ROZPRAWY INŻYNIERSKIE • ENGINEERING TRANSACTION • 22, 3, 421–426, 1974
Polska Akademia Nauk • Instytut Podstawowych Problemów Techniki

SOME PECULIARITIES OF JET FLOWS IN A DEFLECTING STREAM

A. EPŠTEIN and V. HENDRIKSON (TALLIN)

Results of experimental study of turbulent nonbuoyant and buoyant jets issuing into the cross stream are presented. It has been shown that the flow has different patterns depending on initial ratios of jet to stream momentum and of jet buoyancy to stream momentum. For given ratios different types of temperature distributions were observed at distances near the orifice and far downstream with tendency to similarity at each stage.

Nomenclature

- x coordinate parallel to the main stream direction,
- y coordinate normal to x,
- v_0 velocity of jet at the outlet of nozzle,
- w velocity of the main stream,
- T_0 temperature of jet at the outlet of nozzle,
- T_w temperature of the main stream,
- ΔT_0 excess temperature of jet at the outlet of nozzle,
- ΔT excess temperature in cross-section of the jet,
- ΔT_m excess of the maximum temperature in a cross-section of jet,
- D_0 nozzle diameter,
- g gravitational constant,
- r "equivalent" radius,
- $r_{0.5}$ "half" radius, corresponding to $\Delta T = 0.5\Delta T_m$,
- S area enclosed by certain isotherm,
- I complex parameter $T_w v_0^2/T_0 w^2$,
- J complex parameter $gD_0 \Delta T_0 v_0/T_0 w^3$.

The problem of a round jet in deflecting stream attracts attention of investigators in connection with certain technical applications (combustion chambers, spreading of effluents from chimneys, VTOL aircraft, etc.) [1 – 6]. Specific demands of actual applications and also rather bulky routine of experiment results in the fact that, although considerable amount of experiments were carried out, we know quite little about basic features of such flows. The major amount of information obtained concerns determination of the jet's trajectory. Much less has been studied the structure of the flow and regularities of mixing. Lack of knowledge about the nature of the flow does not permit to suggest an adequate theoretical model of this phenomenon.

Present report concerns some peculiarities of the flow which were established experimentally. Subsonic nonbuoyant and buoyant jets issuing perpendicularly to the main horizontal stream were studied. Experiments were carried out in a low-speed wind tunnel with the size of working section $1.1 \times 0.9 \times 1.2$ m. Initial parameters of the jet and the main stream were:

$$D_0 = 20 \text{ or } 40 \text{ mm}, \quad v_0 = 1-50 \text{ m/s},$$

$$w = 0.5-11.5 \text{ m/s}, \quad \Delta T_0 = 10-200°.$$

In the course of experiments two complex parameters

$$I = \frac{T_w v_0^2}{T_0 w^2}, \quad J = \frac{g D_0 \Delta T_0 v_0}{T_0 w^3}$$

which are responsible for the influence of initial momentum and initial buoyancy, respectively, were varied in ranges:

$$I = 4-100, \quad J = 0-3.30.$$

Measurements of the temperature fields constitute the main bulk of experimental procedure. These were carried out with help of chromel-copel thermocouple. Also some measurements of the total and dynamic pressures in the plane of symmetry were made by three-hole probe.

