UDC 532.522

A SYSTEM OF PLANE TURBULENT JETS

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Inzhenerno-Fizicheskii Zhurnal, Vol. 9, No. 2, pp. 180–186, 1965

The results are given of experimental investigations of the flow parameters (velocity, static pressure, temperature and mixture concentration fields) pertaining to the mixing of five plane turbulent jets.

Mixing of several turbulent jets is of common occurrence in heat engineering. Existing theoretical solutions to the problem of calculating the resultant flow structure [1, 2] are based on the supposition that the jet axes (lines of maximum velocity) retain their initial directions during the mixing process.

Experiments do not always confirm this supposition but indicate that when turbulent jets mix, they enter into a very complex interaction, and that the structure of the resultant flow is far from simple. The behavior of each jet in the mixing process is determined by the system of jets as a whole.

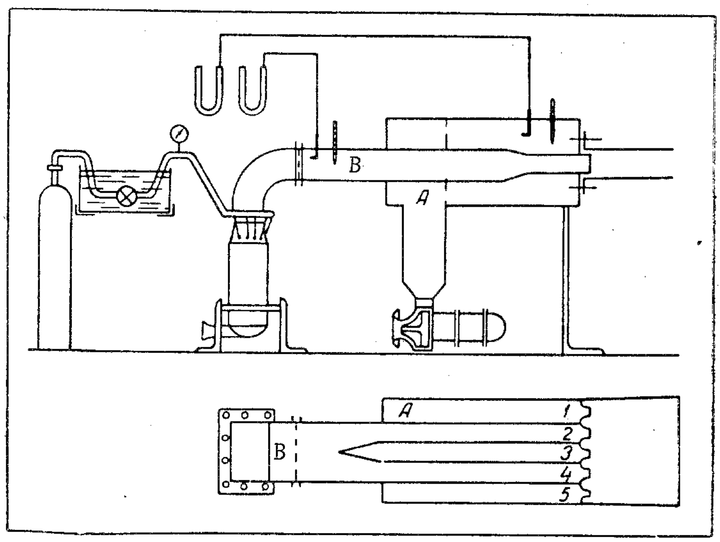

Fig. 1. Experimental setup.

The present paper gives the results of investigations of the mixing of five plane turbulent air jets discharging into the atmosphere from slit nozzles (Fig. 1).

Air was supplied by a centrifugal blower to the receiver A and thence to nozzles 1, 3, and 5. A grating was installed in the receiver to smooth out the velocity field. Air reached nozzles 2 and 4 from a heater equipped with a fan through receiver B and two channels passing inside receiver A. The total pressure and temperature in receivers A and B were measured

The nozzle profiles were determined by Vitoshinskii's method. The dimensions of all the exit slits were made identical: 8 mm wide and 30 mm long. The slits were at equal distances of 30 mm apart.

The discharge from the nozzles passed into a space bounded by two parallel walls, which prevented the jets from spreading sideways and ensured a plane-parallel flow structure during mixing.

Slots were cut in one of the walls of the measuring sections to permit movement of the scale carrying the sensing elements for measuring the flow parameters.

The velocity, temperature, concentration of carbon dioxide and flow direction fields were investigated in the resultant flow at various distances from the nozzle exits (up to 350 mm).

The probes described in [3] were used to measure total and static pressure and flow direction. The readings were brought out to a water U-tube manometer, which recorded total and static pressure relative to atmospheric (h^* and h_{st}) and also the flow inclination angle α.

The air reaching nozzles 2 and 4 was preheated during investigation of the temperature fields, the maximum heating being 80° C. The temperature difference between any point in the resultant flow and that in receiver A was measured

Parameters of the air reaching the nozzles.

