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# REYNOLDS NUMBER INFLUENCE ON INTEGRAL AND STATISTICAL CHARACTERISTICS OF THE TURBULENT SWIRL FLOW IN STRAIGHT CONICAL DIFFUSER

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**Abstract**:

Results of experimental investigations of the turbulent swirl flow in straight conical diffuser are presented in this paper. Diffusers have the inlet diameter 0.4 m and total divergence angles 8.6°. The incompressible swirl flow field is generated by the axial fan with outer diameter 0.397 m. Measurements are performed in one measuring sections downstream the axial fan impeller, i.e. in conical diffuser ($z/R_0 = 1$) with one-component laser Doppler anemometry (LDA) system, for four flow regimes. Axial and circumferential velocities are measured. Reynolds numbers calculated on the basis of the average axial velocity, ranges from 149857 to 216916. Integral parameters, such as volume flow rate, average circulation and swirl number are determined. Statistical characteristics are calculated such as level of turbulence, skewness and flatness factors. The highest levels of turbulence for axial velocity are reached in the region $0.4 < r/R < 0.6$, where $D = 2R$. The highest levels of turbulence for circumferential velocity are reached in the region around $r/R \approx 0.4$ for lower values of circulation, respectively in the core region for higher values of circulation.

**Key words**: turbulence, swirl, flow, fan, diffuser, LDA

## 1. Introduction

An overview of the turbulent flow experimental research in diffusers is presented in papers [1], [2]. Statistical properties of the turbulent swirl flow in diffusers are studied in [3]. Study of the influence of Reynolds number on integral and statistical properties of generated turbulent swirl flow is studied in [4], [5]. Results of experimental investigations of the turbulent swirl flow in three straight conical diffusers with various diffuser total angles (8.6°, 10.5° and 12.6°) are presented in paper [6] and [7]. Original classical probes were used for those measurements. One of those diffusers, with angle of 8.6°, is the subject of research in this paper. Laser Doppler anemometry systems were used for measurements.

## 2. Experimental test rig and measuring techniques

Experimental test rig, for the turbulent swirl flow researches, is shown in Fig. 1 [2], [6], [7].

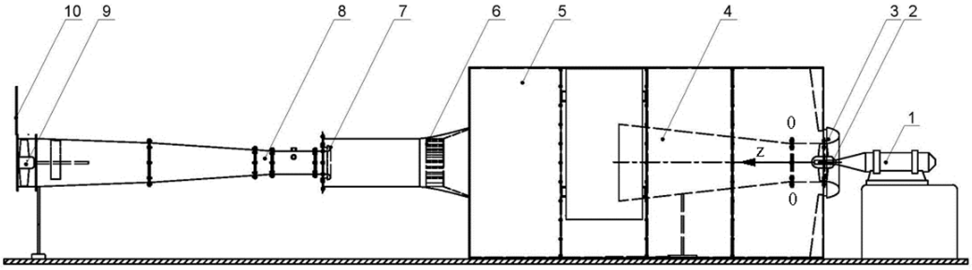



Figure 1. Test rig for experimental investigation

The incompressible swirl flow field is generated by the axial fan impeller (2) with rotational speed controlled motor (1) (Fig. 1). The main geometry characteristics of the axial fan impeller, model AP 400, Minel, Serbia, are given in [8]. Impeller has seven blades adjusted at the angle of 29° at the outer diameter. The axial fan is in-built in the straight pipe section with a profiled inlet nozzle (3). The impeller is followed by the straight conical diffuser (4), which is placed in the chamber (5). The test bed is equipped with the honey-comb (6), flow meter (nozzle) (7), pipe (8), booster fan (9) and flow regulator (10).

The diffuser has inlet diameter $D_0$ = 0.4 m, outlet diameter $D_9$ = 0.67 m, length $L$ = 1.8 m and angle $\alpha_{dif}$ = 8.6°.

Velocity fields were measured at cross-sections, number 2 in [6], [7], $z_2$ = 0.2 m, $z_2/R_0$ = 1, $z_2/L$ = 0.22, in one measuring direction with 21 measuring points along the radius $R_2$. Measurements were performed for 4 regimes, with different booster fan rotation speed, same fan rotation speed ($n$ = 1000 $\text{min}^{-1}$) and open flow regulator position.

One-component LDA measurements have been performed successively for all two velocity components in specified measurement sections along the horizontal radius on distance 10.9 mm ($0.05R_2$) each. LDA systems (Dantec, laser power 35 mW), signal processor (BSA F30) and thermal fog machine for seeding (Antari Z3000II, liquid EFOG) described in **Error! Reference source not found.**. Seeding was naturally sucked in the test rig by the fan. On the diffuser are made slots for the laser beam so that the measuring direction coincides with the horizontal axis cross-section of the diffuser. Over these openings are glued to the foil (Fig. 2.).

