THE INFLUENCE OF NOZZLE CONTRACTION UPON THE NEAR FLOW FIELD FOR AXISYMMETRIC FREE JET

A. Pawłowska, N. Obała

Institute of Thermal Machinery, The Faculty of Mechanical Engineering and Computer Science, Czestochowa University of Technology, Armii Krajowej 21, 42-200 Czestochowa

Abstract

The paper presents the results of experimental research in axisymmetric free jet performed in order to compare two test rigs (vertical aerodynamic channels) with different area contraction ratios of a nozzle. Both test rigs are of identical design as far as the settling chamber is concerned, but they have different area contraction ratio of a nozzle equal to , C_1 = 144 and C_2 = 225 respectively. Experiment was performed for range of the Reynolds number from 5 000 to 20 000, cylindrical nozzle extensions were used to change the exit shear layers thickness. Velocity and turbulence intensity distributions at the nozzle exit and along the jet axis were analysed. Integral parameters, maximum values of turbulence intensity in shear layer and mean values of turbulence intensity in a potential for two test rigs are also presented. Measurements were taken using the single wire CTA probe.

Keywords: inlet conditions, axisymmetric free jet, turbulence intensity

1 Introduction

The paper presents the comparison of two test rigs with different area contraction ratios of the nozzle based on the experimental investigation. Those test rigs are to be used for experimental verification of the idea that has been formulated by Bogusławski et al.[1] Regime of self-sustained oscillations under some conditions was found in [1] as a result of numerical investigations provided that sufficiently thin exit shear layer and sufficiently low level of turbulence intensity at the nozzle exit were provided. Experimental verification of the paramount importance of these parameters in existence of self-sustained oscillations was the motivation of present investigation.

As it was found in numerous investigations of the axisymmetric free jet, the near flow field change propagates even to the far flow field, which is caused by the extreme sensitivity of the round jet to initial conditions. As it was stated in review paper by Ball and Pollard [2] as it was also noticed by Nathan [3] *"…jest never forgets…"*. Shape and convection velocities of large-scale vortices may also be affected even by small changes of initial conditions, as it was proved by for example Orlandi [4] and Romano [5]. The influence of jet nozzle contraction upon the distributions of turbulence intensity Tu and integral parameters at the jet inlet were analyzed in the present research in order to examine how the change the area contraction ratio affects the near and far flow field of the axisymmetric jet.

2 Experimental test rig and signal processing

The sketch of the test rig is presented in Fig.1. Two test rigs are investigated. The similar design of the plenum chamber was applied for two test rigs as far as wire screens are concerned, the area contraction ratio was the only one parameter that was different for both test rigs. Experimental test rig No. 1 was characterized by area contraction ratio C_1 = 144, while the second one by C_2 = 225. In both cases the outlet nozzle diameters were equal d = 0.015 [m], the variable contraction ratio was obtained by different diameters of settling chambers.

The air is supplied at the bottom and at the start passes through the heaters, which will be used in the future investigations concerning the influence of inlet overheat ratio. In the heater electric heaters are filled with iron pellets to make the flow more uniform and increase the heat capacity. Then the air enters the settling chamber and gets to the nozzle and to the outlet. Six wire gauzes are located in the settling chamber to make the flow more uniform and reduce the turbulence intensity at the nozzle outlet. Some parts of the rig are located outside the measuring area and are not shown at the sketch.

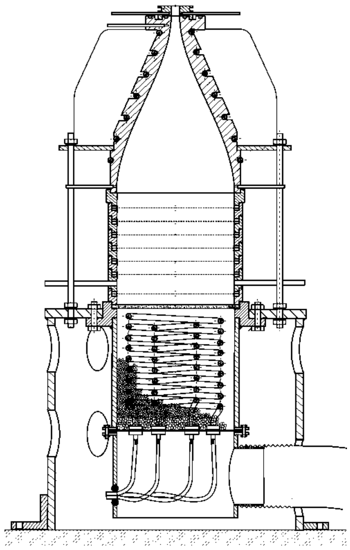

Figure 1: The sketch of the test rig.

Two different values of area contractions ratio applied were supposed to provide different values of turbulence intensity at the nozzle outlet. Cylindrical nozzle extensions were used to vary the exit shear layer thicknesses. The outlet nozzle diameter was equal d = 0.015 [m], while the ratio of lengths “L” to exit jet diameter “d” of cylindrical extensions were equal to : L/d = 1; 7; 15; 25 respectively. The influence of the Reynolds number on the outlet parameters was investigated as well, the rig allows to perform measurements with a range of the Reynolds number from 5 000 to 20 000. Various designs of the shape of the nozzle exit were tested [6] and finally the free-slip nozzle shape was applied for both test rigs.