Regime	h^*_A, N/m²	h^*_B, N/m²	Δt_0, °C	x_0, %
I-*T*40	980	980	40	0
I-*T*60	980	980	60	0
I-*K*10	980	980	0	10
I-*K*20	980	980	0	20
II-*T*40	980	245	40	0
III-*T*40	3920	245	40	0

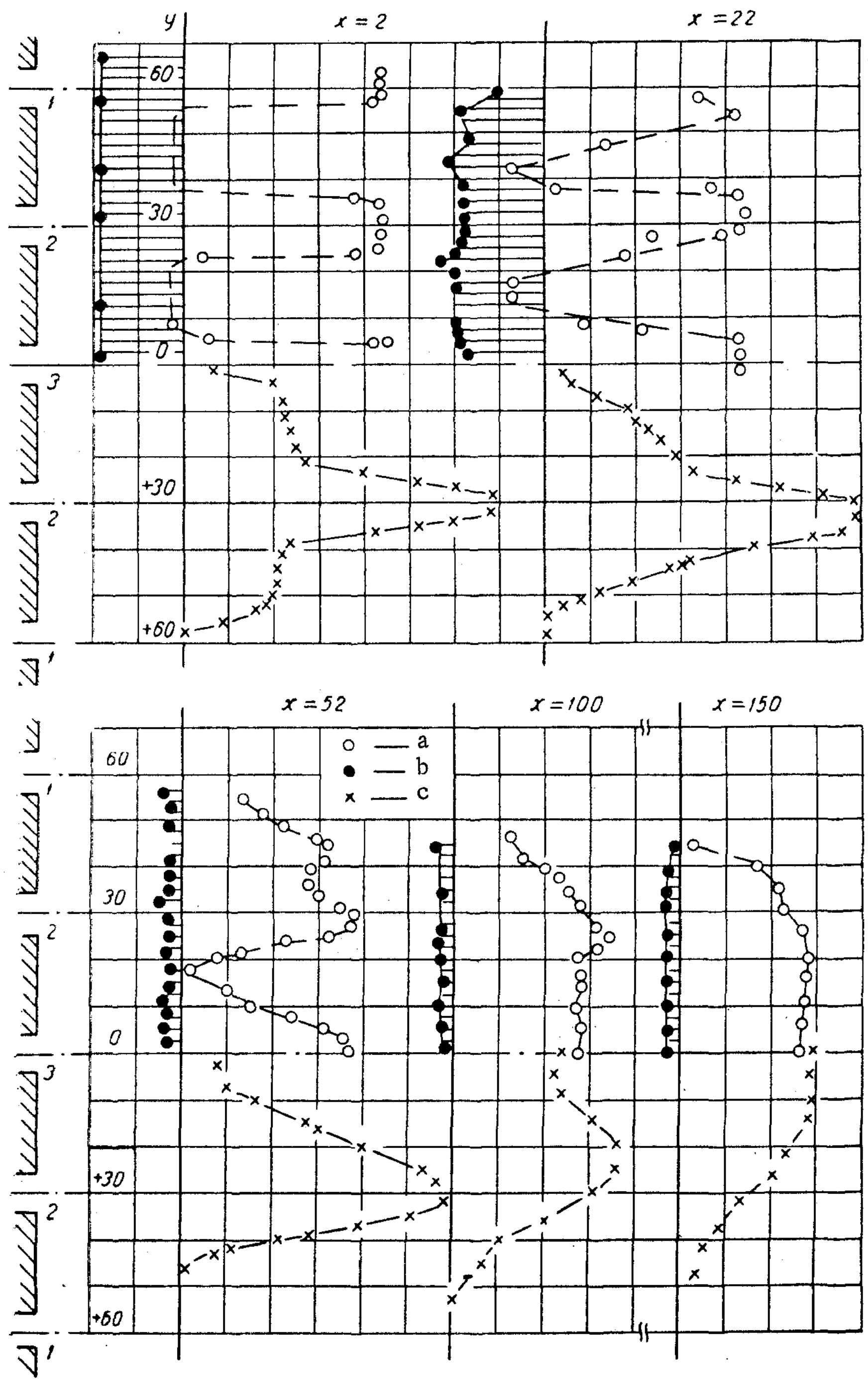

Fig. 2. Fields of a) axial velocity components, b) static pressure, and c) temperature in regime I-T40.

with two twin chromel-kopel thermocouples, the readings being taken on a potentiometer. The thermocouple calibration showed a linear relation between temperature difference and thermocouple emf:

$$\Delta t\,[°C] = 15.5\,\pi,$$

where π is the potentiometer reading.

