TRAJECTORIES OF SINGLE JETS OF DIFFERENT DENSITIES PROPAGATING IN A DEFLECTING AIRSTREAM

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Data are presented on the influence of the density of a gas jet on the position of the dynamic and thermal axes during its propagation in a deflecting airstream.

In work on the investigation of single jets propagating in a transverse stream ([1-9] and others) it has been established that when a jet is injected at a 90° angle to the stream the position of its axis is determined by a hydrodynamic parameter equal to the ratio $\bar{q}$ of the initial velocity heads of the jet and the stream. The geometrical locus of points with the maximum values of the total pressure or velocity, measured in the plane of symmetry of the jet, is taken as the dynamic axis, while the locus of points with the maximum (minimum) temperature or the maximum concentration is taken as the thermal axis. However, in experiments [10] with jets of high density, $\bar{\rho} = \rho_j/\rho_s \simeq 20$, which were conducted at pressures of $(60\text{-}100)\cdot10^5$ N/m^3, according to visual observations, the trajectories of jets of liquid kerosene discharging from a nozzle into a deflecting stream of gaseous nitrogen with a temperature of 800°K lay higher than the trajectories of ordinary gas jets whose density is the same as the density of the deflecting stream. At such supercritical temperatures and pressures a liquid jet of kerosene does not differ in its properties from a gaseous jet. The hypothesis that the density affects the trajectory of the jet was also advanced in [11].

In order to clarify the influence of the ratio of densities of the jet and the deflecting stream on the position of the jet axis, we conducted experiments with gases of different densities on an installation consisting of a horizontally placed wind tunnel of the open type with a cross section of 180 × 230 mm^2 in which the deflecting stream was produced by a blower. The jet discharged upward at a 90° angle to the stream from a nozzle 5 mm in diameter, made (in accordance with Vitoshinskii) with fivefold constriction and mounted flush with the lower surface of the channel. The gas was supplied to the nozzle from tanks through a measuring section and a receiver. Preliminary measurements showed that the discharge coefficient of the nozzle is $\mu_n \approx 1$. As the working substances of the jet we used Freon-22 ($\bar{\rho} \approx 3.2$), heated air ($\bar{\rho} \approx 1.05$), argon ($\bar{\rho} \approx 1.4$), and helium ($\bar{\rho} \approx 0.13$). The main studies were conducted on helium and air jets. The fields of total pressures and temperatures in the cross sections of the jet were measured with a combination manifold consisting of Pitot tubes with an inner diameter of 0.7 mm and thermocouples. The total pressure was recorded by water piezometers and the temperature by a loop oscillograph. The concentration distribution of helium and argon in the jet cross sections were determined by an instrument with a pickup of the thermal detector type [2]. The instrument readings were graduated using preliminarily calibrated measuring washers. The combination manifold and the concentration detector were mounted in a coordinate spacer with five degrees of freedom. In measuring the jet parameters the manifold was placed perpendicular to the jet axis in the plane of symmetry.

The velocity of the deflecting stream was kept constant and equal to 15 m/sec.

The results of measurements of the fields of total pressures (Fig. 1A) and of temperatures and concentrations (Fig. 1B) with $\bar{q} = 125$, which were made in seven cross sections at different distances from the nozzle, are presented in Fig. 1. The clear stratification of the fields of total pressures, concentrations, and temperatures is seen from the measurements presented (especially in cross section III), with the maximum of the total pressure in the Freon jet lying higher than those in the argon, air, and helium jets. From this it follows that at equal values of the hydrodynamic parameter $\bar{q}$ the heavier Freon jet has a deeper penetration, which indicates the influence of the ratio $\bar{\rho}$ of densities of the jet and the stream

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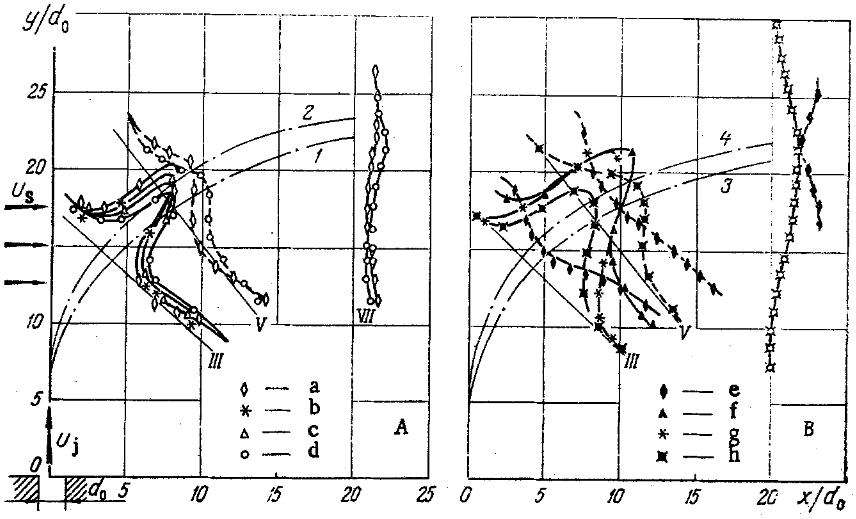

Fig. 1. Distribution of the total pressures P^* (A), temperatures t, and concentrations C(B) in jet cross sections, $\bar{q}$ = 125; P*: a, b, c, d) Freon, argon, air, helium; t: e, f) Freon, air; C: g, h) argon helium; 1, 2) dynamic and 3, 4) thermal axes of the helium and Freon jets. III, V, VII) cross sections.

