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THE INFLUENCE OF THE FLOW TURBULENCE ON THE FLOW STRUCTURE BEHIND A SPHERE

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ABSTRACT

Flow turbulence intensifies processes of momentum, heat and mass transfer in a flow or on surfaces immersed in such a flow. This paper presents results of experimental investigations of the influence of the inflow turbulence on the velocity and the shear stress distributions behind the sphere for a selected distance. It is assumed that a flow structure behind the sphere is dependent on the flow structure in a boundary layer on a sphere that is under the inflow turbulence control. The inflow turbulence changes the pattern of distributions of the average pressure and its turbulent fluctuations on the sphere surface. Because of that the flow behind the sphere becomes dependent on the intensity of the flow turbulence in front of the sphere area. Radial profiles of the average velocity behind the sphere becomes more flat as the inflow turbulence increases. The shear stress profiles and the profiles of velocity fluctuations are also modified by the inflow turbulence level. When the intensity of the inflow turbulence increases the radial profiles of uv correlations representing the mixing properties of the flow behind the sphere get more flat but reach larger radius.

INTRODUCTION

The turbulence level of flow above the surface intensifies the momentum and the heat transfer processes on the said surface [1]. Commonly used descriptions of the shear stress or heat transfer distributions usually assume a certain level of intensity of the turbulence of the free flow that overflows a surface. For most technical applications, the level of turbulence and its structure can vary widely. What is more, this level is difficult to predict based on the channel geometry, especially when promoters of turbulence occur. Experimental data indicate that an increase in the turbulence intensity causes increased heat and momentum transfer coefficients even when the average flow velocity does not change [2]. To estimate the influence of the external flow turbulence on the local distribution of shear stress and mixing process in the flow, a sphere was selected as the simplest, repeatable geometry. The local shear stress and its turbulent fluctuations distributions can be used as an indicator of the intensity of momentum transport phenomena in a boundary layer and, additionally, the distribution of velocity fluctuations in the wake behind the sphere as an indicator of the intensification of the mixing processes in the flow.

The external flow turbulence influences the momentum transfer processes in the boundary layer due to an interaction between the inflow and the flow phenomena in the layer near the surface. The turbulence of the inflow modifies the local transport characteristics on the surface [3] and the downstream flow characteristics. The investigations of the influence of the external flow turbulence on the local pressure distributions on the sphere indicated that the external flow turbulence changes the local pressure distribution on the sphere surface. This effect influences the drag coefficient [4] and the average velocity profiles behind the sphere.

This observation we can explain to be the result of the changes in the turbulent shear stress distributions. It is perhaps the results of the interaction of the inflow external turbulence and the local production of turbulence. To explore this influence, measurements of the average velocity profiles and shear stress distributions behind the sphere were performed.

NOMENCLATURE

d	[m]	Diameter of the sphere
D	[m]	Diameter of the nozzle outlet
P	[Pa]	Static pressure
r	[m]	Radial direction
U	[m/s]	Average velocity in the axial direction
u	[m/s]	Turbulent fluctuations of velocity in the axial direction
v	[m/s]	Turbulent fluctuations of velocity in the radial direction
x	[m]	Distance from the nozzle outlet

Special characters

τ	[N/m^2]	Shear stress
Φ	[^{0}]	Angle

Subscripts

o	Reference value
rms	Rood mean square

EQUIPMENT AND EXPERIMENTAL SETUP

To perform the experimental investigations an open wind tunnel was used. A turbulent free jet was generated by a round nozzle of the diameter of 0.06 m. The level of turbulence in the jet axis changed from about 1% near the nozzle outlet to approximately 20% far from the nozzle outlet. Changing the flow velocity at the nozzle outlet enabled getting the same value of average velocity with different level of flow turbulence at different distances from the nozzle outlet. The sphere diameter of 0.03 m was used for the reported experiments. A constant temperature anemometer TSI IFA 300 with a hot wire probe was used to measure the free jet flow turbulence. For the uv correlation, two hot wires configured as an X probe were used. The TSI ThermalPro 5.09 (digital flow analyzer) was used for the acquisition and analysis of the measurement data. Because of a high level of velocity and pressure fluctuations long data samples were used for the time averaging procedure.

Measurements of the static pressure and its fluctuations were done using electronic micro-manometers and a digital acquisition system. The TSI surface probe was used for the measurements of the shear stress distributions on the sphere surface. A diagram of the experimental set up and equipment has been shown in Figure 1.

