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EXPERIMENTAL INVESTIGATIONS OF THE FLOW UNIFORMITY AND JET DEVELOPMENT ON THE FREE JET CALIBRATION WIND TUNNEL

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Abstract:

Results of experimental investigations of the flow uniformity and axisymmetric jet development on the free jet wind calibration tunnel are presented in this paper. At the outlet of calibration tunnel a profiled Witoshinsky nozzle is located, with outlet diameter of D = 145 mm. Flow uniformity measurement for 34 flow regimes was conducted, in the jet cross-section located at horizontal distance of x = 30 mm from the outlet of the nozzle. Velocity profile measurements were performed with Pitot probes. Based on the measurement results for the calibration tunnel, it can be concluded that flow is uniform to within ± 1 % across the test section with radius of 58-60 mm. In addition, development of the jet in the near-field region ($0 < s/D < 4.828$) is investigated by measurements of mean velocity profile in several streamwise cross-sections for four different regimes. Axisymmetric nature of the jet is proved. It was also shown that velocity profiles in the jet core are uniform, as well as that the jet geometry does not depend on the air flow velocity. This confirms calibration possibilities of this free jet calibration wind tunnel for velocity probes of various types.

Key words: wind tunnels, uniformity, jet, jet core.

1. Introduction

The reliability and accuracy of the wind velocity meters (anemometers) are ensured by their calibration. The calibration is performed by accredited calibration laboratories, according to the appropriate standards. Calibration laboratories must have a program for calibration to ensure that all the results of calibration are in accordance with the general standard ISO/IEC 17025 [1].

The calibration of the anemometers is carried out on wind tunnels (with open or closed test section), according to relevant procedures or standard such as: MEASNET: Cup Anemometer calibration procedure [2] or ISO 17713-1: Meteorology - Wind measurements - Part 1. Wind tunnel test methods for rotating anemometer performance [3].

The general requirements for the wind tunnel, following standard [2], are: “the wind tunnel shall be well equipped and carefully prepared to carry out accurate anemometer calibrations, …

the presence of the anemometer shall not affect substantially the flow field in the wind tunnel (the blockage ratio shall not exceed 0.1 for open test section and 0.05 for closed test section), ... the axial turbulence intensity at the anemometer's position shall be below 2%, ... the flow across the anemometer frontage shall be uniform", etc.

The following issues are of the interest for this research: „The flow uniformity shall be assessed prior to the anemometer's calibration. Flow uniformity can be estimated using velocity sensing devices, i.e. Pitot tubes, hot wires or Laser Doppler velocimetry and measuring flow profiles in longitudinal, transversal and vertical direction. The flow shall be uniform to 0.2 % across the area covered by the anemometer. These investigations shall be carried out for the wind tunnel once and additionally after each modification of the wind tunnel aerodynamics" [2].

According to [3] „the wind tunnel shall have a relatively flat velocity profile. The air flow in the wind tunnel shall be uniform to within ± 1 % across the test section volume occupied by the cups or propeller of the anemometer under test" [3].

Flow uniformity in the free jet wind calibration tunnel is the subject of the research in this paper. Standard Pitot tubes, used in these measurements, are manufactured at the University of Belgrade (UB), Faculty of Mechanical Engineering (FME), Hydraulic Machinery and Energy Systems Department (HMESD).

2. Wind calibration tunnel and measuring techniques

The wind calibration tunnel with free jet (Fig. 1) is designed to provide the axisymmetric jet, with a uniform axial velocity profile at the exit of the profiled nozzle. It is located at the UB FME HMESD. The incompressible flow field is generated by the centrifugal fan (1) which is in-built in test rig (Fig. 1) with flow regulator i.e. conical valve (11). Fan is powered by a motor of 40 kW and nominal rotational speed of 1464 rpm. Also, there is a possibility to install an axial fan with an inverter instead of a flow regulator (11) at the tunnel inlet. The blower is followed by the straight conical diffuser (2) and chamber (3) with flow-settling (perforated plates) placed in the chamber. Afterwards the test rig is equipped with the confuser (4), pipe (5) with flow straightener and profiled outlet nozzle (6).