The standard CTA bridge *DISA* Type 55M10 and single hot-wire probe *DANTEC,* with wire diameter d’= 0.005 [mm] and wire length l’= 2 [mm], were used in all measurements. The external protection wire gauze surrounding the entire measuring volume was used to prevent the influence of draughts and possible convective motions in the laboratory.

Probe was calibrated at each measurement in the range of velocity from minimum one determined by the smallest reading from the micromanometer to the value exceeding the maximum velocity expected for particular Reynolds numbers.

Dual-channel acquisition was carried out, first channel contained AC and DC signal and was a source of data to mean velocity calculation second channel contained AC signal only, these data were amplified and used to turbulence intensity calculation.

3 Discussion of results

Three values of the Reynolds number equal to 5 000, 10 000 and 20 000 were used in the experiment, the Reynolds number was based on outlet nozzle diameter. The goal of investigation was to find difference between mean and fluctuating velocity fields obtained for two test rigs characterized by different area contraction ratio. The results obtained for test rig with smaller contraction ratio are denoted in the paper as “exp. 1” while for the rig with larger contraction as “exp. 2”. Measurements were taken along the jet diameter at the exit plane (denoted as x/d = 0) and along the jet axis “x”, where the distance of the measuring point from the exit plane is denoted as “x/d”. At the exit plane in the shear layer the radial measuring step had to be as small as 0.01 millimetre to achieve the required accuracy of integral parameters and shear layer thicknesses estimation.

The sample distributions of mean velocity “U” and turbulence intensity “Tu” at the exit plane are shown in Fig. 2 for Re = 10 000 and nondimensional length of nozzle extension L/d = 1 for both test rigs analyzed.