For investigation of the concentration fields, carbon dioxide was supplied from bottles through a pressure reducer to a header and then to receiver B. The reducer was located in a bath with circulating hot water to prevent icing up. A constant mass flow rate of carbon dioxide was maintained in terms of the readings of a manometer recording pressure downstream from the reducer. The maximum carbon dioxide concentration in the jets was 20%.

Details of the regimes investigated are shown in the table.

The experimental data have been plotted as graphs of the variation of the flow parameters: static pressure $h_{st} = h_{st}(y)$, the axial velocity component $u = u(y)$, the temperature difference $\pi = \pi(y)$, and the carbon dioxide concentration $\varkappa = \varkappa(y)$ for each section measured.

The absolute velocity ω was calculated from the dynamic head $p_{dyn} = h^* - h_{st}$:

$$w = \left(2g\frac{p_{st\,0}}{\gamma_0 T_0}\,p_{dyn}\frac{T}{p_{st}}\right)^{1/2} = 24.0\left(\frac{p_{dyn}T}{p_{st}}\right)^{1/2}.$$

The axial velocity component was determined as $u = \omega\cos\alpha$. When necessary, the temperature and concentration fields were expressed as dimensionless ratios: $\overline{T} = (t - t_e)/(t_B - t_e)$, $\overline{\varkappa} = \varkappa/\varkappa_0$. The variation of the parameters of the resultant flow in the case when all five jets discharge at identical pressure drops in shown in Fig. 2.

In this regime the central jets (2, 3, and 4) flowed without exhibiting a tendency to change direction (parallel to the nozzle axes) right through mixing: the distances between the velocity maxima of these jets up to section x = 52 mm corresponded to the distance between nozzles. The side jet (1) was deflected: its maximum velocity was displaced successively from section to section toward the central jets.

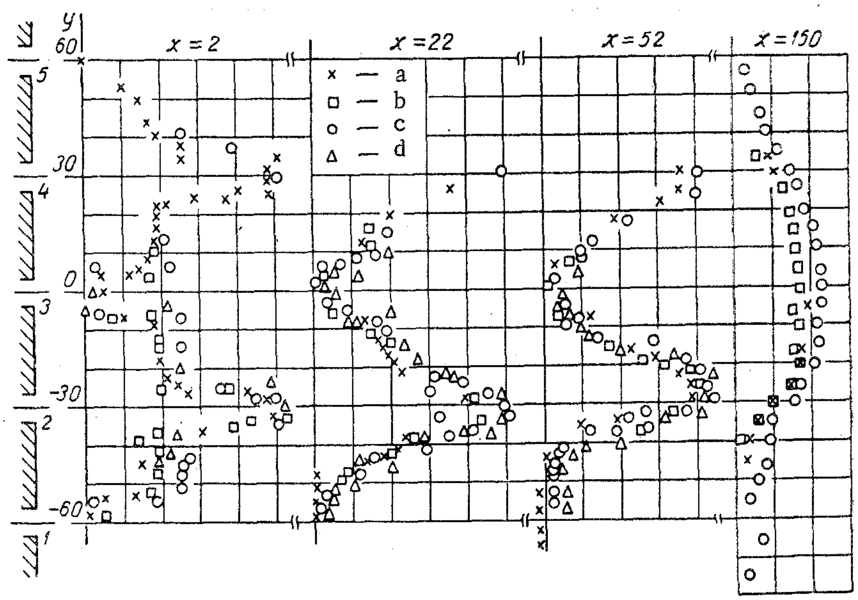

Fig. 3. Fields of relative temperature and relative concentration in regime I: a) regime I-T40; b) I-T60; c) I-K40; d) I-K60.

