T H E A R C H I V E O F M E C H A N I C A L E N G I N E E R I N G

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EFFECT OF PIPE LENGTH ON THE CHARACTERISTICS OF ISSUING HELICAL JET

The helical flow is generated by a jet from a single nozzle inflowing tangentially into a pipe. The effect of the distance travelled by the air in the pipe from its tangential inlet to its axial outlet on the issuing jet is investigated. The axial and tangential velocity distributions were measured at the outlet cross-section of the pipe using the hot-wire probe. It was observed that for a short pipe the strongest asymmetry of the flow velocity distributions exists for a part of the pipe cross-section near the pipe wall. Contrary to this, for a long pipe, the largest deviations from axisymmetry appear in the middle part. In this result the total effect of asymmetry expressed by RMS of swirl number considerably decreases.

1. Introduction

Axisymmetric flow with tangential velocity component is defined as the swirling flow. Swirling flows exist in aircraft engines, cyclones, pneumatic conveying systems and suchlike. Swirling is a well known technique used to enhance the mass and heat transfer in burning process.

Much effort has been devoted in last years to study the characteristics of turbulent swirling flows in pipes [1], [2], [3], [4], [5]. In several experimental investigations of this problem, it was observed that the tangential and axial velocity distributions are continuously changing as they approach fully developed parallel flow. It was noted that the distance required to reach a nearly parallel flow depends on the initial swirl intensity, roughness of the pipe wall surface and the Reynolds number. The experiments were conducted with the use of swirl generators prepared to have the axisymmetric flow of high quality, i.e. characterized by uniform flow velocity distributions on concentric circles. Such

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a flow, however, does not exist in majority of industrial flow systems in which swirling is employed. Very frequently, the swirling flow is generated by a jet from a single nozzle inflowing tangentially into a pipe. Due to the asymmetric supply, a screw-like jet superimposed on the mean swirling flow appears in the pipe. This complex flow pattern, the helical flow, is investigated experimentally in the present paper. The goal of these investigations is to find the characteristics of the jet issuing from the pipe depending on the pipe length, i.e. on the distance from its tangential inlet to its axial outlet.

2. Swirl intensity

For axisymmetric flow, the swirl intensity S, the normalized angular momentum flux, is defined as

$$S = 2\pi\rho \int_0^R u \, \mathrm{v} \, r^2 dr \Big/ \pi\rho \, R^3 U^2 , \tag{1}$$

where u, v and U are the axial, tangential and bulk velocity, respectively, r and R radial coordinate and the pipe radius, ρ is fluid density.

For asymmetric (helical) flow, the average values of flow velocities $\bar{u}$ and $\bar{\mathrm{v}}$ on concentric circles are used in relationship (1) to calculate the average angular momentum flux $(\bar{S})$. The deviation from axial symmetry is expressed by root-mean-square (RMS) of S

$$\varepsilon = \frac{\int_0^R r^2 \int_0^{2\pi} \sqrt{(u-\bar{u})^2 (\mathrm{v}-\bar{\mathrm{v}})^2} \, d\theta \, dr}{2\pi \int_0^R \overline{u\mathrm{v}} \, r^2 dr} . \tag{2}$$

3. Experimental set-up

A schematic diagram of the experimental set-up is shown in Fig. 1. The test pipe (70 mm in diameter) was supplied with compressed air from two nozzles. One of them was placed coaxially with the pipe and the other tangentially to the pipe wall (normally to the pipe axis). The axial jet was used to avoid the secondary back flow which could exist in the core of the swirl flow. The flow rates of both tangential and axial jets from the nozzles were adjusted by means of valves and measured by diaghragms.

Several pipes of relative length $L/R = 4, 6, 8, 14$ and 20 made of the polyvinyl chloride were used in the experiments. For each pipe, the axial and tangential velocity components were measured at their outlet cross-sections at points distributed on the circles with radii 10, 15, 20, 25, 30 and 32,5 mm with the step of the azimuthal coordinate 20°. An x-hot wire probe with 5 μm tungsten sensors was used.

