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FLOW UNIFORMITY AND TURBULENCE LEVEL MEASUREMENTS BY LDA IN THE WIND TUNNEL FOR ANEMOMETERS CALIBRATION

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Abstract: *Existing wind tunnel in the Laboratory for Hydraulic machinery and energy systems, Faculty of Mechanical Engineering, University of Belgrade, is redesigned, by adding axial fan regulated by the inverter at the tunnel inlet and flow straightener in the pipe before the carefully profiled Witoshinsky nozzle. Various anemometers could be calibrated in the axisymmetric uniform jet after the nozzle with inner diameter of 145 mm. In this paper are presented experimental results of the flow uniformity and turbulence levels, as well as skewness and flatness distributions for various flow regimes in the wind tunnel measurement section by one-component laser Doppler anemometry (LDA) along the horizontal radius in 27 points. Time-averaged axial velocity profiles have been obtained for twenty Reynolds numbers in the interval Re = 1780 to 148869, determined for point on the jet axis r/R =0. Uniform velocity profiles are obtained in the jet core region, i.e. up to r/R = 0,9 for all Reynolds numbers except the lowest one. Turbulence levels have been also reported for all these cases and achieved turbulence levels were below 2% in the free jet core region for almost all measuring points and regimes, what follows standard ISO 17713-1 requirements. Achieved validation was high. Sampling rate varied and in most of the cases was in average 250-400 Hz. Thermal fog seeding was applied at the calibration tunnel inlet, i.e. at the axial fan suction side.*

Keywords: *wind tunnel, anemometers calibration, ISO 17713-1:2007, turbulence, LDA.*

1. INTRODUCTION

Anemometers calibration is performed on wind tunnels with open or closed test sections, after the relevant standard such as ISO 17713-1:2007: Meteorology - Wind measurements - Part 1: Wind tunnel test methods for rotating anemometer performance [1]. This standard was last reviewed and confirmed in 2016, so this version stays current [2]. Its abstract is provided at the ISO internet web page: „ISO 17713-1:2007 describes wind tunnel test methods for determining performance characteristics of rotating anemometers, specifically cup anemometers and propeller anemometers. It also describes an acceptance test and unambiguous methods for measuring the starting threshold, distance constant, transfer function and off-axis response of a rotating anemometer in a wind tunnel." In this paper will be discussed wind tunnel performance for calibration for almost all anemometers, except cup anemometers.

In standard normative annex A.1.4 Velocity profile is stated: „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. At air speeds greater than 10 m· s−1, the wind tunnel shall have an axial turbulence intensity level of less than 2 % as measured at the anemometer test location. The axial turbulence intensity level is equal to the standard deviation of the mean wind tunnel air speed divided by the mean wind tunnel air speed. Flow uniformity and turbulence intensity can be measured by a hot wire anemometer, a laser Doppler anemometer or other equally sensitive air flow measurement instrument." [1]

Determination of the flow uniformity and turbulence levels, as well as skweness and flatness distributions, in the free jet wind calibration tunnel in the measurement section for various Reynolds number values is the focus of the research presented in this paper. These velocities are achieved for various fan rotation speeds. Only the lowest velocity was under Re = 2320. Measurements have been performed by use of the one-component LDA system.

2. WIND TUNNEL AND LDA SYSTEM

2.1. Wind tunnel

Wind tunnel is located in the Laboratory for Hydraulic Machinery and Energy Systems Faculty of Mechanical Engineering University of Belgrade.

It is described in [3-7]. Wind tunnel is redesigned and presented in Fig. 1., where 1- axial fan with adjustable blades and variable fan rotation speed, 2- diffuser, 3- settling tank with screen, 4- confuser, 5- pipe, 6- a wooden two part nozzle and 7- LDA system.