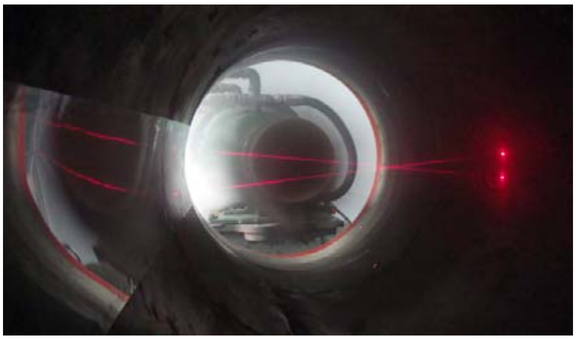


Figure 2. Laser Doppler anemometer measurements in diffuser

### *2.1 Integral and statistical characteristics*

Volume flow rate is calculated as:

$$Q = 2\pi \int_0^{R_2} rU\mathrm{d}r \,. \tag{1}$$

Average circulation is given as:

$$\Gamma = \frac{4\pi^2}{Q_2} \int_0^{R_2} r^2 W U dr . \tag{2}$$

Swirl flow parameter [2] is defined as:

$$\Omega = \frac{Q}{R_2 \Gamma} . \tag{3}$$

Average axial velocity is defined as:

$$U_m = \frac{Q}{\pi R_2^2} . \tag{4}$$

Reynolds number:

$$\mathrm{Re} = \frac{U_m D_2}{\nu} . \tag{5}$$

Reynolds normal stresses and levels of turbulence for axial and circumferential velocities are calculated as follows [4, 8]:

$$\overline{\boldsymbol{u_i^2}} = \sum_{j=0}^{N-1} \eta_j \left(\boldsymbol{u_i^2}\right)_j , \quad \text{where } \eta_j = \frac{\boldsymbol{t_j}}{\sum_{k=0}^{N-1} \boldsymbol{t_k}} \quad \text{and} \quad \frac{\sigma_{\mathrm{i}}}{\boldsymbol{U_m}} = \frac{\sqrt{\overline{\boldsymbol{u_i^2}}}}{\boldsymbol{U_m}} . \tag{6}$$

Here $\eta_j$ is weighting factor, $t_j$ is transit time of the $j$-th particle crossing the measuring volume and $u_i = u$ and $w$ are fluctuating velocities in axial ($x$) and circumferential ($\varphi$) directions respectively.

Normalized central moments for axial and circumferential velocity components of the third $S_i$ (skewness), and the fourth order $F_i$ (flatness) are calculated in the following way:

$$S_i = \overline{u_i^3} / \sigma_i^3 , \quad F_i = \overline{u_i^4} / \sigma_i^4 . \tag{7}$$

## 3. Experimental results

Experimentally obtained time averaged dimensionless axial ($U$) velocity and time averaged dimensionless circumferential ($W$) velocities are presented in Fig. 3.

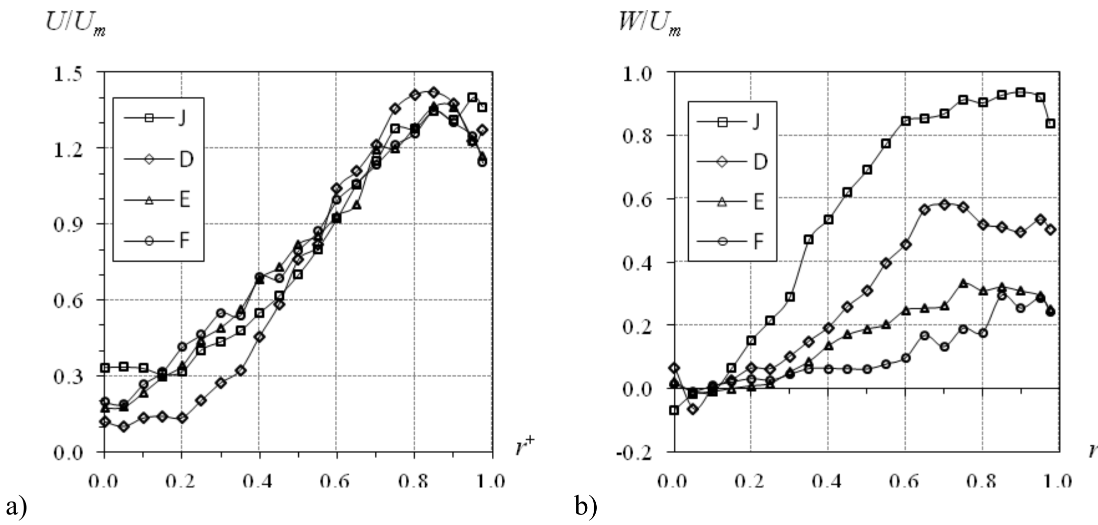



Figure 3. Dimensionless a) axial and b) circumferential velocities in measuring sections 2 in diffuser, for regimes J, D, E and F