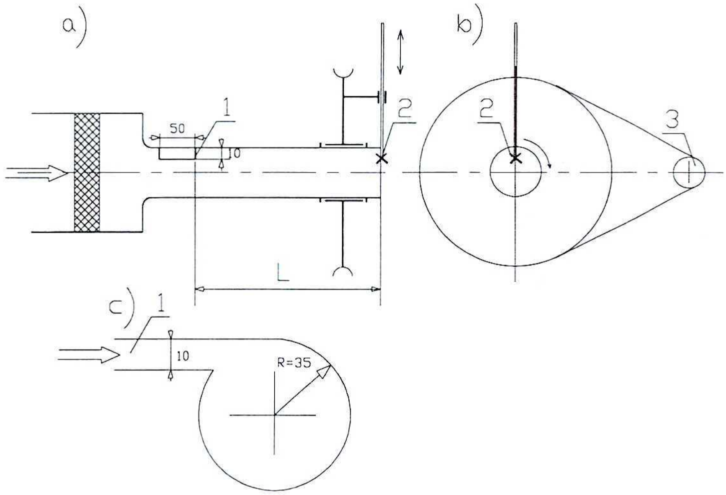


Fig. 1 Experimental set-up, (a) general scheme, (b) driven system of x-wire probe, (c) pipe cross-section with tangential nozzle, 1 – tangential nozzle, 2 x-wire probe, 3 – step motor

The data acquisition system was based on a PC computer and 12 bit A/D converter. All sampling procedures were controlled by the computer. It also drove a system of a step motor automatically adjusting the azymuthal position of the x-probe. Constant pressure of supplied air was maintained during the experiments. The Reynolds number $\mathrm{Re} = \dfrac{4Q}{\pi D \nu \rho}$ (where Q is the flow rate, D the pipe diameter and ν the viscosity coefficient) was in the range from 10^5 to $1.2 \cdot 10^5$ for pipes of lengths mentioned above.

4. Results

Axial and tangential velocity distributions around selected circles are displayed in Fig. 2. It is visible that the distributions have distinct maxima and minima. For any pipe from the series under consideration, the maxima and minima occur at nearly constant azymuthal coordinates. These coordinates changed periodically in the range from 0 to 360° as the successive pipes with increasing lengths were installed. This proves that flow velocity distribution in the pipe is of a screw-like shape. For a short pipe, the strongest variations of axial velocity (u) exist around the circles near the pipe wall.