Measurement of the static pressure in the flow in this regime showed that in the initial sections in the entire region between the side jets (both in the reverse flow zones between jets 1 and 2 and between 2 and 3, and in jets 2 and 3 themselves) the static pressure was below atmospheric. This reduction reached 20% of the velocity head of the jets at discharge and evidently caused the deviation of the side jets 1 and 5 towards the common flow axis.

The measured temperature data show that heat transfer in the jet system began long before the boundaries of the separate jets met. For example, at the section x = 2 mm, each jet propagated as an individual stream, separated from its neighbors by reverse flow zones. At the same time, intense mixing of air in the reverse flow zones led to the establishment of a constant temperature, close to the mean of the neighboring jets. A temperature increase occurred at this section and in the boundary layers of the cold jets facing toward the center of the flow, so that the boundary layer picked up air from the hot zones of reverse flow of the neighboring jets.

Following mixing of the jets (section x = 52 mm) the temperature varied monotonically from a maximum to a minimum. There were two temperature maxima, corresponding to the number of heated jets, although the velocity field retained five maxima; thus it does not make sense to look for an analogy (as obtains for a single jet) between the distribution of temperature and resultant flow velocity in this case.

At a considerable distance from the nozzle exits (x = 150 mm) the heat had been so well distributed that measurement revealed only one temperature maximum in the resultant flow, on the common flow axis, where a temperature dip was observed at the earlier sections, due to the cold central jet 3.

Increase of the initial heating of the jets to $\Delta t_0 = 60°$ C (regime I-T60) did not lead to any kind of qualitative change in the flow picture in comparison with the I-T40 regime.

Measurements of the concentration of carbon dioxide flowing in from jets 2 and 4 (regime I-K10) gave the same picture as did the temperature measurements.

The quantitative presentation of the experimental data in the form of fields of relative temperature $\overline{T}(y)$ and relative concentration $\varkappa(y)$ (Fig. 3) is evidence of the complete analogy between heat and mass transfer processes in the jet system.