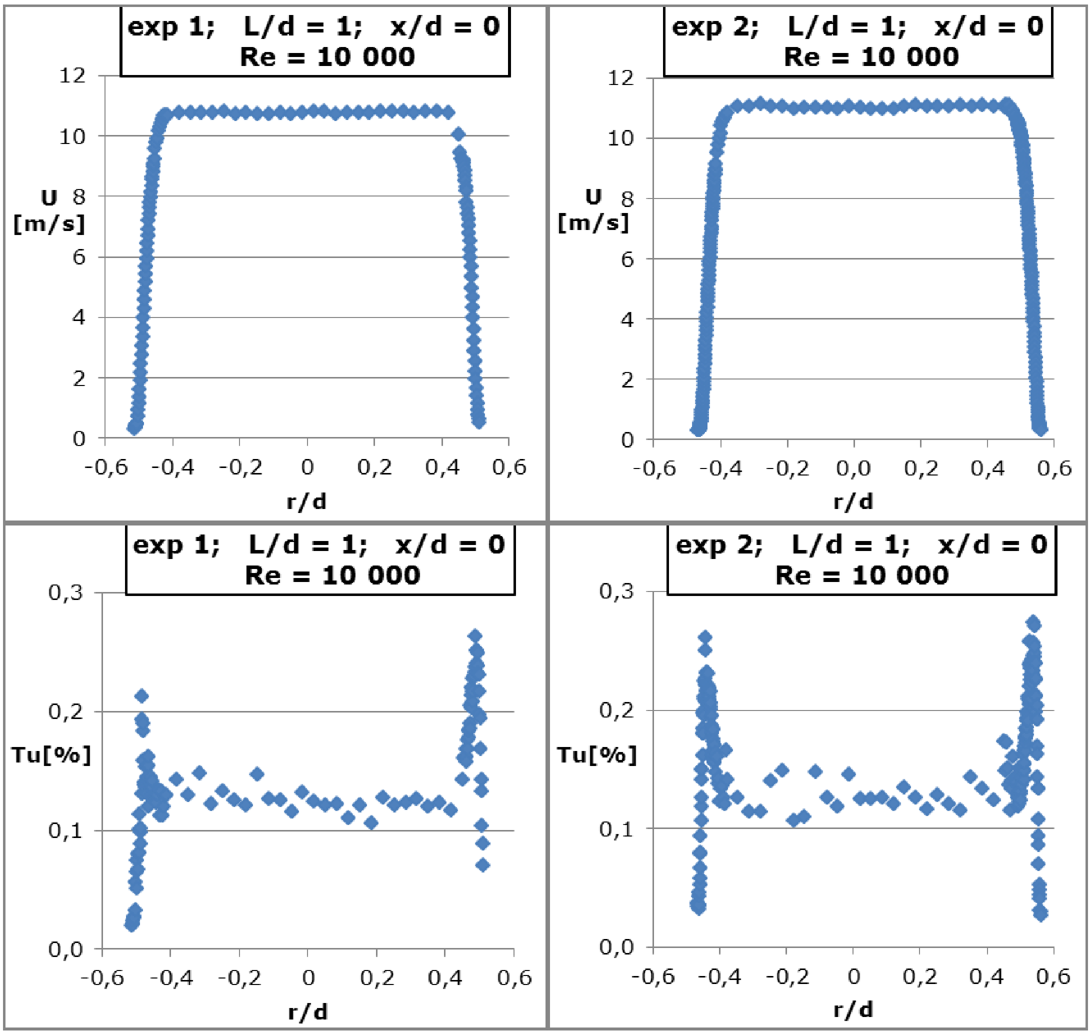

Figure 2: Radial profiles of mean velocity "U" and turbulence intensity "Tu" at the exit plane for Re = 10 000 and nondimensional extension tube length L/d = 1.

One may notice the top – hat profile of mean velocity with negligible overshoot and very thin shear layers, where maximum value of turbulence intensity appears. The large contraction ratio gives a very low level of turbulence intensity Tu < 0.15 [%] in the jet core for both experimental test rigs and similar values of Tu in shear layers. The slight asymmetry visible for both experiments results from very thin shear layers, where the Tu profiles were so sharp that even the 0.01 [mm] elementary probe displacement did not secure that the location of a measuring point coincided with the location of the turbulence intensity peak.

Summary of turbulence intensity measurements taken at the exit plane are shown in Figure 3, which presents maximum values of turbulence intensity in shear layer and mean values of turbulence intensity in potential core.