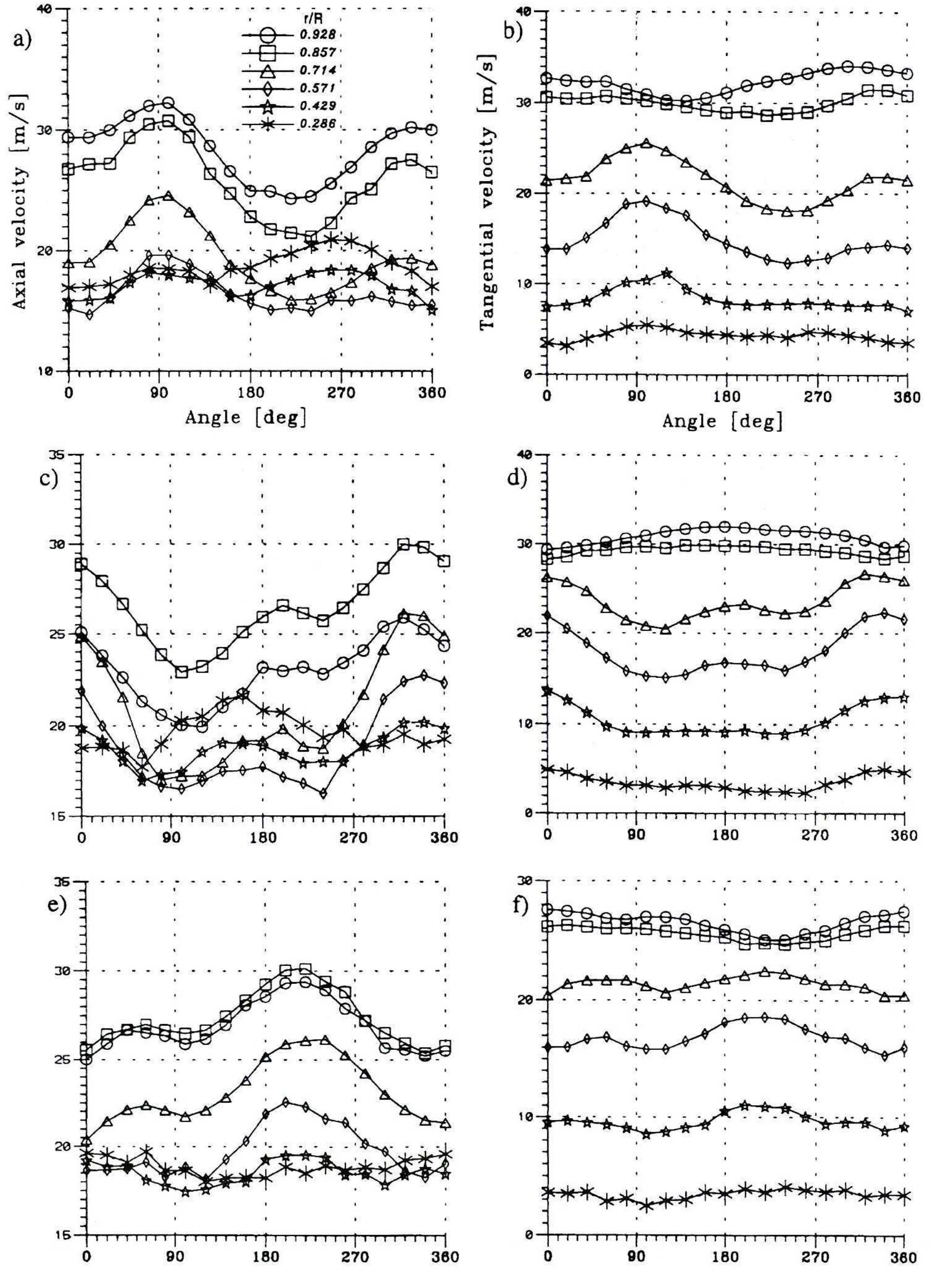


Fig. 2 Continuation in next page

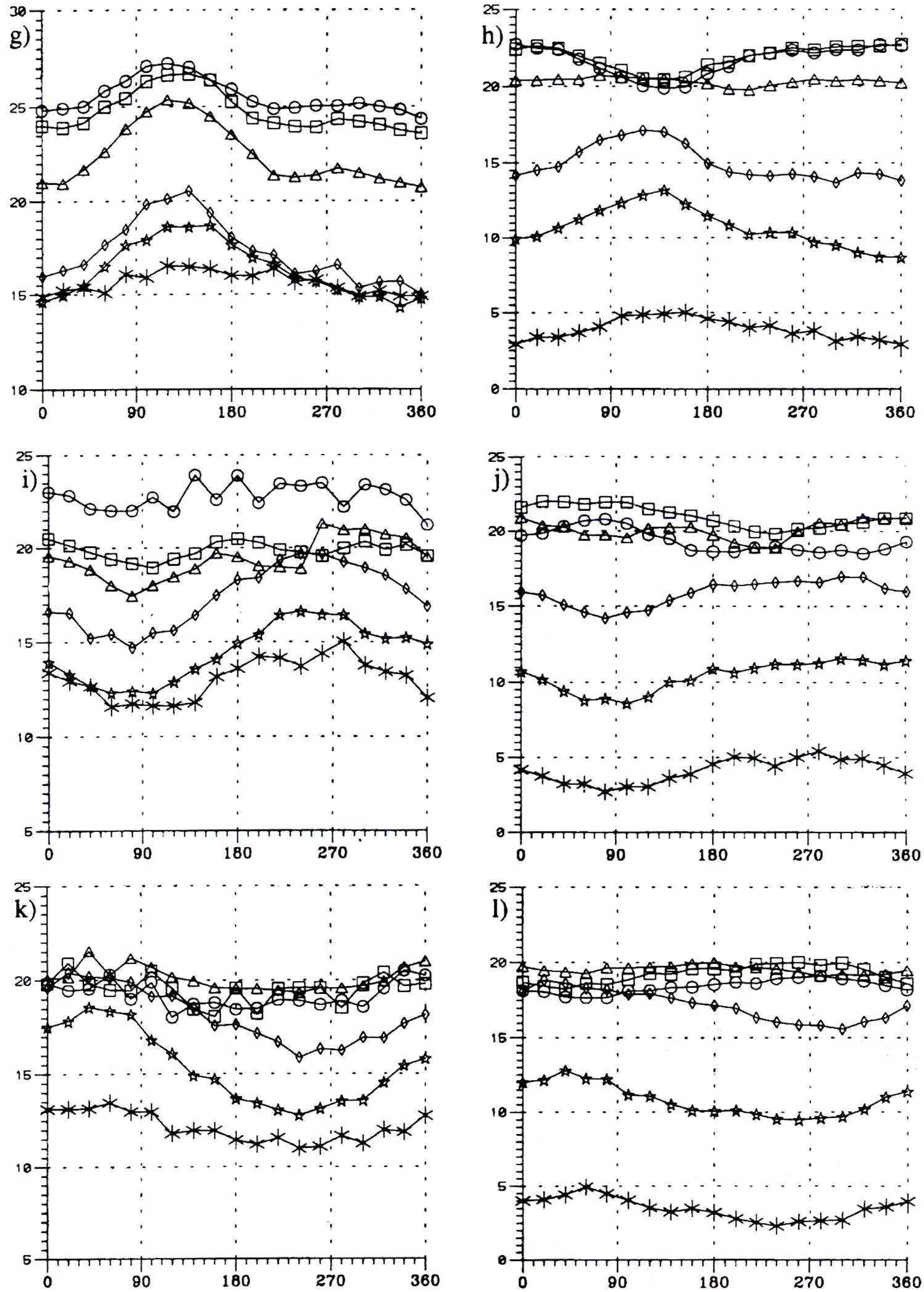


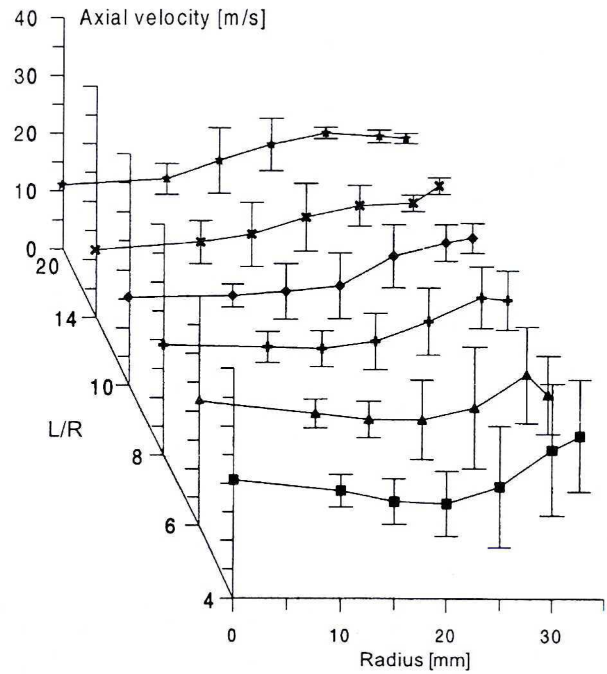
Fig. 2 Azymuthal distributions of axial (left column) and tangential (right column) flow velocity components, L/R=4 (a,b), 6(c,d), 8(e,f), 10(g,h), 14(i,j) and 20(k,l)

As the pipe length increases, this is observed around circles of smaller radii. Simultaneously, the deviations from uniform distributions decrease. The tangential velocity component (v) shows, to some extent, an analogous behaviour. In this case, however, the strongest variations occur around the circles smaller then the circles corresponding to the largest amplitude of the axial velocity.

Figure 3 shows the radial distributions of the flow velocity components averaged around the circles. Deviations from average values for each circle are marked by vertical segments. They are obtained from the curves in Fig. 2 by neglecting the higher order components of u and $v(\theta)$ spectra. One can note that the average flow velocity profiles at the outlet cross-section of the pipe distinctly depend on the pipe length. For a short pipe $(L/R=4)$, the maximum tangential flow velocity exists close to the pipe wall. For a long pipe $(L/R=20)$, the maximum occurs at $r/R=\sim 0.7$. This suggests that the swirl flow approaches to the Rankine-like vortex observed in previous papers [3], [4], [5]. The axial flow velocity distributions $\overline{u}(r)$ also depends on the tube length. For a short pipe $(L/R=4)$ a distinct minimum of $\overline{u}$ can be noted at $r/R\approx 0.7$. As the pipe length increases, the minimum disappears $(L/R=8)$. Eventually, for a long pipe $(L/R=20)$, the axial flow velocity, like the tangential one, reaches the maximum for $r/R=\sim 0.7$.