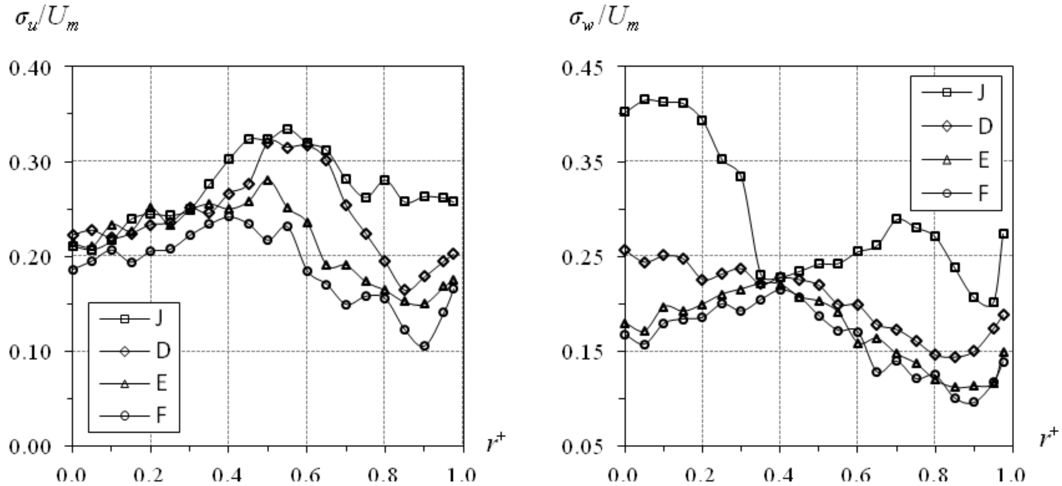
Non-dimensional axial velocity profiles are almost the same for all regimes, so these distributions are similar. Circumferential velocity distributions for all regimes have in the central flow region forced vortex distribution, while mainly uniform distribution for $r^+ = r/R_2 > 0.65$. The highest circumferential velocity is achieved of case J, without booster.

Integral flow parameters in measuring sections 2 such as volume flow rate, average circulation, swirl flow parameter, average axial velocity and Reynolds number, are calculated on the basis of eq. (1-5) and presented in Table 1.

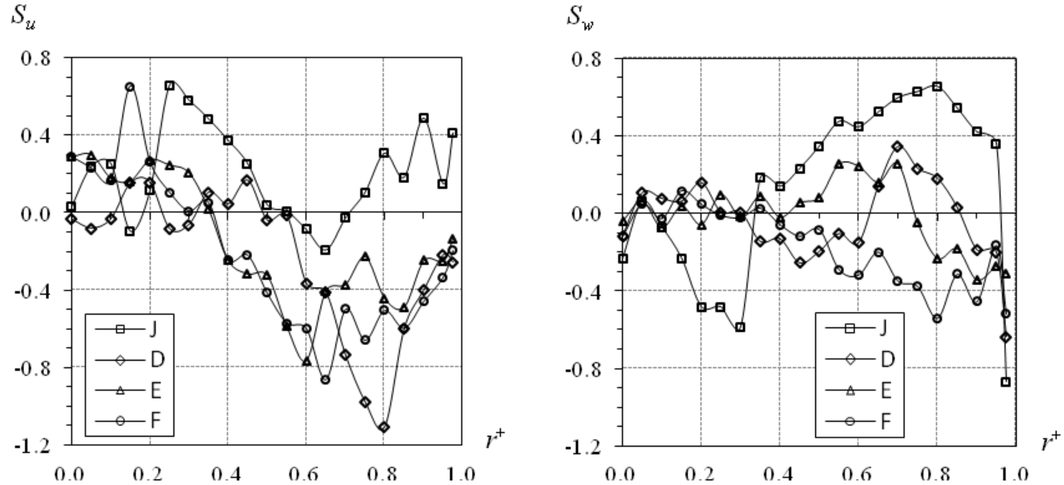
| Regime | $Q$ [m$^3$/s] | $\Gamma$ [m$^2$/s] | $\Omega$ [-] | $U_m$ [m/s] | Re [-] | Booster |
|---|---|---|---|---|---|---|
| J | 0.720 | 4.27 | 0.78 | 4.87 | 149857 | no |
| D | 0.899 | 3.10 | 1.33 | 6.02 | 185201 | yes |
| E | 0.995 | 1.84 | 2.47 | 6.66 | 204932 | yes |
| F | 1.050 | 1.41 | 3.43 | 7.05 | 216916 | yes |