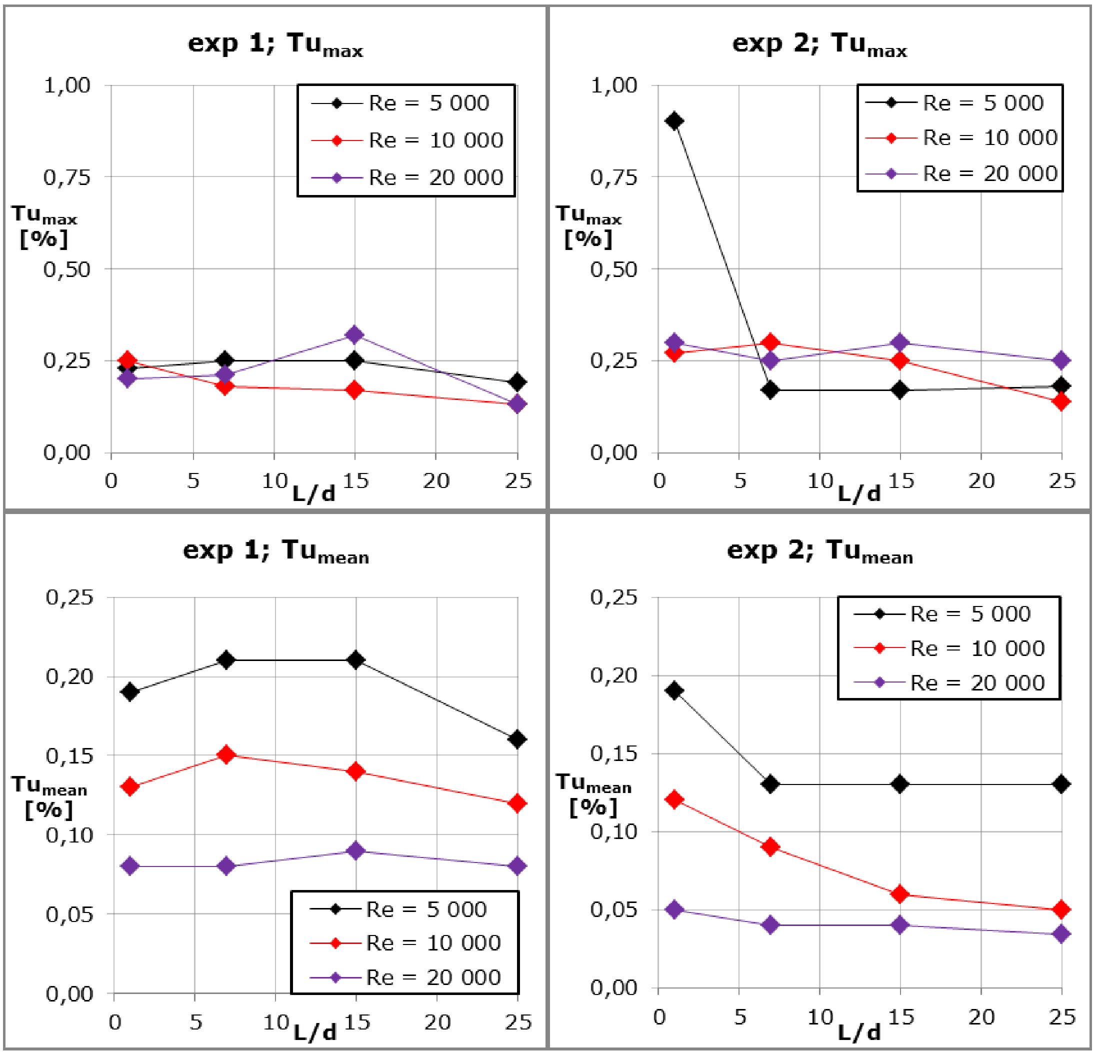

Figure 3: Variance of maximum and mean values of turbulence intensity at the exit plane for each Reynolds number dependent on the extension length.

As can be seen at two upper graphs in Fig. 3 there is virtually no difference in Tu maximum values for two test rigs except the shortest extension L/d = 1 for the Reynolds number equal 5 000 for test rig number 2. Extreme sensitivity to external conditions could be a reason of this strange behaviour. The analysis of two bottom graphs of Fig. 3 reveals that Tu mean values in potential core are lower for experiment number 2, in accordance with the previous expectations.

The integral parameters (given in millimetres) for two test rigs are summarised in Table 1 which presents values of: shear layer thickness "δ", displacement thickness "δ^*", momentum thickness "θ" and shape parameter "H" for all Reynolds numbers and all nondimensional lengths "L/d" of extension tubes.

Table 1: Comparison of integral parameters for both test rigs.

		δ [mm]		δ^* [mm]		Θ [mm]		H	
Re	**L/d**	**exp1**	**exp2**	**exp1**	**exp2**	**exp1**	**exp2**	**exp1**	**exp2**
5 000	1	1.635	1.660	0.545	0.553	0.210	0.213	2.59	2.60
	7	2.510	2.748	0.837	0.916	0.337	0.360	2.49	2.55
	15	3.773	3.723	1.258	1.241	0.492	0.496	2.56	2.50
	25	4.624	4.292	1.541	1.431	0.610	0.553	2.53	2.59
10 000	1	1.065	1.196	0.355	0.399	0.138	0.154	2.57	2.59
	7	1.849	2.215	0.616	0.738	0.243	0.283	2.53	2.61
	15	2.844	2.991	0.948	0.970	0.373	0.387	2.54	2.51
	25	3.891	3.809	1.297	1.270	0.490	0.492	2.65	2.58
20 000	1	0.729	0.874	0.243	0.291	0.093	0.110	2.62	2.66
	7	1.560	1.443	0.520	0.481	0.193	0.184	2.70	2.61
	15	1.846	1.859	0.615	0.620	0.242	0.241	2.54	2.57
	25	2.655	2.589	0.885	0.863	0.333	0.322	2.66	2.59

One may notice that there is almost no difference in integral parameters between experiments N°1 and 2, that means that substantial increase of contraction ratio did not affect the shear layer thickness. The only pronounced difference was observed for the shortest extension tube L/d = 1 for Re = 10 000, where the increase of contraction ratio caused the increase of boundary layer thickness (this observation will be addressed later).

The values of shape parameter H are close to theoretical value predicted by Blasius that confirms that the shear layers are laminar.

Momentum thickness evolution as a function of the Reynolds number is shown in Figure 4. According to Boguslawski [7] and Sreenivasan [8] the increase of momentum thickness should be linear function of the inverse of the square root of the Re and this tendency is observed in general for all Reynolds numbers and all values of "L/d" analyzed in the paper. One should notice however that the linear fit is the better the lower is the value of "L/d".

