quantity α, equal to the ratio of the measured density to the calculated density, is introduced. It depends on the dimensionless coordinate x/a and the dimensionless time t/τ. The comparison indicates that rupture of the diaphragm gives rise to a flow which approximates to the theoretical one at times several times greater than the time of opening of the diaphragm.

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