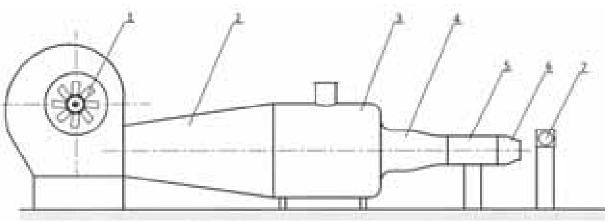

Figure 1. Wind tunnel [4]

A wooden two-part nozzle is positioned at the wind tunnel exit. The first part is profiled after the equation proposed by Witoshinsky [5-8]. The second part is a diffuser extension. Nozzle total length is 320 mm and its outlet inner diameter is $2R$ = 145 mm. Measurements in the nozzle outlet section are performed along the horizontal radius, on 30 mm distance from the wind tunnel outlet section. Velocities in the jet are adjusted by axial fan inverter. Fan rotation speed was in the range n = 100 to 2000 rpm with step of 100 rpm, i.e. in twenty regimes.

The main wind tunnel reconstruction was performed by installing the axial fan at the inlet (Fig. 1., pos. 1) and flow straightener in pipe 5 (Fig. 1.). In order to minimize turbulence intensity and improve flow homogeneity in pipe 5 (Fig. 1.) is positioned flow straightener (Fig. 2.).

Figure 2. Flow straightener – a look through the nozzle

2.2. LDA system

Wind tunnel with LDA system and flow seeding is presented in Fig. 3., where 1- axial fan, 2- wind tunnel, 3- LDA probe positioned on the linear guide, 4- thermal fog generator, 5- inverter, 6- laptop for data collection and 7- PC for linear guide control.

Figure 3. Wind tunnel with LDA **system** and flow seeding

Positioning of the LDA probe in the nozzle outlet measuring section is presented in Fig, 4. Laser is positioned to measure axial velocity, i.e. velocity along the wind tunnel axis. In the measuring section was checked also radial velocity component.

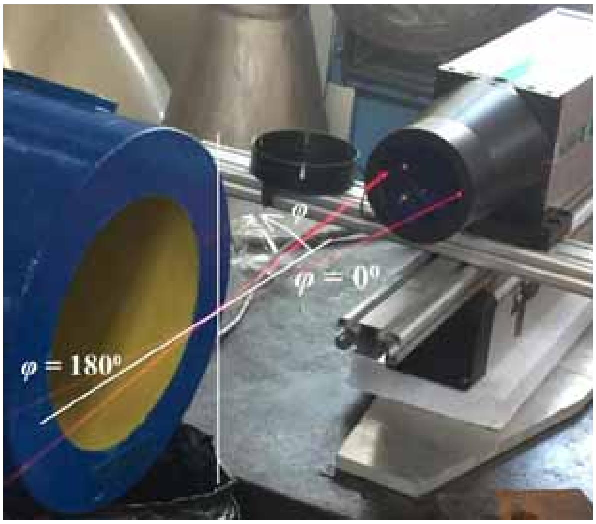

Figure 4. LDA probe positioning

One-component LDA system, model Flow Explorer Mini LDA with BSA Flow Software, by Dantec, was employed in these measurements. Main characteristics of the system are: laser with 35 mW power, red light wave length 660 nm, focus 300 mm, measuring volume size 0.1 x 0.1 x 1 [mm^3] and specified measuring uncertainty of 0.1%. This LDA system works in backscatter mode and with Bragg cell.

Seeding was generated by Antari Z3000II, and liquid “Heavy Fog”. Thermal fog generator was positioned at the wind tunnel inlet (Fig. 3.). In this way, seeding was naturally sucked in the wind tunnel, and mixed by the axial fan and directed afterwards. Sampling time was set to 10 s. Sampling rate and validation varied along the horizontal diameter, but had high values. The minimum value in all points for all regimes was 86.21%, while mainly above 95%. Sampling rate (f) is in function of the radius and flow regime (i.e. velocity) and, in most of the cases is up to 400 Hz (Fig. 5.). Angle φ = 0º represents thirteen points on the horizontal diameter closer to the LDA probe (Fig. 4.). So, in total, there are 27 points in the measuring section.

