NOTE ON "OBTAINING AND INVESTIGATING SUPERSONIC JETS OF RAREFIED GAS" BY L. L. VASIL'EV, Yu. A. LAPSHIN, AND A. N. PISKUNOV*

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A striking feature of the article in question is the large Mach number and flow diameter realized using a porous material (Table 4, Fig. 4). For material 1 with retardation parameters p_0 = 1055 torr, T_0 = 600°K at a distance x = 100 mm from the material, a Mach number M = 23.1 in an isentropic flow of diameter D = 140 mm was quoted. These figures seem questionable, for the following reasons.

1. These parameters would correspond to a temperature T = 5.6°K and pressure $p = 8 \cdot 10^{-5}$ torr in the flow, and for any of the gases used condensation is possible under these conditions.

2. The figures M = 23.1 and D = 140 mm quoted contradict the data of Table 1, which reflect, generally speaking, the maximum possible values for the equipment used, apart from the dependence on the type of jet source. The data on micronozzles given are in complete agreement with Table 1. Reexpansion of the flow cannot give much benefit without the use of special measures to restore the pressure.

We suggest that there has been an incorrect determination of the retardation parameters of the flow forming when a gas issues from a porous material into a space of low pressure. Since no details of the determination of p_0 and T_0 are given, it is impossible to discuss specific aspects of method and, accordingly, this note will confine itself to general matters of principle.

The retardation parameters of a flow formed using a porous material are determined by the gas parameters at the pore outlet and by the dissipative processes in the region of mixing of the individual jets. Dissipative processes in the channels of the porous plate have no direct effect on the gasdynamics of the free jet. The gas parameters in the chamber preceding entry to the porous material do not uniquely characterize the retardation parameters of the free jet. Hence, if it is required to determine the parameters of the flow behind the porous source, it is necessary to measure them in the flow itself. This was done, for example, in the experiments of [1, 2], using electron-beam diagnostics.

It is possible to determine the total pressure and Mach number in the jet behind the porous source from Pitot-tube measurements, without the need for electron-beam diagnostics. In Fig. 1 (from [1]) the continuous lines I and II show results given by a Pitot tube (diameter 12 mm) on the axis of an air flow behind a porous plate (diameter d = 130 mm) with pressures of 5830 N/m² in the chamber preceding the porous material and p_c = 3.12, 1.62 N/m² in the vacuum chamber. The dashed lines show the corresponding density distributions in arbitrary units. The section de of line I corresponds to Pitot-tube measurements in the Mach disk, as confirmed by the form of the density variation. The section dc is the supersonic region of the free jet, in which a reduction in the Mach number with decrease in x/d is observed. The point c corresponds to the position of the Pitot tube in the flow such that the leading wave reaches the region of flow formation with Mach number unity before reaching the tube and vanishes. The section bc corresponds to measurements when there is no shock wave before the tube is reached, and the measured value corresponds to the total pressure.

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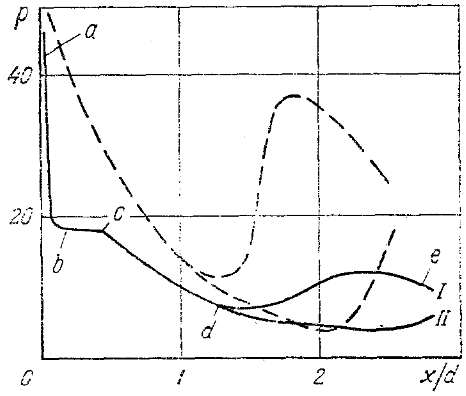

Fig. 1. Axial distribution of total pressure in the flow behind a porous source; p, N/m².

On the section b*a* strong compression of the gas at the pore outlet is recorded by the Pitot tube, and the reading is not the total pressure but a fraction depending on the form, density, and properties of the porous plate and the Pitot tube.

Thus, the total pressure of the flow must be determined on the section bc of the axial distribution of Pitot-tube readings. In continuous and viscous conditions of flow around the Pitot tube, the presence and form of the section bc depend on the relative size of the region of gas mixing at the pore outlet and the region in which the shock wave leaves the tube. Increase in tube diameter enlarges the section bc.

Taking p_0 = 18.1 N/m² for lines I and II of Fig. 1, and taking into account the emission of a shock wave from the Pitot tube according to [3], the values M = 2.42 and 3.37 are obtained for x/d = 1 and 2; these practically coincide with the values M = 2.4 and 3.5 [1] determined independently. The agreement of the results indicates that the method proposed is suitable for determining the total pressure difference.

It is also of interest to consider whether the flow behind a porous material is similar to a free jet behind a sonic nozzle. It seems possible, in the present state of knowledge, to speak of qualitative agreement in structure between the two types of flow. For example, using the formula [4]

$$x_M/d = 0.67\sqrt{p_0/p_C}$$

for the data [1] shown in Fig. 1, the corresponding coordinates for the position of the Mach disk are x_M/d = 1.59 and 2.2. Within the limits of experimental error, these figures agree with the region of increased density for the conditions indicated. The Mach number suggested in [5] for a free jet with x/d = 1 and 2 (M = 2.55 and 3.87) also agree with the results of [1].

Thus, the gasdynamic structure of the flow when a gas issues from a porous material into a low-pressure region does not require extensive independent investigation. The porous material and the sonic nozzle should be regarded as analogous gasdynamic sources. The advantage of the porous source is that the boundary layer at the wall usual in a sonic nozzle is absent. This property was used in [2] in designing a gasdynamic source.

NOTATION

p, static pressure; p_0, retardation pressure; p_C, pressure in chamber; T, static temperature; T_0, retardation temperature; d, source diameter; D, flow diameter; x, coordinate along flow axis; x_M, distance from source to Mach disk.

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REPLY TO THE NOTE BY A. A. BOCHKAREV AND V. G. PRIKHOD'KO

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In our original paper, we cited data on the parameters of a supersonic jet of rarefied gas obtained when a gas issues into a vacuum through a Laval nozzle, a micronozzle, and a porous metal body. The porous body has several advantages over the Laval nozzle and the micronozzle: For the same gas flow rates an isentropic flow core of larger dimensions may be obtained; the porous body may be used as an effective heat exchanger for warming gases and also in the creation of sources of supersonic flow of complex form (sphere, cylinder, cone, ellipsoid, etc.).

The characteristics of the porous structures used as sources of supersonic and hypersonic flows may be varied over broad limits (permeability $K = 10^{-3}$–100 darcy; thermal conductivity $\lambda = 10^{-2}$–10^{2} W/m·deg), which means that it is easy to produce porous nozzles with any parameters. Finally, a porous source may be used simultaneously to generate and to heat the vapor, so that sources of supersonic and hypersonic flow that are compact and autonomous may be obtained. Indeed, this was our aim in undertaking the investigation.

In determining the Mach number in jets behind porous plates, the value taken for the retardation pressure in the Rayleigh formula was the total pressure difference at a section of the plate, which was measured using a Pitot tube with a rubber endpiece. As shown by subsequent experiments, in which the value of M was determined from the ratio of the static pressure to the total pressure at the shock wave, the total pressure difference at the section of a porous plate of low permeability ($K < 10$) is determined with a large error, increasing with decrease in the permeability of the plate. For this reason, the parameters of the porous plates I and II (P_0, M, etc.) given in the paper were too low.

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