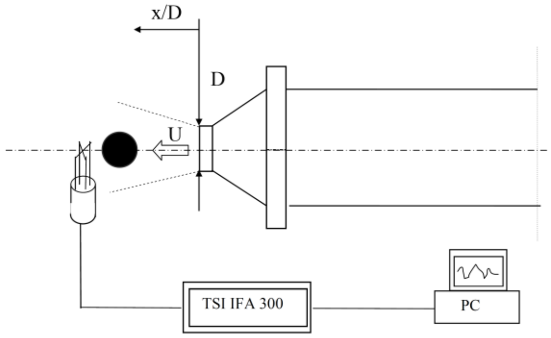

Figure 1 Diagram of the experimental set up and equipment

RESULTS OF EXPERIMENTAL INVESTIGATIONS

The pressure distribution on the sphere determines the flow conditions in the sphere surroundings. The vortex structures generated on the sphere surface flow downstream of the created mixing zone behind the sphere. This phenomenon depends on the intensity of the turbulence in the region above the boundary layer on the sphere surface. As is shown in Figure 2, for small external flow turbulence the static pressure on the sphere surface changes from a maximum value at the stagnation point to 0 at the angle of approximately 50^o and reaches a minimum value at the angle of 70^o. At this point, the boundary layer separates from the surface and large-scale vortices are created. The plot of pressure fluctuations gradually increases. When external turbulence increases to ~16% the point of lowest pressure is shifted to the angle of 85^o and its value is two times smaller than it is for the level of external turbulence of the order of 1.1%. In this case, the distribution of pressure fluctuations changes in a more visible way. The turbulent fluctuations of pressure on the sphere surface reach the highest value at the stagnation point. This is a result of the influence of the external flow turbulence. The velocity fluctuations are converted to pressure fluctuations. Next, the pressure fluctuations go down and beyond the angle of ~45^o their values stabilize on a high level as is shown in Figure 2.

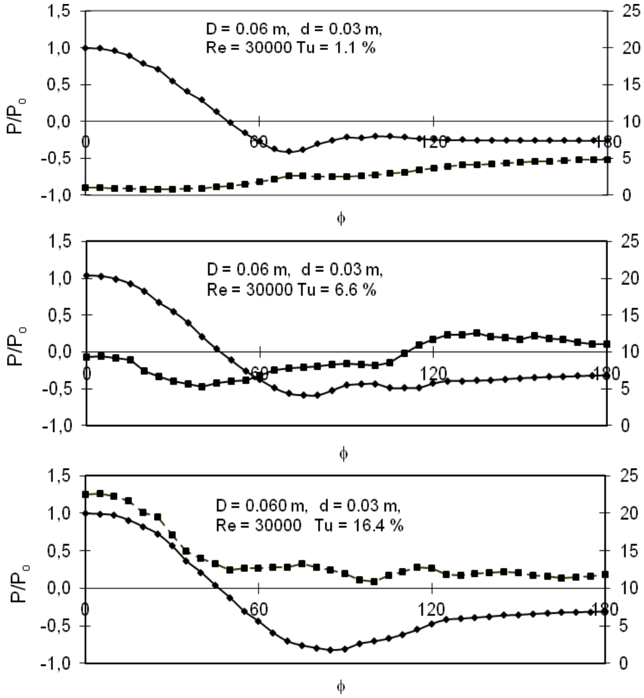

Figure 2 Distribution of the average static pressure and its fluctuations on the sphere surface for different turbulence level of the inflow

Changing patterns of the pressure distributions on the sphere surface influences the fluid motion in the sphere boundary layer and the flow behind the sphere. Because of this phenomena the external flow turbulence influences the velocity wake behind the sphere and the mixing properties of the flow in this region.

The effect of external flow turbulence on the boundary flow over the sphere surface is also visible in the modification of the shear stress distribution in the boundary layer. The relative value of the distributions of local shear stress and its fluctuations on the sphere surface for different values of the turbulence level are presented in Figure 3. As is shown, these distributions are dependent on the inflow turbulence. An increase in the turbulence level of flow causes an increase in the intensity of the transfer phenomena of heat and momentum even for constant values of the inflow average velocity. The distributions are heavily non-uniform. Both values measured by the surface probe increase as the inflow turbulence increases, which is why the changing momentum losses of the flow around the sphere are observed. The location of the local minimum in p and τ plots indicates that shifting of the separation of the boundary layer occurs when the turbulence of the inflow increases.