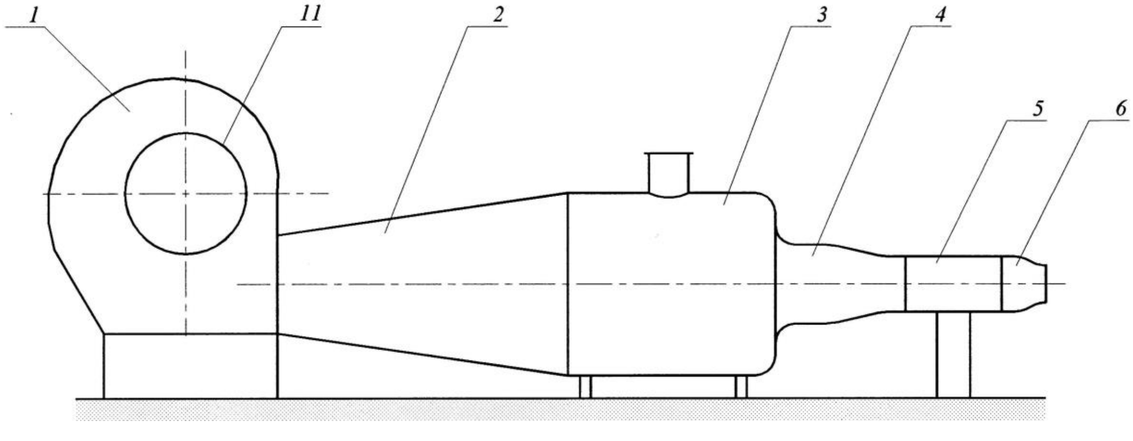

Fig. 1. Wind calibration tunnel with free jet

At the exit cross-section of the tunnel is a wooden two-part nozzle (6). The first part is shaped according to the rotational surface made by the rotation of a curve, the definition of which was proposed by Witoshinsky. Equation of the nozzle inner surface is defined by the equation given in [4]. The second part is diffuser extension that enables uniformity of the velocity profile in the jet. Nozzles have exit inner diameter of D = 145 mm. The main goals of the measurements are verification of the flow uniformity and study of jet development in the near-field region ($0 < x/D < 4.828$).

The first series of experiments are measurements of mean axial velocity in cross-section of the jet located at the distance x = 30 mm (x/D = 0.207) from the outlet of the nozzle. The measurements were made along the inner diameter of the nozzle in the horizontal direction, and also verified in the vertical direction. Measurements were performed for 34 regimes (different Reynolds numbers), defined with different: a) inverter frequency for test rig with axial fan (29 regimes, with $n \approx 50, 100, 150, \ldots 1400, 1450 \text{ min}^{-1}$ and velocity approximately from 0.8 to 24 m/s) or b) flow regulator position for test rig with centrifugal fan (5 regimes, velocity approximately 25, 30, 40, 50 and 60 m/s).

The second series of experiments includes experimental study of jet development in the near-field region in several measuring sections, in the horizontal direction. Measurements were performed for 4 regimes (different Reynolds numbers), defined with different flow regulator position for test rig with centrifugal fan (velocity approximately 25, 30, 40 and 60 m/s).

Velocity measurements were performed with the standard Pitot probes (not Pitot-static probe). The Pitot probe, with diameter of 1.5 mm, does not impair significant disturbance in the flow because the standard requirement [5] is satisfied d/D = 1.5/145 = 0.01 < 0.02 and the blockage ratio does not exceed 0.1. The Pitot probe measures time-averaged (mean) total pressure. Mean dynamic pressure is equal to the difference between the mean total pressure and surrounding, ambient pressure, and it was measured by the differential pressure sensor. The differential pressure sensor is connected with logger to the computer. According to the standard [2] “the sampling frequency shall be at least 1 Hz and the sampling interval 30 sec”. This condition was fulfilled during measurements, with the sampling time interval equal to 60 seconds. The probe was positioned using a linear guide along the horizontal direction of measuring sections.