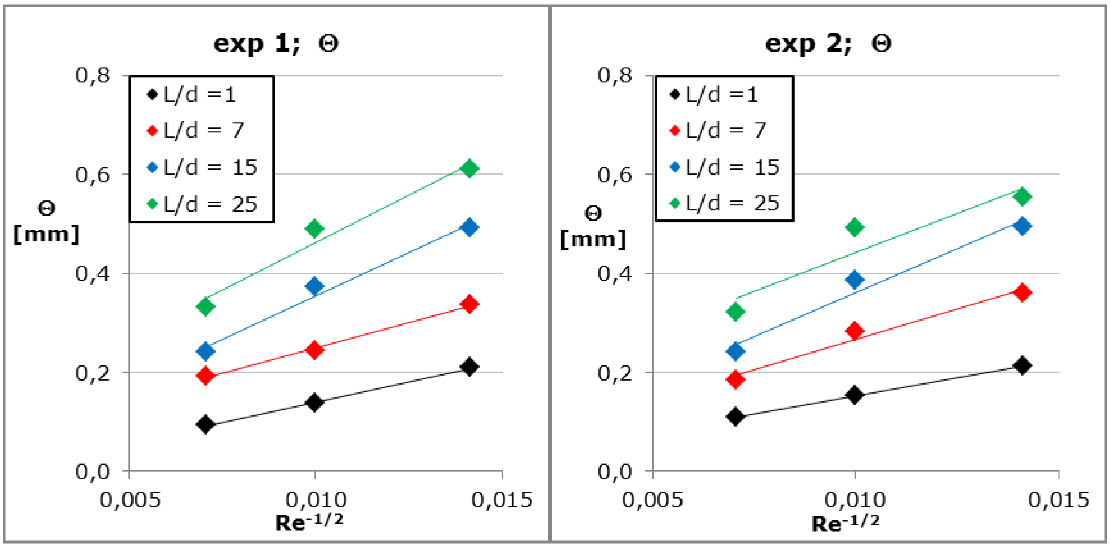

Figure 4: Jet exit shear layer momentum thickness dependence upon the Re number.

One may conclude that the increased contraction ratio of exp. N^o 2 brought about the lower level of Tu in the potential core of the jet at exit plan. The influence of the reduced Tu at the inlet plane on the jet far flow field is shown in Fig.5, which presents the mean velocity and turbulence intensity evolution along the jet axis for sample Re and L/d value.

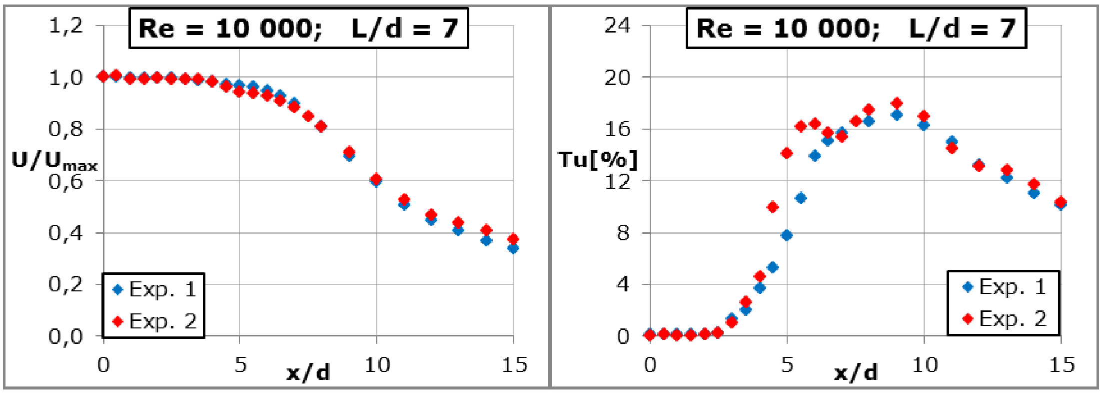

Figure 5: Mean velocity and turbulence intensity distribution along the jet axis for L/d = 7, Re = 10 000.

More pronounced plateau and higher value of local turbulence intensity maximum are clearly visible at right graph of Fig. 5, even if the centreline velocity decay has the same length for both test rigs (see left graph of Fig. 5).

The above figure presents the evolution of the mean and fluctuating centreline velocity for the same value of L/d. In order to complete the analysis.

The mean velocity and turbulence intensity distributions along the jet axis for the Reynolds number equal to 10 000 are shown in Fig. 6 for the shortest (upper row of graphs) and the longest extension tubes (lower row of graphs).

One may notice that for the the shortest extension tube (L/d = 1) the local plateau in Tu longitudinal profile is more pronounced for exp. N^o 1 that means that despite the higher value of Tu at the exit plane one observes more favorable conditions for creation of self-sustained oscillation for first test rig. This behaviour may results from the fact that despite the mean and maximum Tu values are the same, then the integral parameters are significantly different for this case (this was noticed when discussing results from Table 1).

