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Shear stress distribution on sphere surface at different inflow turbulence

L. Bogusławski

Chair of Thermal Engineering
Poznań University of Technology
Piotrowo 3, 60 965 Poznań, Poland
e-mail: leon.boguslawski@put.poznan.pl

1. Introduction

Momentum and heat transfer processes on surfaces are sensitive on intensity of turbulence of flow above surface. Descriptions of share stress or heat transfer distributions usually assume certain level of intensity of turbulence of free flow which overflows surface. When structure of flow is formed as developed flow for typical channels one can assume that turbulence level and structure of turbulent flow is repeated. In such case detailed knowledge of flow turbulence is not necessary because Reynolds number indicated average flow similarity and similarity of turbulence by the way. Unfortunately for most technical applications level of turbulence and its structure can vary in wide borders. More over this level is difficult to prediction based on channel geometry especially when any promoters of turbulence occur. Experimental data indicate that increase of turbulence intensity cause increasing heat and momentum transfer coefficients even when average flow velocity does not change [1],[2],[4]. To estimate the influence of external flow turbulence on local distribution of shear stress a sphere was chosen as the simplest, repeatable geometry.

2. Measurement technique and apparatus

Open wind tunnel was used to perform experimental test. Flow was generated by a free round jet. Level of turbulence, in the jet axis, change from about 2% near the nozzle outlet till about 20% far away from the nozzle. Changing of the average flow velocity at the nozzle outlet it was possible to keep constant value of velocity at different distances from the nozzle outlet. The constant temperature anemometer (CTA) was used to measure level of flow turbulence. Distribution of local shear stress and its turbulent fluctuations was measured by means of TSI 1237 surface probe connected to constant temperature anemometer bridge TSI 1050 [3]. Dimension of the hot sensor of the TSI probe was of 0.2 mm width and of 1mm long. This kind of sensor can measure, by analogy, local shear stress and shear stress fluctuations on the surface till about 5 kHz.

The sphere diameter of 0.03 m with local shear stress sensor on its surface was rotated in range of angles Φ from of 0^o till about of 180^o . The analog signal was digitized by 16 bit A/D converter and next recorded and analyzed using PC computer.
Reference turbulent level of jet flow was measured at distance where sphere stagnation point was located. As the reference value of all measured values the values obtained for lowest level of external flow turbulence was taken into account.

3. Results of experimental investigations

As literature data indicated [1] the external flow turbulence influence on heat and momentum transfer phenomena on surfaces. In this case the average flow velocity used in Reynolds number for flow description is not good enough to describe turbulent flow structures. The level of turbulence, as the simplest parameter of intensity of turbulence can be used in this case. For sphere, increase of turbulence level of flow cause increase of average coefficients of heat and momentum transfer phenomena even for constant value of inflow average velocity. Because the local shear stress distribution is strongly irregular, the question is, how external turbulence influence on this distribution.

Distributions of local shear stress relative value and its fluctuations on sphere surface for different value of turbulence level are presented in figure 1. Presented set of experimental data was performed for the Reynolds number $6*10^4$ based on sphere diameter for selected value of turbulence level in external flow.

For the lowest level of turbulence (2.5%) when sphere was located near nozzle outlet local value of shear stress increase monotonically and reach maximal value at angle about of 45^o. Next value of shear stress go down and reach minimum at angle about of 90^o. In rear part of the sphere shear stress increase in nearly linear way. In this case local shear stress fluctuations keep constant value till about of 70^o. Next one can observe small perturbation with a local maximum at about of 80^o. This maximum occur 10^o before angle where minimum of local shear stress distribution is located. Then value of local fluctuations increase nearly parallel to shear stress line. Local jump of shear stress fluctuations have no visible response in plot of shear stress.

When external flow turbulence increase to 4.5% distribution of local shear stress does not change character in front part of sphere only shear stress value increase. On rear part of sphere two local perturbations in shear stress plot appear. First, at about of 100^o and second, greater, at about of 120^o. For the angles beyond of 150^o value of shear stress does not change. Level of shear stress fluctuations increase but character of plot in front part of sphere does not change in visible way. One can observe small depression of plot and rise the local maximum at the angle of 80^o. The increasing of shear stress fluctuations on rear part of sphere lost monotonical character. One can observe creation of two additional , local picks at the angles of 100^o and 120^o. This picks very good corresponds to local picks in shear stress plot. Beyond the angle of 150^o value of shear stress fluctuations stabilized. When turbulence of external flow increase till 6.5% plot of local shear stress generally do not change so mach. In shear stress fluctuations plot local disturbances get more visible. At beginning fluctuations go down, next perturbation at the angle of 80^o and 120^o get greater scale. For the angle greater then about of 160^o both plots go down.

For the highest value of external flow turbulence both plots keep described tendency, except near stagnation region. The shear stress and its fluctuations keep the constant value till about of 10^o. Also decreasing tendency in both plots beyond the angle of 150^o is stable. Increase of external flow turbulence shift localization of minimum in shear stress plot from 90^0 to about 100^o.

Analysis of plots presented in figure 1 indicated that for low level of external flow turbulence the turbulence intensification of momentum transfer phenomena occur on the rear of sphere. The boundary layer on the front surface of sphere is strong enough to isolate surface from external flow influence.