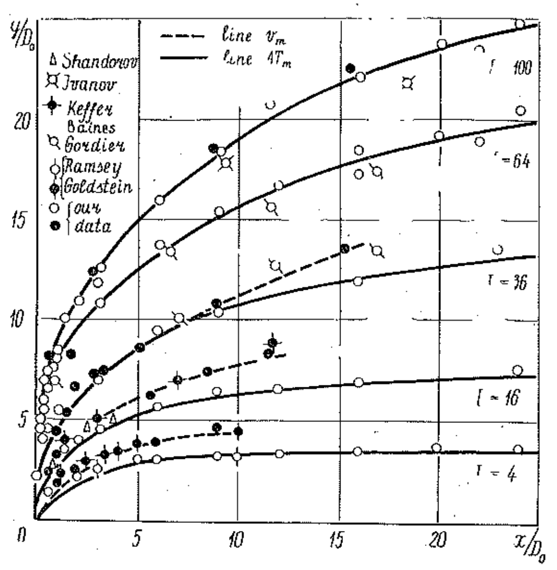

Fig. 1

Measurements were performed in the following manner. Primarily, jet's trajectory was determined. Further, detailed measurements in planes normal to jet's axis were carried out up to distances $x/D_0 = 24$. It is worthwhile to note that the terms "jet axis" or "jet trajectory" have in fact rather conventional meaning because of numerous possibilities to determine them. Figure 1 shows the trajectories of non-buoyant jets at different values of I. Solid lines correspond to temperature maxima and dotted lines to velocity maxima. As it can be seen, the difference between these two lines tends to increase with distance and is more pronounced at smaller values of I. It can also be seen that our experimental data are in a quite good agreement with data of other investigators [1, 2, 4, 5, 6]. Presence of budyancy forces strongly influences the trajectory (Fig. 2). Basic attention in the experiments was devoted to the detailed study of the evolution of temperature distribution in the process of jet development.

Several investigators [1, 2, 3, 4] have noticed some peculiarities of such distributions which strongly differ from distributions in a jet in a stagnant environment. For instance distortion of isotherms and so-called "bifurcation" of the jet were

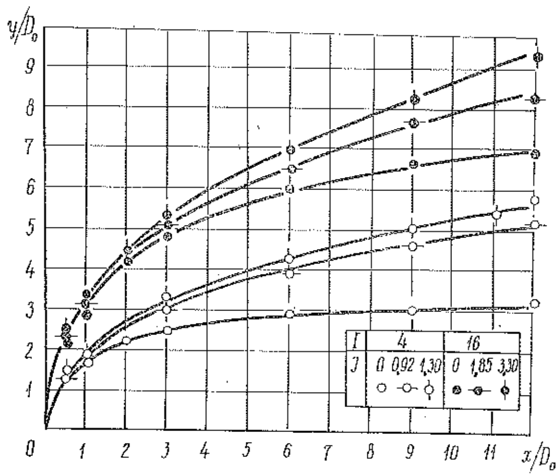

Fig. 2

mentioned but nobody correlated these essential phenomena with parameters of the flow. Our experiments have shown that the pattern of flow can rather be different depending on values of the parameters I and J. It appears that at small values of I=4.16 (for non-buoyant jet) the distortion of isolines which takes place in the proximity to the nozzle (Fig. 3a) tends to decrease quite quickly. Further isotherms restore their shape to almost oval form (Fig. 3b). A quite different pattern of evolution was observed at greater values of $I \geqslant 36$. In these cases, the process of distortion is more efficient. If, at close distances to orifice, cross-section has a typical kidney shape (Fig. 4a) further isotherms show tendency to separation with appearance of two lateral maxima which have greater values than the central one (Fig. 4b). Such basic differences in jet evolution are obviously determined by the peculiarities of jet interaction with the cross flow.

Presence of buoyancy in jet strongly intensifies the process of bifurcation which can now be observed even at small values of I (Fig. 5a, 5b). To get a more quantitative picture of process, the experimental data presented in the form of isotherms were analysed in the terms of "equivalent" jet. Corresponding "equivalent" radius was calculated as