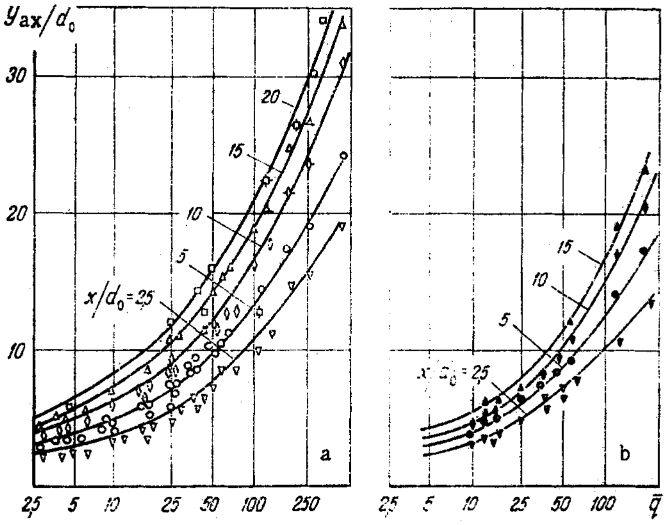

Fig. 2. Coordinate of dynamic (a) and thermal (b) axes of air jets: experimental points: data of [12-18] and the authors.

on the trajectory of the jet. Similar results in the dependence on the density were also observed for the temperature and concentration fields.

The experimental measurements made it possible to plot the location of the dynamic and thermal axes of the jets of helium (curves 1 and 3, Fig. 1) and of Freon (2, 4) in the form of the dependence $y_{ax} = f(\bar{x})$. The axes of the air and argon jets lie between them. The studies conducted showed the intensive decrease in the parameters along the jet axis. Thus, for a helium jet at a distance of 18.5 diameters from the nozzle cut ($\bar{x} \approx 8$) the total pressure at the axis comprises 3.5% of the total pressure at the nozzle cut while the concentration is 5% of that at the nozzle cut. At a distance of $\bar{l}$ = 33 ($\bar{x} \simeq 20$) from the nozzle the distribution of total pressures in the jet cross section does not have a distinct maximum but the total pressure at the axis is close to the pressure of the deflecting stream, while in the lower region of the jet it is even less than the stream pressure. But the distribution of concentration fields has a pronounced jet character. The distributions of parameters of air, argon, and Freon jets, both along the axis and in the cross sections, vary similarly. From the data obtained it follows that the experimental determination of the position of the dynamic axis from measurements of the total pressures at $\bar{l} \geqslant 33$ ($\bar{x} \geqslant 20$) and of the jet boundaries at $l \geqslant 18$ ($x \geqslant 8$) becomes difficult or even impossible.

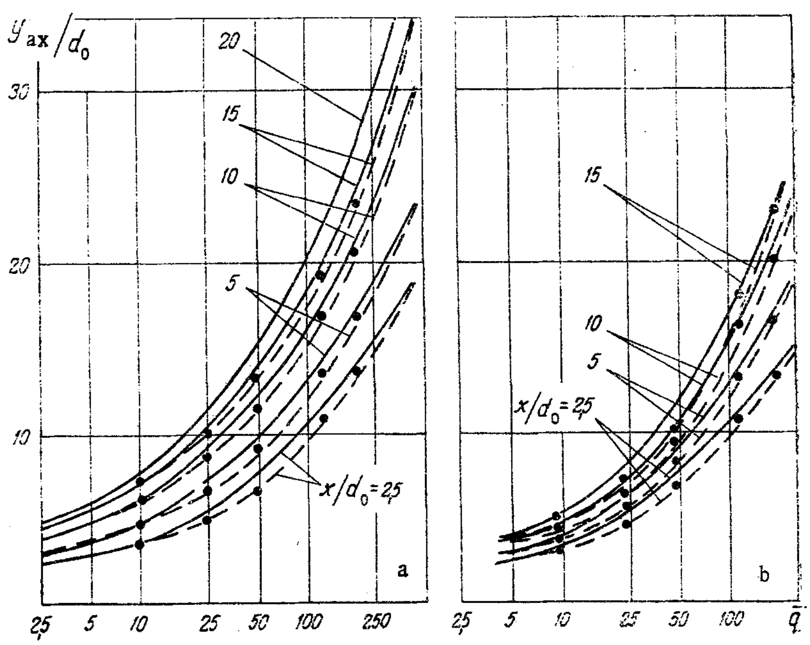

Fig. 3. Coordinates of dynamic (a) and thermal (b) axes of air and helium jets: points are for helium, based on authors' experiments.