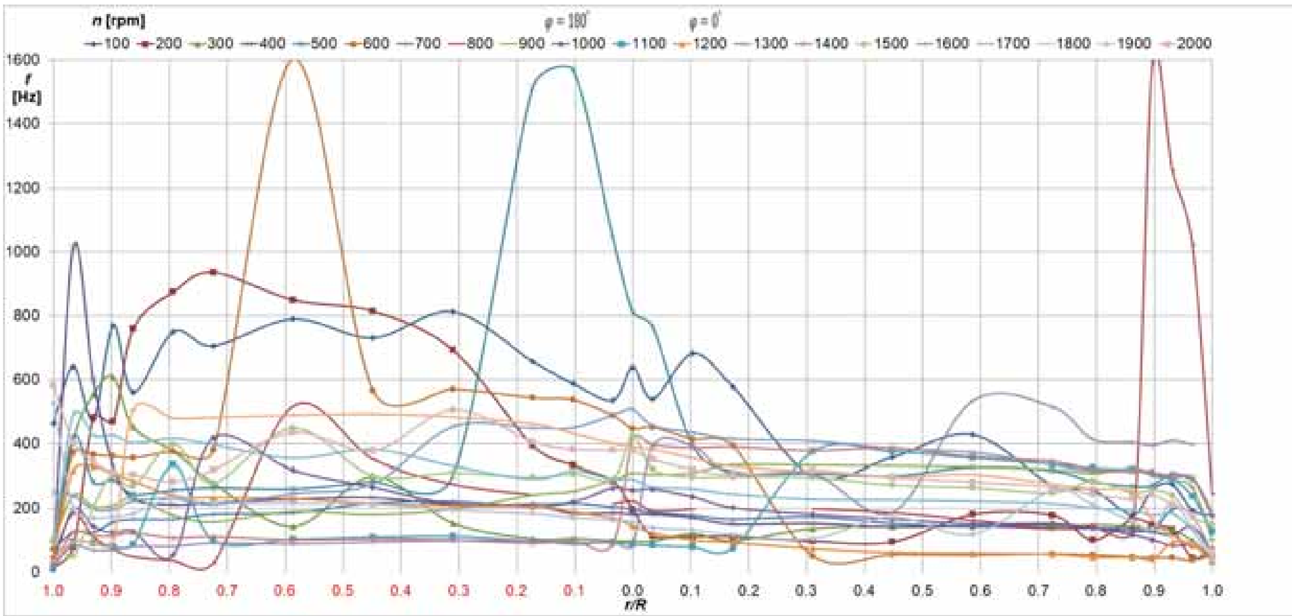

Figure 5. Sampling rate along measuring section

3. EXPERIMENTAL RESULTS

3.1. Average velocity measurements

Time averaged velocity in axial direction (U), in the specified radius r/R, is calculated in the following way:

$$U = \sum_{i=0}^{N-1} u_i / N, \qquad (1)$$

where u_i is instantaneous axial velocity and N is number of samples. In Fig. 6. average velocity profiles, for all flow regimes, are presented.