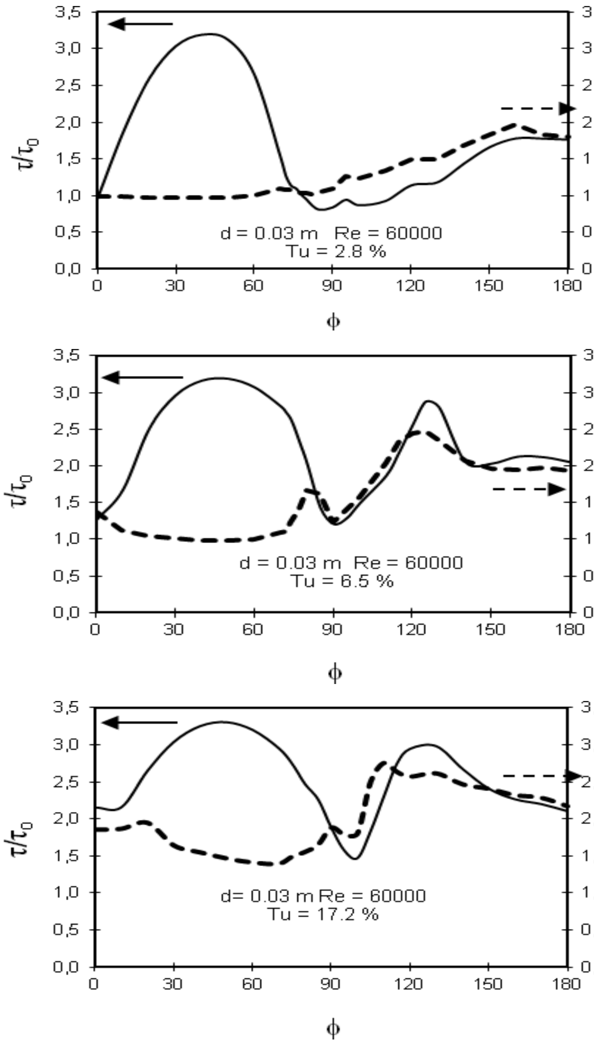

Figure 3 Distribution of the local average shear stress and its turbulent fluctuations on the sphere surface at different inflow turbulence levels

To estimate the changes in the flow behind the sphere average velocity distributions and its turbulent fluctuations were measures and analyzed.

For the constant value of the inflow average velocity and variable levels of the flow turbulence, the profiles of average axial velocity components behind the sphere were measured. Plots presented in Figure 4 were measured downstream at a distance of 2.5 of the sphere diameters behind the sphere. The velocity profiles measurements indicate that at lover distances the large-scale circulation flow causes a flow in reverse direction. Hence, in this region, strong dissipation of large-scale vortices occurs which renders the measurements of average velocity profiles in such unstable flow useless.

As an indicator of the flow mixing properties in the wake behind the sphere the uv correlation of axial and radial components of velocity fluctuations was taken into account.

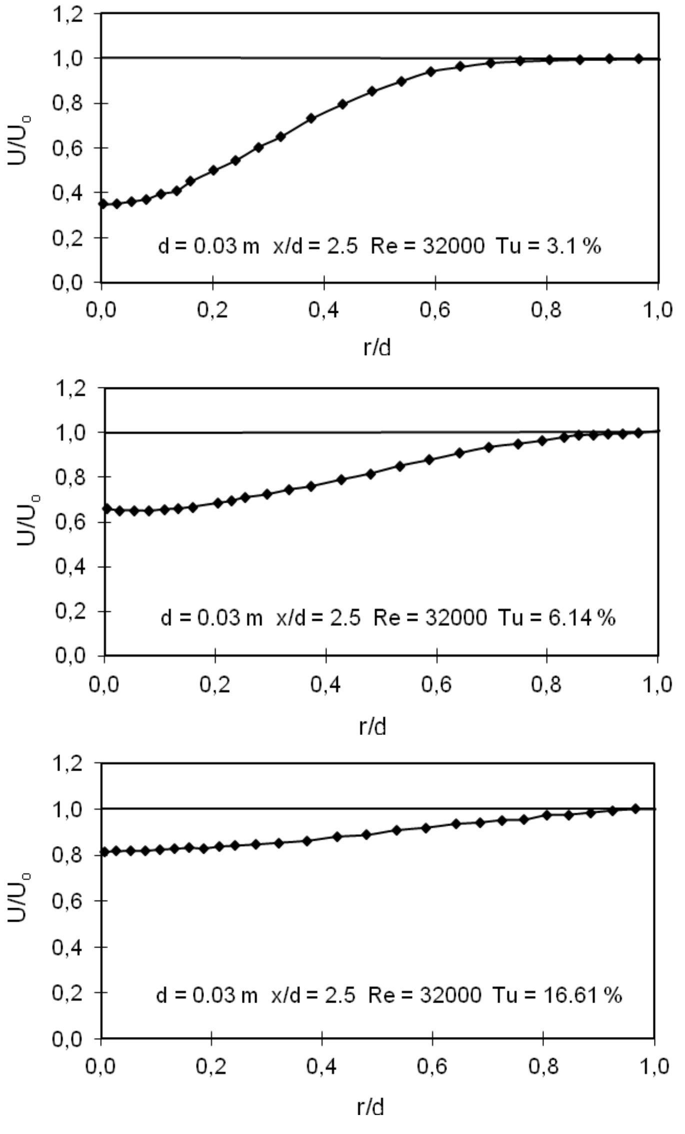

Figure 4 Radial distribution of the average axial velocity profiles behind the sphere surface for different turbulence levels of the inflow at a distance of 2.5 of the sphere diameters

This value is proportional to the flow shear stress responsible for the intensity of the mixing phenomena in the flow.