The integral effects of pipe length on helical flow characteristics are shown in Figs 4a-4c. The curves in these figures were obtained by interpolation of experimental results using the function $y=\alpha\, x^{-\beta}$, where α and β are constant coefficients. The coefficients were obtained using the least square interpolation method. They are as follows: for flow rate $\alpha=0.15$, $\beta=0.1383$; for swirl number $\alpha=1.124$, $\beta=0.1639$; for RMS of swirl number $\alpha=0.2273$, $\beta=0.8575$. Due to friction, the flow rate decreased as the pipe length was increased (the supply pressure was constant). The flow rate for the longest pipe was about 20% lower then for the shortest one (Fig. 4a). The 23% decay of swirl number was observed (Fig. 4b). The decay of swirl, however, is not proportional to the decay of flow rate; the swirl is normalized with the momentum flux based on the bulk velocity (see formula 1). Strong decay of the RMS of the swirl number was observed in the present experiments (Fig.4c). It decreased from 0.07 to 0.02 as the pipe length was increased from $L/R=4$ to $L/R=20$. This high decrease of RMS is presumably caused by the secondary flow (across the pipe) which appears due to asymmetric pressure distributions in the pipe cross-sections induced by asymmetric tangential velocity profiles.

(a)



(b)

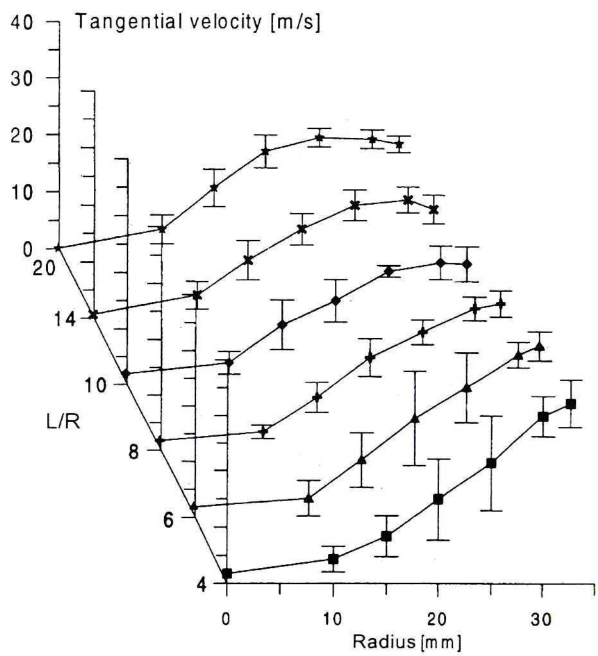


Fig. 3 Radial distributions of axial (a) and tangential (b) flow velocities averaged around circles and extremal deviations around each circles (vertical segments)