For turbulence of order 10% transport phenomena on the front of the sphere increase with no change of distribution form. This level of turbulence is able to intensify shear stress fluctuations at stagnation region. The highest value of shear stress is roughly the some at the angle about of 45^o independent from the external flow turbulence.

For higher value of turbulence increasing of shear stress is observed in the front surface of the sphere for angles smaller then 45^o and in the rear surface of the sphere for angles between of 90^o and 150^o.

Momentum transport phenomena in range of angles from of 45^o till of 90^0 and from of 150^o till of 180^o kip nearly the some level independent from external flow turbulence.

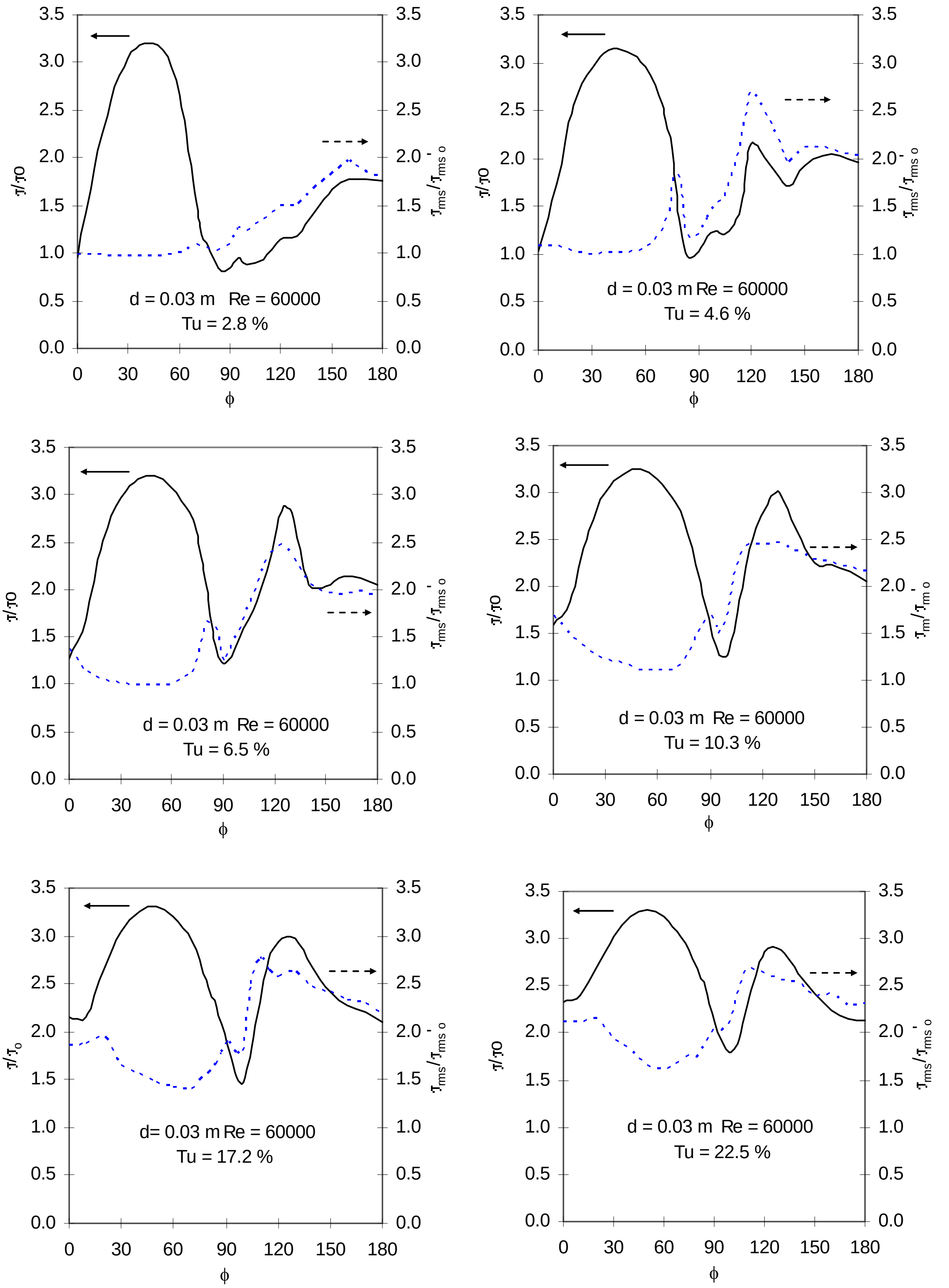

Figure 1. Distribution of the local average shear stress and its turbulent fluctuations on the sphere surface at different inflow turbulence level.

4. Conclusions

The increase of turbulence of external inflow intensifies momentum transfer phenomena on the sphere. This process is not uniform around the sphere surface.

External flow turbulence intensify momentum transfer process in front part of the sphere in range of angles till of 45^o and range of 90^o till 150^o.

Momentum transfer process on remaining part of the sphere surface is nearly independent from external turbulence level. Independence of momentum transfer in region of 45^o till 90^o is perhaps due to strong acceleration of flow in boundary layer in this region.

The total effect of intensification of momentum transfer process is the results of real intensification in limited portion of the sphere surface. Processes in remaining part of sphere surface are very weak dependent on external flow conditions. This regions of the sphere surfaces are under influence of local sources of flow disturbances. Perhaps, large scale eddies generated on back side of the sphere are not so sensitivity on disturbances caused by smaller scale structures coming from the external flow.

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