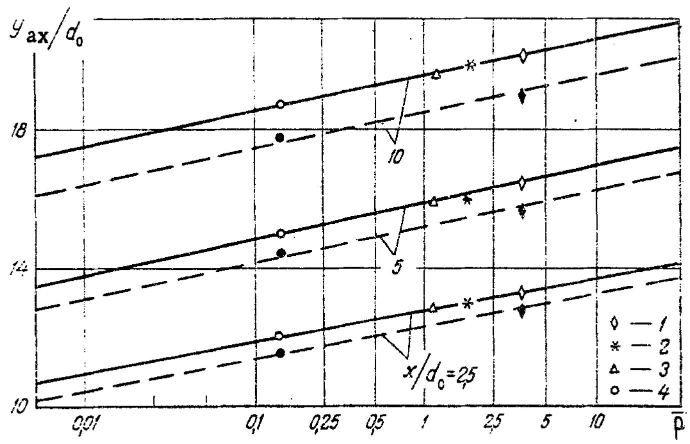

Fig. 4. Coordinates of dynamic (solid curves) and thermal (dashed curves) axes of jets as a function of density; $\bar{q}$ = 125; 1-4) Freon, argon, air, and helium, respectively.

For the practical application of the extensive experimental data on the study of single jets in a deflecting stream we generalized the results of [12-18] and others and constructed dependences of the coordinates of the dynamic (Fig. 2a) and thermal (Fig. 2b) axes of air jets ($\bar{\rho}$ = 1.0) in the form of the function $y_{ax} = f(\bar{q})$ for fixed $\bar{x}$ in the range of values of the hydrodynamic parameters of $\bar{q}$ = 1-500. From a comparison of the coordinates of the dynamic and thermal axes it is seen that in a wide range of variation of $\bar{q}$ the dynamic axis lies higher than the thermal axis, which is probably connected with the penetration of cold masses of air of the deflecting stream into the forward region of the jet. The use of generalized graphs allows one to construct the dynamic and thermal axes of a jet for any values of $\bar{q}$.

The results of the studies on the propagation of helium jets in a deflecting stream performed in the present work were presented in the same coordinates, which made it possible to compare the positions of the dynamic (Fig. 3a) and thermal (Fig. 3b) axes of helium and air jets. It follows from Fig. 3 that at values of $\bar{q}$ greater than 10 the dynamic and thermal axes of helium jets (dashed curves) lie lower than the corresponding axes of air jets (solid curves). Such an effect can be explained by the character of the distribution of static pressure measured in the plane of a round nozzle. At $\bar{q}$ > 10 the difference in the static pressures ahead of and behind the helium jets is greater than that for air. The influence of the density of the jet on the variation in the position of the dynamic (solid lines) and thermal (dashed lines) axes for different fixed $\bar{x}$ at a constant value of the hydrodynamic parameter $\bar{q}$ = 125 is shown in Fig. 4. If the densities of the gases of the jet and the deflecting stream differ slightly from each other then the positions of the dynamic and thermal axes of the jet depend weakly on the density ratio and are mainly determined by the parameter $\bar{q}$.

On the basis of the experiments conducted, one can state that, besides the hydrodynamic parameter $\bar{q}$, the ratio $\bar{\rho}$ of densities of the jet and the deflecting stream also affects the depth of penetration of jets, with the effect becoming stronger, the larger the ratio. The essence of this effect consists in the difference in ejecting abilities of the jets. With equality of the initial momenta, a lighter jet incorporates a relatively greater amount of matter from the stream, which leads to a sharper decrease in the axial velocity and, as a consequence, to its lesser penetration into the deflecting stream. This fact is in definite accordance with the well-known data on the influence of $\bar{\rho}$ on the ejecting abilities of flooded jets [2, 3].

It should be noted that the strongest influence of the density ratio $\bar{\rho}$ on the trajectories of the jets under consideration was observed at values of $\bar{q}$ = 25-125, i.e., under conditions of the most developed flow in the deflecting stream.

NOTATION

d_0, nozzle diameter; l, distance along jet axis; $\bar{l}$, ratio of distance along jet axis to nozzle diameter; x, distance from nozzle axis; $\bar{x}$, ratio of distance from nozzle axis to its diameter; y_{ax}, coordinate of jet axis; $\bar{y}_{ax}$, ratio of coordinate of jet axis to nozzle diameter; μ_n, discharge coefficient of nozzle; U_j, U_s, initial velocities of jet and stream, respectively, m/sec; ρ_j, ρ_s, densities of jet and stream, kg/m³; $\bar{\rho} = \rho_j/\rho_s$, density ratio; $q = \rho_j U_j^2/\rho_s U_s^2$, ratio of initial velocity heads of jet and stream.

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