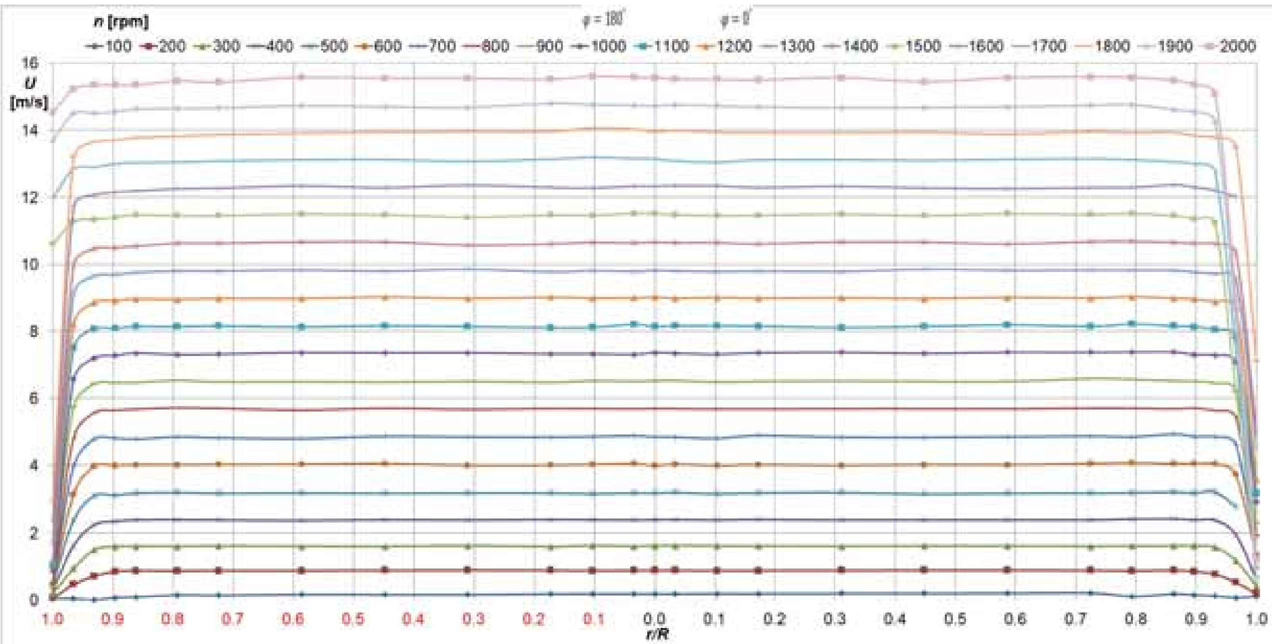

Figure 6. Averaged velocity profiles

Here are presented measurements in the region from very low velocity 0.2 m/s up to 15.5 m/s. Namely, 540 points are presented in Fig. 6.

All generated flow regimes, except for the lowest rotation speed, are turbulent. Flow was isothermal for all regimes.

Reynolds number is calculated for the central point, i.e. on the jet axis (r/R = 0), and presented in Table 1.

Table 1. Reynolds number values on the jet axis ($r/R = 0$) for all flow regimes

Fan rotation speed [rpm]	Re
100	1780
200	8490
300	15538
400	22900
500	30542
600	38078
700	46377
800	54414
900	62383
1000	70460
1100	77860
1200	86397
1300	93988
1400	102058
1500	110172
1600	117989
1700	125788
1800	133494
1900	140914
2000	148869

Reynolds number is calculated on the basis of the temperature 20ºC and jet outlet radius $R = 72.5$ mm. Flow axisymmetry and homogeneity are obvious in the jet core, i.e. in almost complete flow domain. It means that 90% of the measuring section is acceptable for calibration.

3.2. Statistical moments

Turbulence level is calculated in the following way:

$$Tu = \sigma_i / U \cdot 100[\%], \quad (2)$$

where standard deviation is calculated as follows:

$$\sigma_i = \sqrt{\sigma_i^2},\ \sigma_i^2 = \frac{1}{N}\sum_{i=0}^{N-1}(u_i - U)^2. \quad (3)$$

Turbulence levels for all flow regimes and measuring points are presented in Fig. 7.