Table 1. Calculated integral flow parameters in measuring sections 2

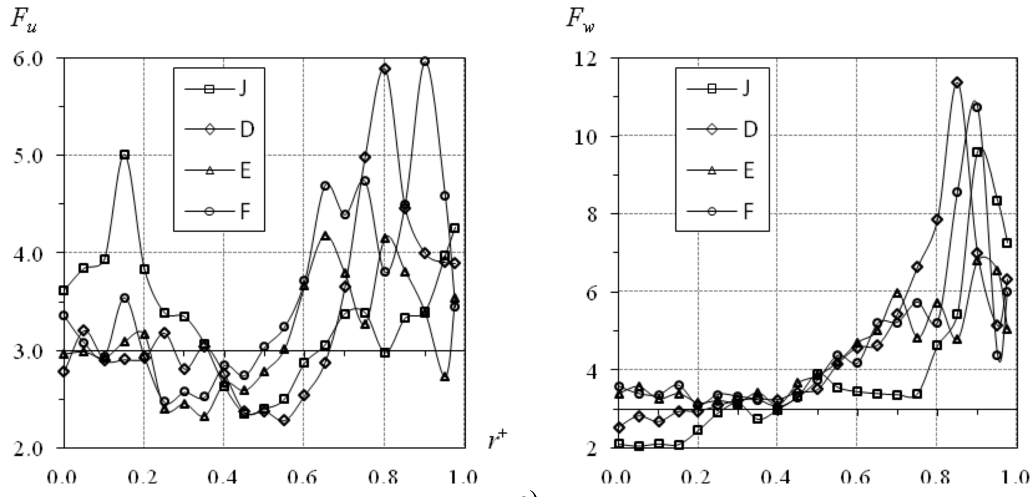
Distributions of the turbulence level, skewness ($S_w$) and flatness ($F_w$) factors for both velocities in measuring section 2 are presented in Fig. 4. These statistical values are calculated on the basis of the relations (6-7).




a)




b)




c)

Figure 4. Statistical moments in diffuser (measuring section 2) for four regimes: a) turbulence level, b) skewness and c) flatness factors for axial and circumferential fluctuating velocities

The highest levels of turbulence for axial velocity are reached in the region $0.4 < r/R_2 < 0.6$, for all regimes. The highest levels of turbulence for circumferential velocity are reached in the region around $r/R \approx 0.4$ for regime E and F (with higher values of Re and $Q$, and lower values of circulation), respectively in the core region $0 < r^+ < 0.3$ for regime D and J (with lower values of Re and $Q$, and higher values of circulation) (Fig. 4a).

Distribution of the skewness factor is non uniform for all regimes (Fig. 4b). It is not equal to Gaussian probability distribution value ($S_w = 0$), as well that negative and positive values occur. Skewness factor for axial fluctuating velocities has maxima in the center of the diffuser (central flow region). It has minimum in $r^+ = 0.65$ for regime J, without booster fan. Skewness factor for circumferential fluctuating velocities for regimes with booster fan has values close to 0 in the center of the diffuser and oscillates around it till $r^+ = 0.3$.

Flatness factor for axial fluctuating velocity differ from value 3 for all regimes. The highest values are reached for regime J in the vortex core, while in the rest of the measuring section for regime F. Distribution of flatness factor for circumferential fluctuating velocity is similar for almost all regimes. $F_w$ oscillates around the value for normal, i.e., Gaussian probability distribution ($F_w = 3$) till $r^+ = 0.4$, for regimes with booster fan. The biggest difference is for regime J without booster fan (Fig. 4c).

## 4. Conclusions

Experimental investigation of the turbulent swirl flow in straight conical diffuser behind the axial fan is presented in this paper. Measurements are performed with one-component laser Doppler anemometry (LDA) system.

Similar axial velocity distributions are achieved. Solid body circumferential velocity profiles are generated for all regime (Reynolds numbers ranges from 149857 to 216916).

Statistical moments up to the fourth order are calculated. High values of statistical moments and significant deviation from normal, i.e., Gaussian distribution in measuring sections for all regimes, are determined on the basis of the experimental results.

Influence of Reynolds number on all statistical characteristics is obvius. It is shown (Fig. 4a) that the smallest values for turbulence levels, for both velocities are reached for the regime F with the highest Reynolds number and vice versa in regime J, without booster fan. Distributions for axial velocity are more similar, then for circumferential fluctuating velocities, where regime J has completely different character. This is correlated to the values of average circulation (Table 1).

These experiments, as well as in the pipe [5], discover intermittent character of the observed turbulent flow, as well, the existence of the coherent structure in the vortex core and shear layer.

## 5. Acknowledgments

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