Mean axial velocity is calculated in the following way according to [3]:

$$c = k_b \frac{1}{n} \sum_{i=1}^{n} \sqrt{\frac{2k_c}{C_h} \frac{\Delta p_{ref,i}}{\rho}} \ [\mathrm{m/s}], \tag{1}$$

where density is calculated as [3]:

$$\rho = \frac{1}{T}\left(\frac{p_b}{R_a} - \varphi p_v \left(\frac{1}{R_a} - \frac{1}{R_w}\right)\right) \left[\frac{\mathrm{kg}}{\mathrm{m}^3}\right]. \tag{2}$$

Neglecting probe (blockage ratio and head of the probe) and humidity influence, mean axial velocity (*c*) can be calculated as:

$$c = \frac{1}{n} \sum_{i=1}^{n} \sqrt{\frac{2 p_d}{\rho}} = \frac{1}{n} \sum_{i=1}^{n} \sqrt{\frac{2 p_d R T_a}{p_b}} \ . \tag{3}$$

3. Experimental results

Profiles of mean axial velocity in cross-section x/D = 0.207 are presented in Fig. 2, for 16 flow regimes, with velocity intensities in range of 0.8 to 60 m/s. It can be concluded that velocity profiles for all regimes are uniform in the central region with radius 58-60 mm. This is also the case for other 18 regimes, which are not shown here. This conclusion is derived on the basis of the standard [3] demand that the air flow uniformity should be ± 1 % across the test section.

Development of mean axial-velocity profile for regime A (Tab. 1.) in near-field region of the jet is shown in Fig.3, where velocity profiles in seven streamwise cross-sections are presented. For the same regime, the centrally positioned conical jet core and the surrounding boundary layer region are shown in Fig. 4. A line connecting points with a velocity equal to zero is taken as the jet boundary. The jet core is determined on the basis of the criterion for determining the flow uniformity (± 1 %) after the standard [3].