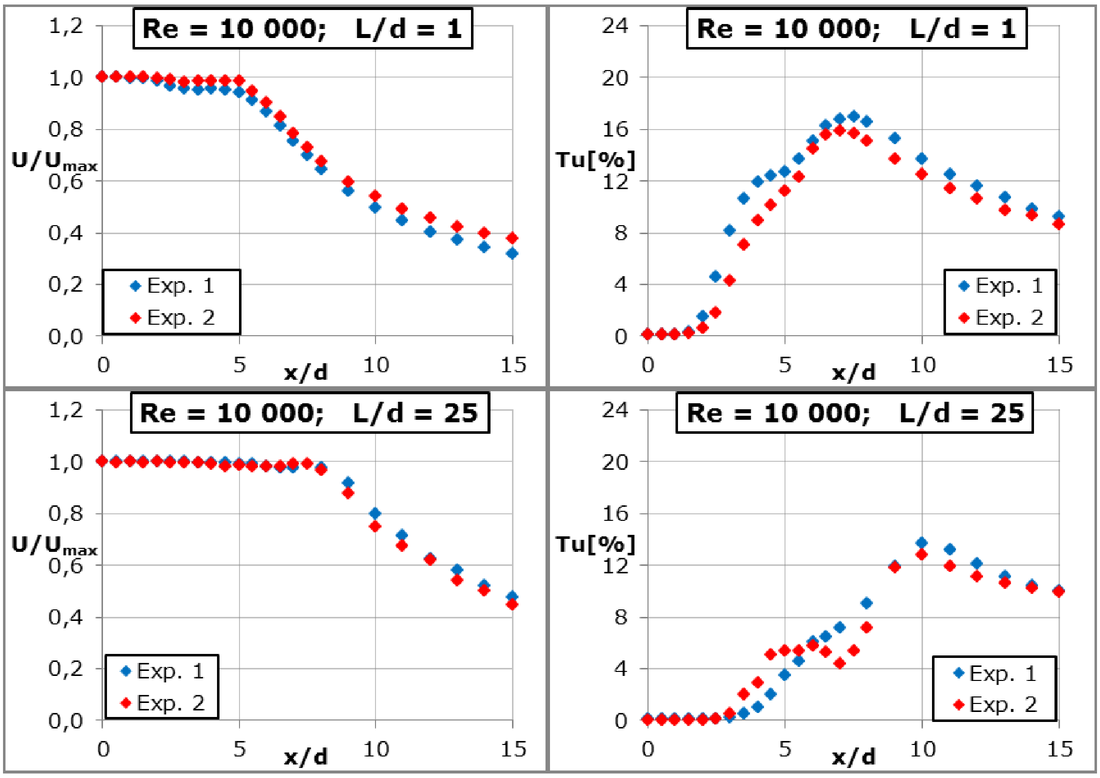

Figure 6: Mean velocity and turbulence intensity evolution along the jet axis for the shortest (L/d = 1) and the longest (L/d = 25) extension tube for one value of Re = 10 000.

For the longest extension tube (L/d = 25 – lower row of graphs in Fig. 6 the integral parameters are the same for both test rigs, but substantially lower value of turbulence intensity at the exit plane in exp. N^{o} 2 triggers the appearance of local maximum of turbulence intensity, which is caused by coherent structures developing in this region. These results confirm earlier findings from [1], that both exit shear layer and level of turbulence intensity at the nozzle exit are among the parameters deciding about development of large scale structures and self – sustained oscillations in round free jet.

4 Conclusions

The investigations confirmed the sensitivity both near and far flow fields of axisymmetric jet to initial conditions, in particular to exit shear layer thickness and level of turbulence intensity at the nozzle exit, which are affected by area contraction ratio of the nozzle.

One may notice only slight difference in maximum turbulence intensity in shear layer for Re = 5 000 for L/d = 7; 15, no difference for L/d = 25 and much more pronounced difference for L/d = 1. The significant difference for L/d = 1 is visible for integral parameters too. For Re = 10 000 one may notice differences in Tu distributions along the jet axis and more favourable conditions for the development of coherent structure for test rig No. 1. However for the same Re = 10 000 but for L/d = 25 the reduced level of Tu mean level in the potential core create more favourable conditions for development of coherent structures for test rig No.2. Summing up, the reaction of the jet to the change of contraction ratio is quite complex and requires further investigations which are being performed.

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