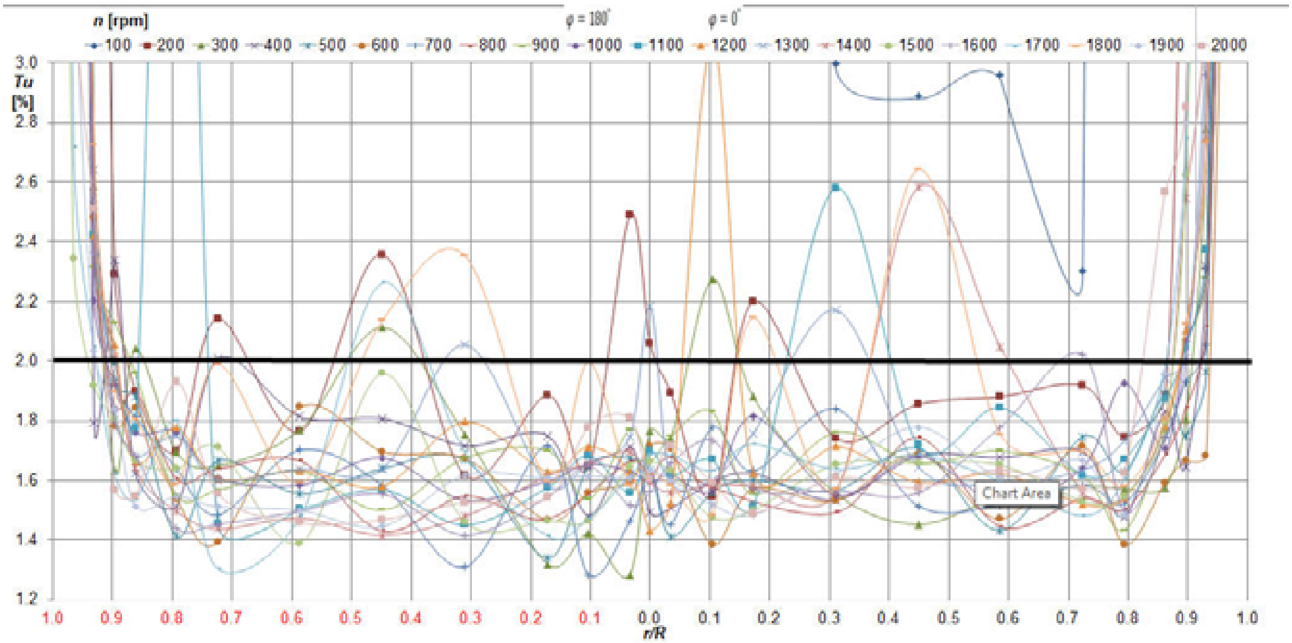

Figure 7. Turbulence levels for all flow regimes and measuring points

Turbulence level is almost for all flow regimes, except in the case for the lowest fan rotation speed, lower than 2% in jet core region, i.e. in 90% of the measuring section. This is in accordance with the flow homogeneity previously examined.

Statistical moments of higher order are also calculated and presented. Skewness (S_u) and flatness (F_u) are calculated as follows:

$$S_u = \frac{1}{\sigma_i^3}\sum_{i=0}^{N-1}(u_i - U)^3,\ F_u = \frac{1}{\sigma_i^4}\sum_{i=0}^{N-1}(u_i - U)^4. \quad (4)$$

Skewness, i.e. statistical moment of the third order, has value 0 for the Gaussian distribution, while flatness 3. These statistical moments are presented in Figs. 8 and 9.