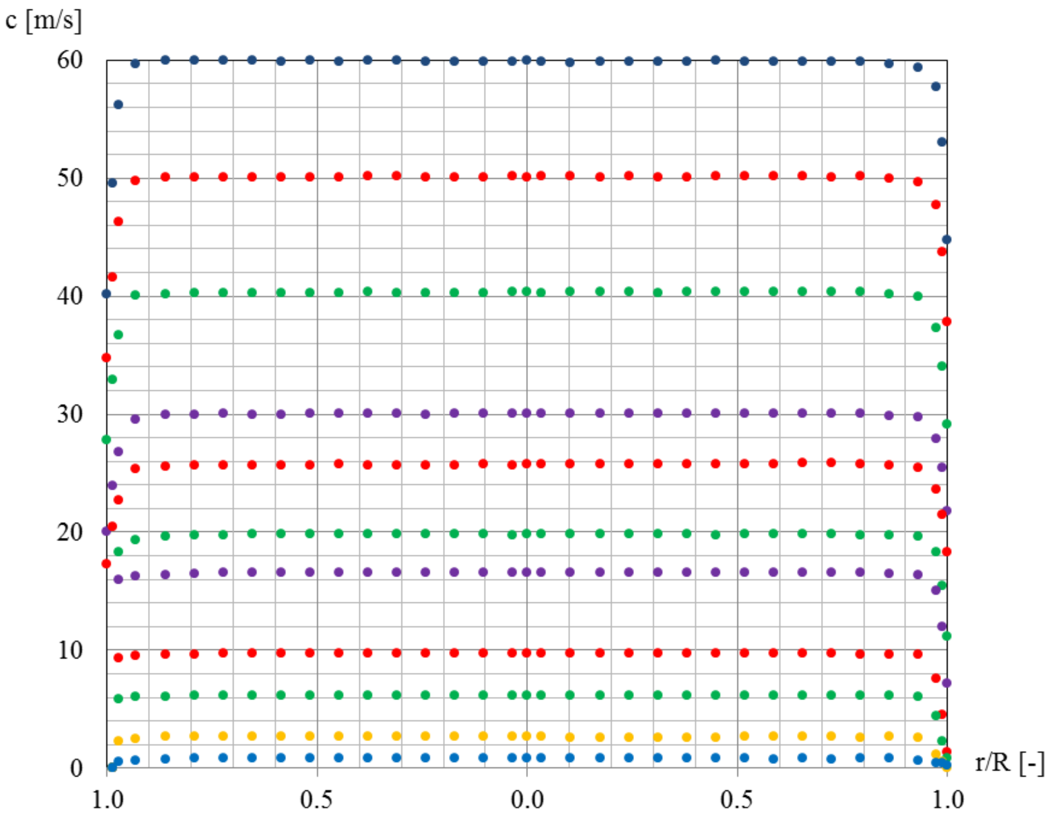

Fig. 2. Axial velocity profiles in measuring cross-sections 30 mm behind of the nozzle outlet section.

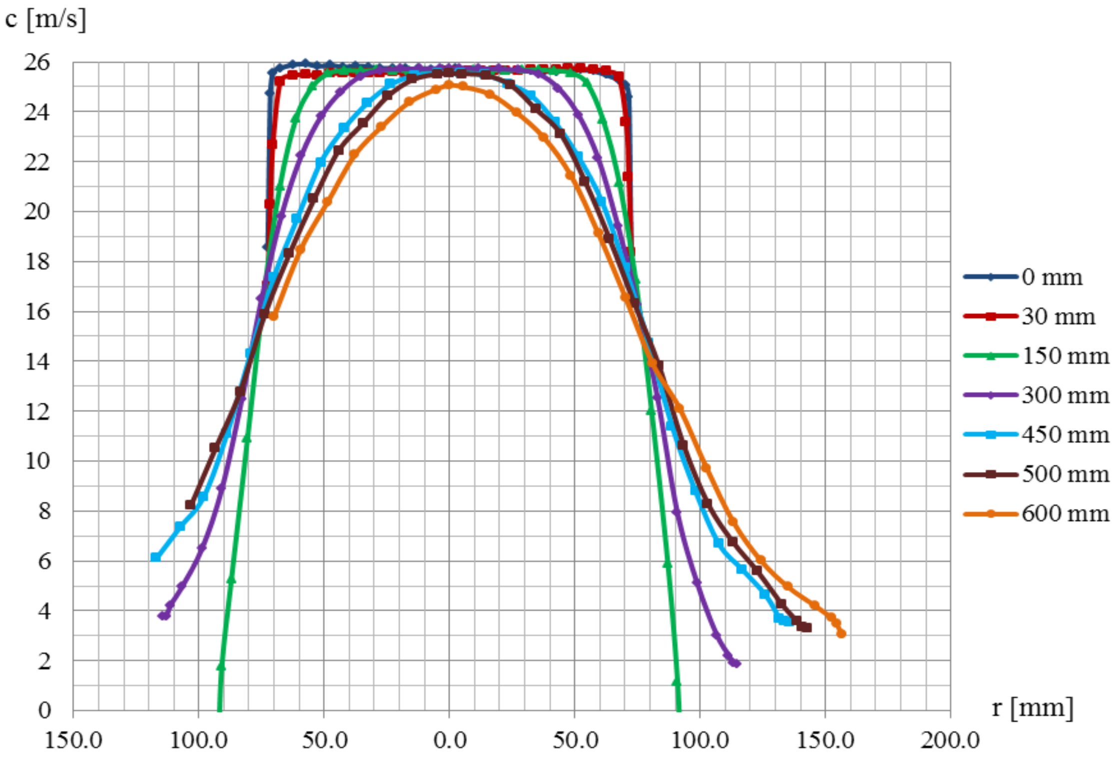

Fig. 3. Jet axial velocity profiles in several measuring sections for regime A [7].