(1) $$r = \sqrt{\frac{S}{\pi}},$$

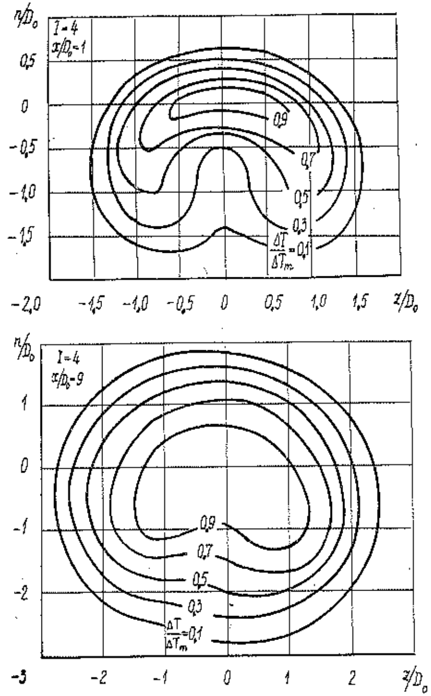

Fig. 3

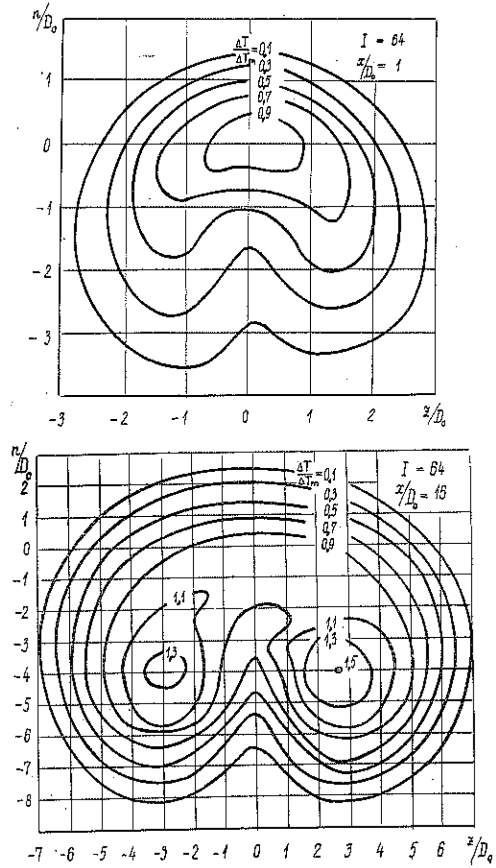

Fig. 4

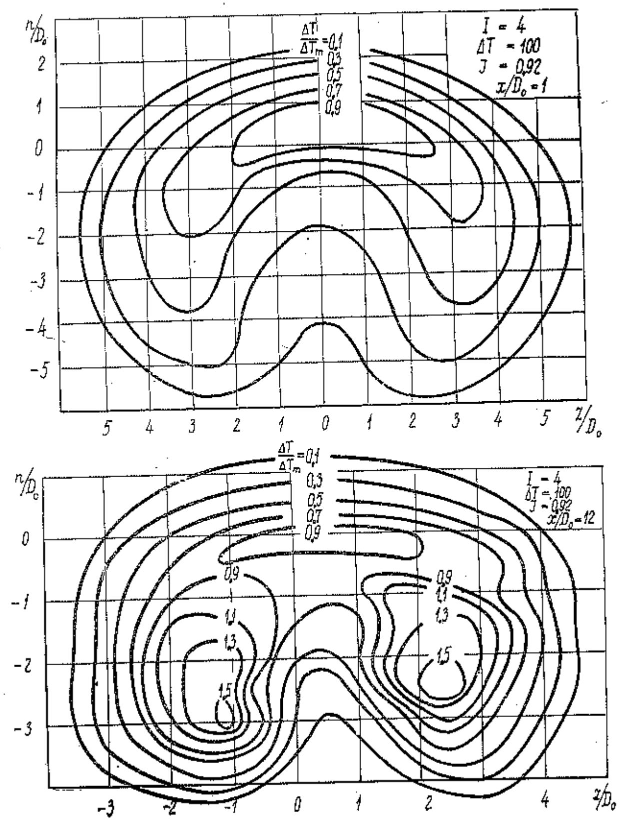

Fig. 5

where S is the area enclosed by certain isotherm. In Fig. 6, the data for two values of I are plotted in coordinates $\Delta T/\Delta T_m$, $r/r_{0.5}$ (where $r_{0.5}$ is the „half" radius). It can be observed in the figure that, at distances in the proximity to nozzle, the experimental data may be described by well-known jet profiles (Gaussian or Shlichting's) in spite of considerable random scattering. At larger distances, experimental points deviate from these profiles and tend to form more narrow profiles also with tendency to similarity.

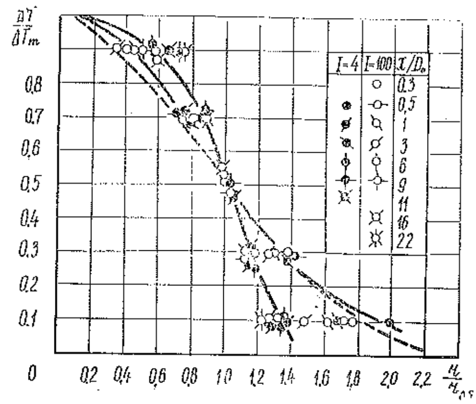

Fig. 6

In Fig. 7 the lateral width of non-buoyant jet (determined by isotherm $\Delta T = 0.1 \Delta T_m$) is plotted against the coordinate y corresponding to the temperature maximum. It appears that the spreading of jet can be described by linear functions, moreover, the rate of spreading depends on value of the parameter I (the larger is I, the slower spreads the jet). It can also be seen that the graphs of spreading of jet consist of two sections and the angle coefficient of the second section is larger than coefficient of the first. The coordinate of the point of