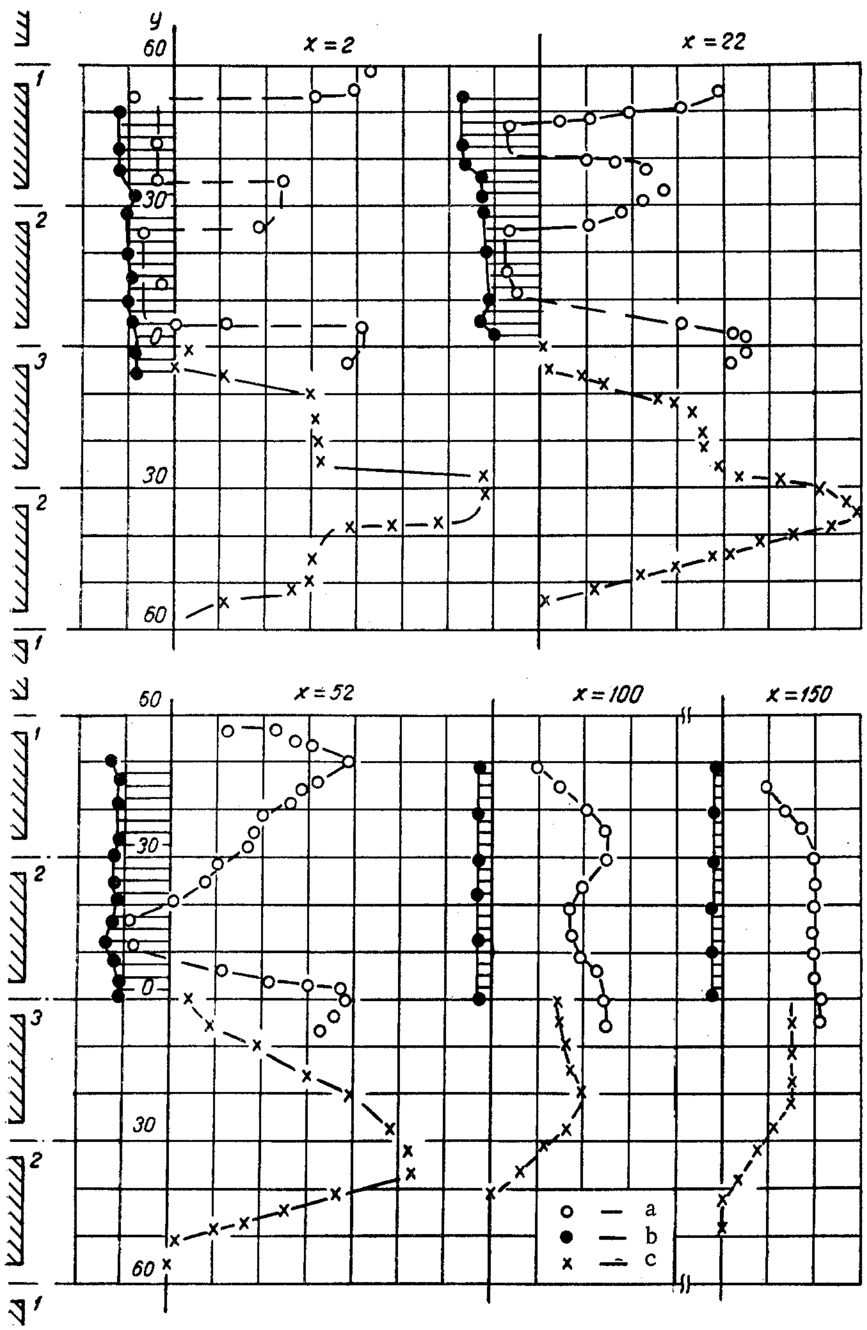

Fig. 4. Fields of axial velocity components, static pressure, and temperature in regime II-T40: a, b, c) see Fig. 2.

Reduction of the discharge velocity of jets 2 and 4 (regime II-T40, Fig. 4) led to a qualitative change in the form of the resultant flow. The central jet 3, in this case, propagated as before, without changing its initial direction, while the side jets 1 and 5 were deflected toward the center. Jets 2 and 4, which in regime I propagated parallel to the common flow axis, were now deflected toward the periphery, i.e., toward jets 1 and 5. In this case, too, the cause of the deflection was evidently the drop in static pressure. Indeed, the measurements of static pressure revealed that the underpressure in the reverse flow zone between jets 1 and 2 was less than that between jets 2 and 3.

Because of the deformation of the jet axis, the zone of reverse flow between jets 2 and 3 advanced further along the flow; whereas at the section $x = 52$ mm, reverse flow was not noticeable in regime I (Fig. 2), reverse flow was observed at the same section in regime II. The existence of such extensive zones of reverse flow increases the nonuniformity of the velocity field in the resultant flow and the hydraulic losses associated with the mixing of the jets.

Increase in the difference in discharge velocity of jets 1, 3, and 5, on the one hand, and jets 2 and 4, on the other (regime III), led to intensification of all the features of the flow noted in regime II.

The temperature fields in regime II-T40, as in regime I, indicated heat transfer between the jets through the reverse flow zone (section $x = 2$ mm) and two temperature maxima in the resultant flow at a considerable distance from the nozzle exits (up to $x = 100$ mm).

NOTATION

x, y—coordinates of measurement point; u—axial velocity component; p_{dyn}—velocity head; p_{st}—static pressure; h_{st}—excess static pressure; t and t_e—temperature at measurement point and of external air; t_B — initial temperature of air discharged from receiver B; Δt—change of temperature at measurement point in comparison with flow temperature in receiver A; Δt_0—initial difference of temperature between jets discharging from receiver B, relative to temperature of flow in receiver A; T—relative temperature; α—angle of inclination of absolute velocity vector; $\varkappa_0$—initial concentration of carbon dioxide in jets 2 and 4; $\varkappa$ and $\overline{\varkappa}$—absolute and relative concentration at measurement point; π—readings of potentiometer (mV); h_A^*—pressure drop relating to discharge of jets from receiver A (jets 1, 3, and 5); h_B^*—from receiver B (jets 2 and 4).

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27 October 1964

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