Measurements with laser Doppler anemometry (LDA) technique in this jet are currently in progress. Preliminary results reveal turbulence levels in interval 2 to 5% for velocities in the range 0.1 to 18 m/s.

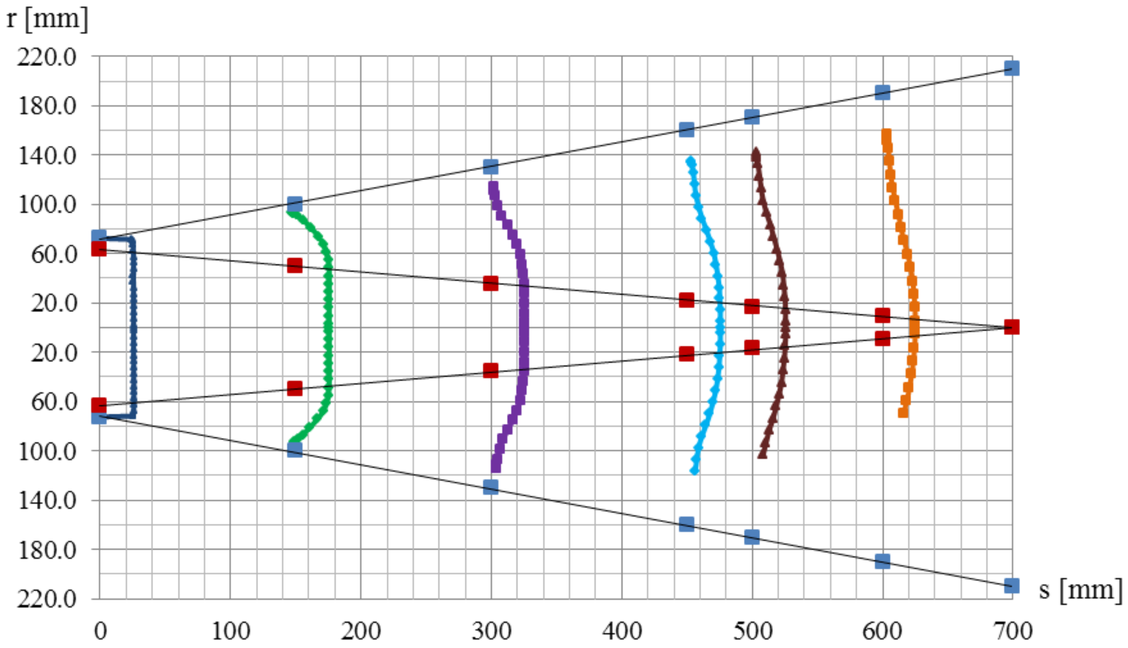

Fig. 4. Jet axial velocity profiles in several measuring sections for regime A [7].

Jet flow characteristics, like jet core radius (Rc) and jet boundary radius (Rb) are presented in tab. 1 for four regimes.

Regime	A (c ≈ 25 m/s)		B (c ≈ 30 m/s)		C (c ≈ 40 m/s)		D (c ≈ 60 m/s)	
s [mm]	Rc [mm]	Rb [mm]	Rc [mm]	Rb [mm]	Rc [mm]	Rb [mm]	Rc [mm]	Rb [mm]
0	63	72.5	63	72.5	63	72.5	68	72.5
150	50	100	50	100	51	100	54	100
300	35	130	35	130	35	130	39	130
450	22	160	22	160	22	160	23	160
500	17	170	-	-	-	-	-	-
540	-	-	14	180	-	-	-	-
600	9	190	10	190	9	190	-	-
650	-	-	-	-	4	200	-	-
700	-	-	-	-	-	-	0	210

Table 1. Cross-section distance (s) of the nozzle outlet section, jet core (Rc) and jet boundary (Rb) radius.