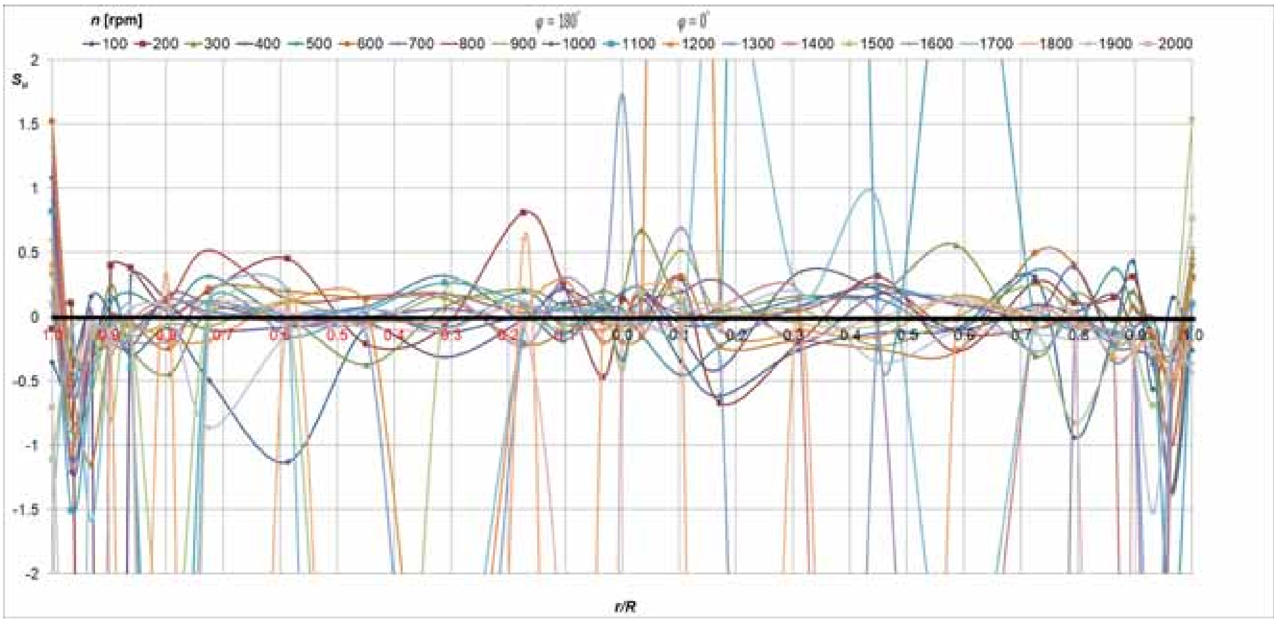

Figure 8. Skewness distribution in the measuring section for all flow regimes

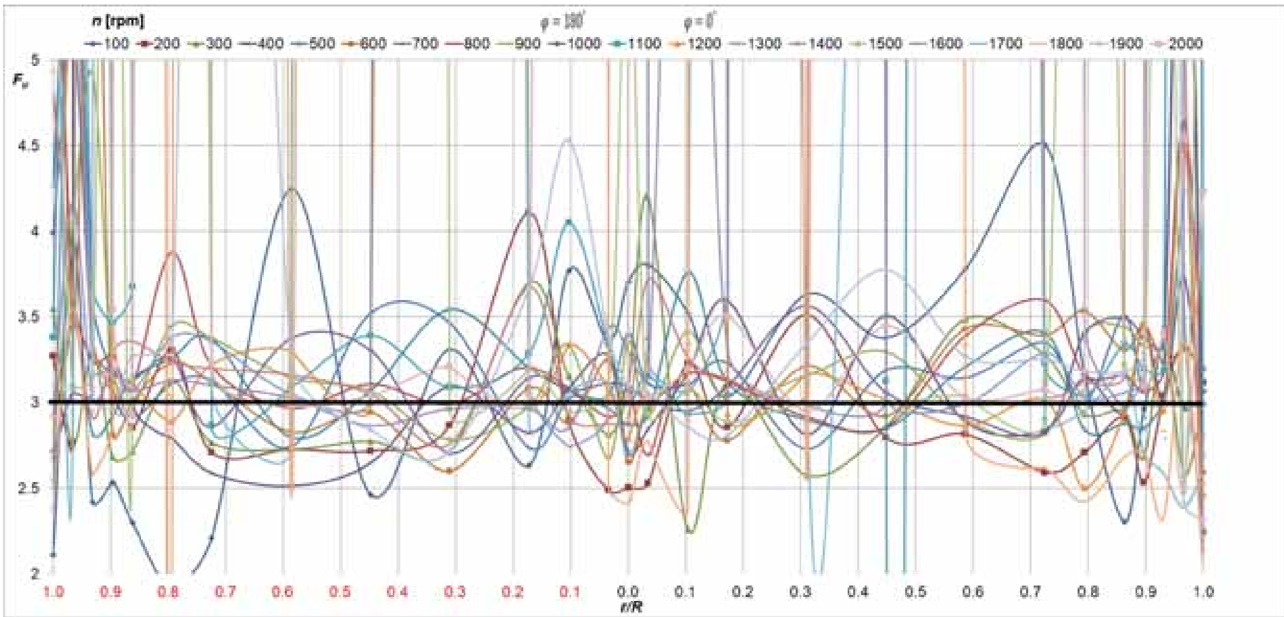

Figure 9. Flatness distribution in the measuring section for all flow regimes

Both coefficients oscillate around values for normal distribution in the majority of points, especially in the jet core region. This is a proof that turbulent flow could be “Gaussian”. Standard ISO 17713-1 claimed nothing on the limitations for these two factors, but they would point out flow irregularities.

4. CONCLUSIONS

Performed redesign of the wind tunnel, with attaching axial fan at the inlet and flow straighteners in the pipe before the jet, resulted with significantly lower turbulence level and higher flow homogeneity. Turbulence level is lower than 2%, what is a demand of the standard ISO 17713-1, in jet core, i.e. in almost 90% of the measuring section. Developed turbulence in the calibration jet is also discussed with statistical moments of higher order. These values oscillate around the ones for the Gaussian distribution. This could be treated as a good result, because it is achieved on the axial fan pressure side.

In addition, applied axial fan with inverter has better regulation and generate isothermal flow for a wide interval, from very low velocities up to a mid-range ones. There is a reserve, so the fan rotation speed could be increased and higher velocities than 16 m/s could be achieved. Continuous inverter regulation enables specific velocity values adjustment. Very low axial fan power of only 3kW is a great advantage comparing to the previously used radial fan.

Acknowledgements

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