As is shown in Figure 4, profiles of the axial velocity components are dependent on the turbulence level of the inflow. At low inflow turbulence levels the average velocity profiles have a clear deep depression at the axis region.

The average velocity in the axial direction is about 40% of the inflow velocity in front of the sphere at small turbulence.

This is the effect of a strong dissipation of energy of motion in the region immediately behind the sphere. When the supplying flow increases the, flow energy intensifies through diffusion and convection in radial directions from the external main flow, which compensates the losses. This makes the velocity losses in the wake behind the sphere smaller but the radius of the wake increases slightly.

For the biggest turbulence level of the external flow the wake gets very small. The velocity in the axis behind the sphere is only 10% lower then the external flow velocity.

It means that the external flow turbulence influences the flow in the wake behind the sphere owing to an increased transport of motion energy in the radial direction. Due to the radial transport of motion energy the flow in the wake accelerates. This is the effect of increasing mixing properties of flow following the increasing flow turbulence in the external flow.

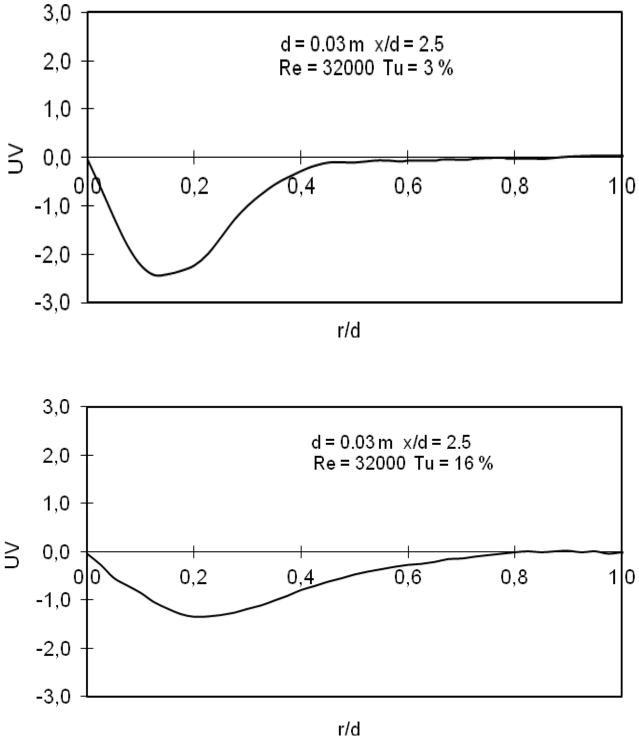

Figure 5 Radial profiles of uv correlation behind the sphere for different inflow turbulence levels at the same Reynolds number of the flow around the sphere

The distributions of axial and radial fluctuations of velocity in the form of averaged uv correlations are presented in Figure 5.

The presented distributions of uv correlations were measured behind the sphere at a distance of 2.5 of the sphere diameter. The first one - for the external turbulence level of 3% and the second one - for 16%. Because a uv correlation of turbulent fluctuations represents intensity of the shear stress in the flow, one can assume that the values are a function of the flow mixing properties in a turbulent flow behind the sphere.

For low turbulence, the mixing process occurs near the axis region mainly and is very intense. For the high value of the turbulence level of the external flow the profile of velocity gets more flat, which is why the local source of turbulence becomes less intense and the distribution of uv correlations gets mainly under the control of diffusion of the turbulence from the external flow. For this case uv profiles have a smaller minimum but the radius of the flow behind the sphere (where mixing process occur) is bigger.

CONCLUSIONS

The increase in the external flow turbulence modifies the static pressure distributions around the sphere. High level velocity fluctuations cause increased fluctuations of the pressure, especially at the stagnation point area. An intensification of turbulent fluctuations near the surface shift the point of flow separation in the boundary layer and intensify vortex generation phenomena behind the sphere.

An increase in the inflow turbulence causes the velocity profiles behind the sphere to get more flat and the visible wake to shrink**.** The axial component of velocity in the axis increases from 40% of the external flow value to approximately 10%, while the external flow turbulence increases from 3% to 16%.

The external flow turbulence also modifies the profiles of uv correlations responsible for mixing processes behind the sphere. The mixing region gets less intense but occurs on a bigger radius when the turbulence of the external flow increases.

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