It is noted that the jet boundaries are the same for all regimes, and the jet core differs slightly, which is negligible. The matching of the jet core, as well as the jet boundary, for all the indicated regimes, confirms the theoretical assumptions about the jet geometry and it is shown in Fig. 5. This is in accordance to the theory of the axially symmetrical jet [6]. It is concluded that the jet geometry depends only on the nozzle radius, and that velocity, i.e. Reynolds number does not have significant influence on the jet geometry.

Reynolds number values for these four regimes are in interval $2.4\cdot10^6$ to $5.8\cdot10^6$.

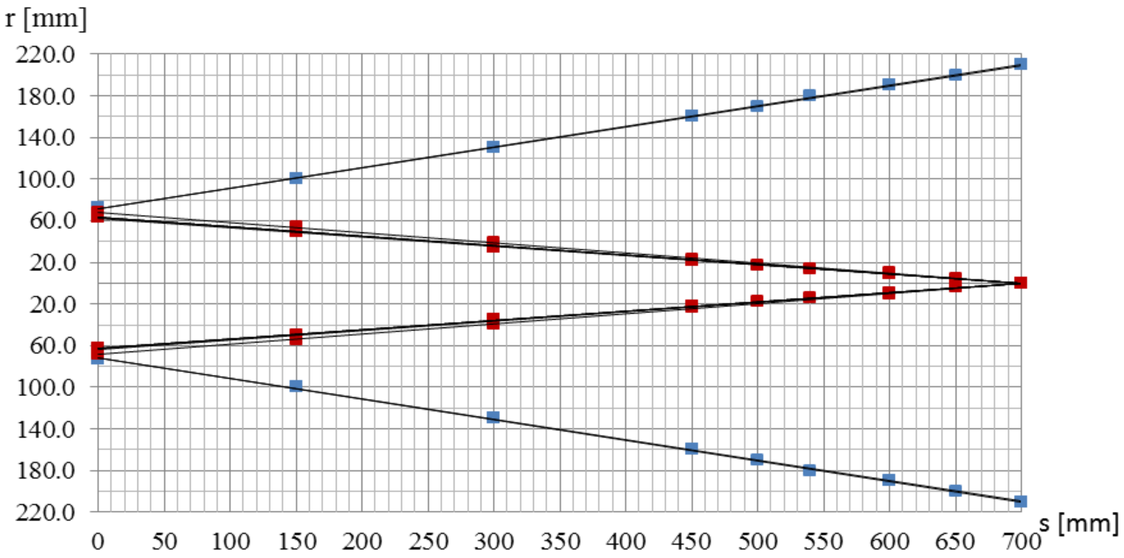

Fig. 5. Experimentally obtained jet development for four regimes in the free jet calibration wind tunnel with the nozzle outlet diameter 145 mm [7]

3. Conclusions

In this paper experimental results for mean axial velocity in axisymmetric jet are presented. These measurements were performed in the free jet calibration wind tunnel with the Witoshinsky nozzle diameter of 145 mm for the velocities 25, 30, 40 and 60 m/s in numerous measuring sections. Measurements were time consuming, with high demands for electrical energy needed for fan operation. They were performed with the Pitot probe in the large number of measurements sections. It was shown that velocity profiles in the jet core are radially uniform in all measuring sections and for all flow regimes. Experimental results confirmed, also, that jet geometry does not depend of the air flow velocity, what is in accordance with the theoretical considerations for this jet type. Measurements with the laser Doppler anemometry technique are in progress. Some preliminary LDA results confirmed low turbulence levels.

Acknowledgment

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