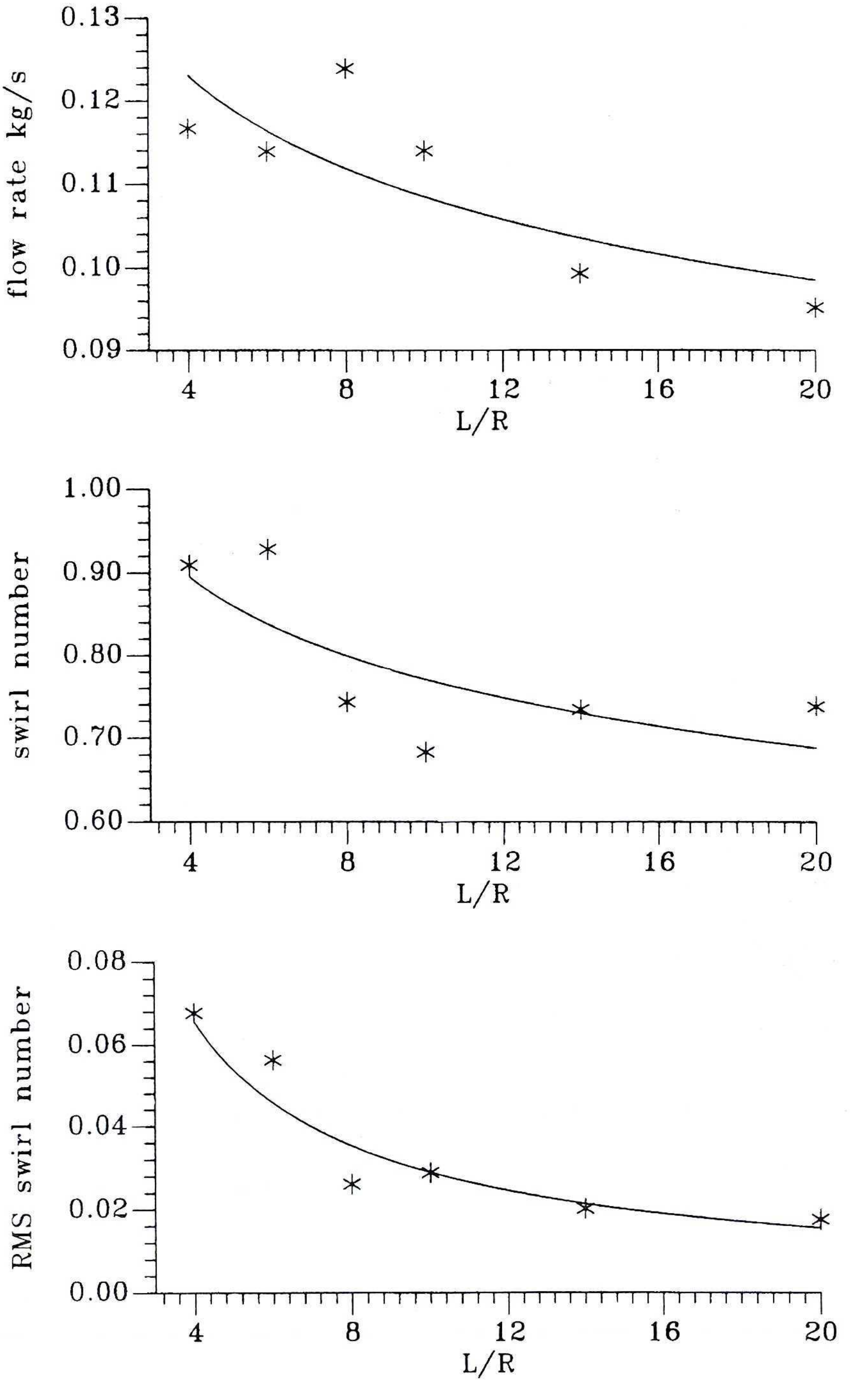


Fig. 4 Flow rate (a), swirl number (b) and RMS of swirl number (c) versus tube length

5. Conclusions

As could be expected, the present preliminary investigations of the helical flow show that the issuing jet characteristics strongly depend on the distance travelled by the air from the tangential inlet to the axial outlet of the pipe. This is revealed in the changing of the asymmetric axial and tangential flow velocity distributions. For a short pipe, the strongest asymmetry exists for a part of the pipe cross-section near the pipe wall. Contrary to this, for a long pipe, the largest deviations from axisymmetry appear in the middle part. In this result, the total effect of asymmetry expressed by the RMS of the swirl number considerably decreases.

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Własności strumienia helikalnego wypływającego z przewodu

S t r e s z c z e n i e

Strumień helikalny wytwarzany jest w przewodzie przez styczny do jego obwodu nadmuch powietrza.

Badany jest wpływ, na strukturę strumienia, drogi przez niego przebytej między stycznym wlotem i osiowym wylotem. Badania prowadzone są poprzez pomiary rozkładów prędkości, w kierunkach osiowym i promieniowym, przy pomocy krzyżowej sondy termoanemometrycznej. Stwierdzono, że w przypadku krótkiego przewodu najsilniejsza osiowa niesymetria strumienia wylotowego występuje w części jego przekroju w pobliżu ścianki. W przypadku długiej rury, w wyniku działania tarcia, niesymetria w tej części zanika. Utrzymuje się natomiast w centralnej części przekroju. W efekcie globalna asymetria wyrażona przez RMS stopnia zawirowania maleje.