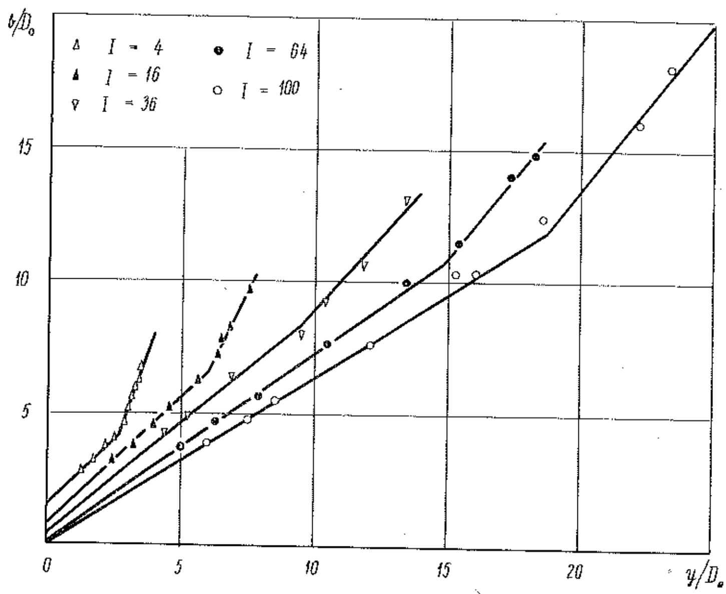

Fig. 7

break also depends on I. Similar regularities were found for buoyant jets but no dependance on the parameter J was noticed.

It is necessary to point out that the above-mentioned transition from one to the other form of the temperature profile takes place in the same region where the more rapid spreading of jet starts.

On the basis of the experimental data obtained it is possible to speak about two different stages of development of the jet in a cross flow. In the first stage this flow retains some general features of typical jet flows. However, in the second stage it is apparently more common with the cylindrical puffs or thermals, which is consistent with ideas put forward by SCORER [7].

REFERENCES

1. Ю. В. Иванов, *Эффективное сжигание надслойных горючих газов в топках,* Эст. Госиздат., Таллин 1959.
2. Г. С. Шандоров, *Истечение из канала в неподвижную и движущуюся среду,* ЖТФ, 27, 1, 1957.
3. И. В. Палатник, Д. Ж. Темирбаев, *Закономерности распространения осесимметричной воздушной струи в сносящем однородном потоке,* Сб. Проблемы теплоэнергетики и прикладной теплофизики, 4, изд. „Наука", Алма-Ата.
4. G. F. KEFFER, F. D. BAINES, *The round turbulent jet in a cross wind,* J Fluid Mech., 15, 4, 1963.
5. R. L. GORDIER, *Studies of fluid jets discharging normally into moving liquid,* St. Anthony Falls Hydraulics Lab. Univ. Minnesota, Techn. paper No. 28, series B, 1959.
6. J. W. RAMSEY, R. J. GOLDSTEIN, *Interaction of a heated jet with a deflecting stream,* NASA GR-72613 HTL TR No. 92.
7. R. S. SCORER, *Natural aerodynamics,* Pergamon Press, 1958.

STRESZCZENIE

NIEKTÓRE WŁAŚCIWOŚCI STRUG W ODCHYLAJĄCYM JE STRUMIENIU

Przedstawiono wyniki badań eksperymentalnych nad strugami turbulentnymi przenikającymi do przepływającego poprzecznie ośrodka, zarówno przy obecności jak i nieobecności sił wyporu. Wykazano, że struktura przepływu zależy od początkowego stosunku pędu strugi do pędu ośrodka, jak również od początkowego stosunku wyporu strugi do pędu ośrodka. Dla danych wartości tych stosunków zaobserwowano różne rozkłady temperatur w różnych odległościach od przekroju początkowego, stwierdzając jednocześnie tendencję do występowania podobieństwa w każdym przekroju.

Резюме

НЕКОТОРЫЕ ОСОБЕННОСТИ СТРУЙ В ОТКЛОНЯЮЩЕМ ПОТОКЕ

Представлены результаты исследований турбулентных струй, втекающих в поперечный поток, при отсутствии и при наличии выталкивающих сил. Показано, что картина течения зависит от начального отношения количества движения струи и потока, а также от начального отношения плавучести струи и количества движения потока. Для данного отношения наблюдались различные распределения температур на разных расстояниях от начального сечения струи, но с тенденцией к подобию в каждом сечении.

INSTITUTE OF THERMOPHYSICS
ACADEMY OF SCIENCES OF U.S.S.R. TALLIN

Received September 21, 1973