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AN EXPERIMENTAL STUDY OF LAMINAR JUNCTURE FLOW DOWNSTREAM OF THE SURFACE-MOUNTED SQUARE CYLINDER

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1. ABSTRACT

This work is devoted to experimental study of free convective flow parameters, around an adiabatic square cylinder, which mounted on heated vertical plate. Here the size of cross section of square cylinder is equal to 0.02 [m]. The cylinder crosses the arising thermal boundary layer thickness, although the aspect ratio of cylinder is preserved equal to 1. The main goal of presented work includes preforming the experimental study to investigate characteristics of laminar free convection heat transfer in downstream region of the cylinder. In addition, the results of numerical simulation in this case are provided to verify obtained experimental data.

2. INTRODUCTION

In the heat transfer study of fluids, the convection is one of the most important mechanisms for thermal energy transferring. Free convection heat transfer over a surface-mounted obstacle applies widely in a number of industrial and environmental situations of practical relevance, such as; heat exchange units, cooling systems and safety applications [1]. Depending on the nature of the incoming free convection boundary layer at the location of the obstacle, the formed flow was categorized as laminar or turbulent [2]. Past two recent decades have seen an increased interest in the turbulent boundary layer that interacts with surface-mounted obstacles, because of uncertainties of the turbulent junction vortex that provide a wide intact field to study. However, the laminar vortex structure studies [3] are significantly important to provide represent meaningful examples for the study of the three-dimensional evolution and mutual interaction of vortices. Furthermore, the solution of many engineering, problems are associated with the need for a more or less detailed description of the laminar flows. The study of laminar flows provides the critical first step in characterizing the effects of surface-mounted obstacle on the rate of heat transfer near the junction region.

3. EXPERIMENTAL STAND AND MEASURING EQUIPMENTS

In this study, free convective boundary layer near a heated vertical plate is provided, by using an experimental setup described in experiments of other researchers [3]. Here the characteristics of the used experimental apparatus allow simulating different flow regimes, up to the Grashof number equal 5×10^{11}.

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The main part of this experimental apparatus, which is shown in Fig. 1, is the junction of cylinder and heated vertical plate. A solid polymer circular/square cylinder is mounted on vertical plate using light glue. The diameter of cylinder fixed to 0.02 [m] and its height is equal 0.04 [m]. The adiabatic condition on cylinder surfaces is provided by very low thermal conductivity of polymer. The principle of this setup is based on the uniform motion of the sensor at a given velocity through inhomogeneous heated static air medium.

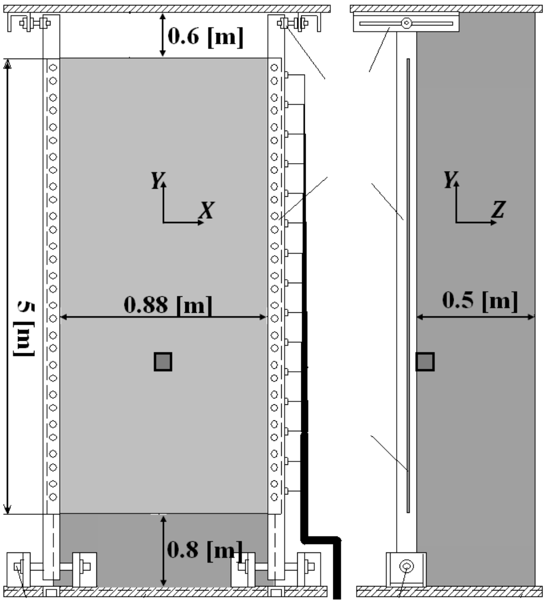

Fig. 1 Schematic view of experimental apparatus.

4. RESULTS

The separation of incoming free convection flow around a square cylinder is of interest to researchers because of sharp edges, which affect the formation mechanism of vortex structure in downstream region of cylinder. Therefore, the formation mechanism of flow structure is described by illustration of two-dimensional resultant velocity (V_{Res}) field and profiles at the YZ symmetry plane ($X/D = 0$). The resultant velocity (V_{Res}) is the combination of longitudinal velocity (V_Y) along the heated vertical plate (in flow direction) and velocity normal to the vertical plate (V_Z):

$$V_{Res} = \sqrt{V_Y^2 + V_Z^2} \qquad (1)$$

A detailed comparison between the measured two-dimensional resultant velocities in the experiment and the numerical simulation is provided using dimensionless profiles of the resultant velocities (V_{Res}^+) in the YZ symmetry plane ($X/D = 0$) at different Y coordinates. Dimensionless resulting velocity (V_{Res}^+) is assumed to be as follows, Where the two-dimensional resulting velocity (V_{Res}) is normalized to a maximum value ($V_{Res_{Max}}$) for each Y coordinate.

$$V_{Res}^+ = \frac{V_{Res}}{V_{Res_{Max}}} \qquad (2)$$

As shown in Fig. 2, by increasing the absolute value of Y/D, the dimensionless resulting velocity profiles of the numerical simulation better agree with the experimental data. This fact is justified by considering the limitations of the experimental method of measurement in near-surface regions. In addition, the unstable nature of the flow at the junction due to the forming complex vortex structure around the junction of the cylinder and the vertical plate causes a large uncertainty in the experimental measurements. The average deviations of the obtained dimensionless resulting velocity of the numerical results from the experimental data are approximately 24%. Despite significant deviations in the values of the dimensionless resulting velocity (V^+_{Res}), Fig. 2 are qualitatively acceptable taking into account the simplifications of numerical modeling and the limitations of experimental measurements.

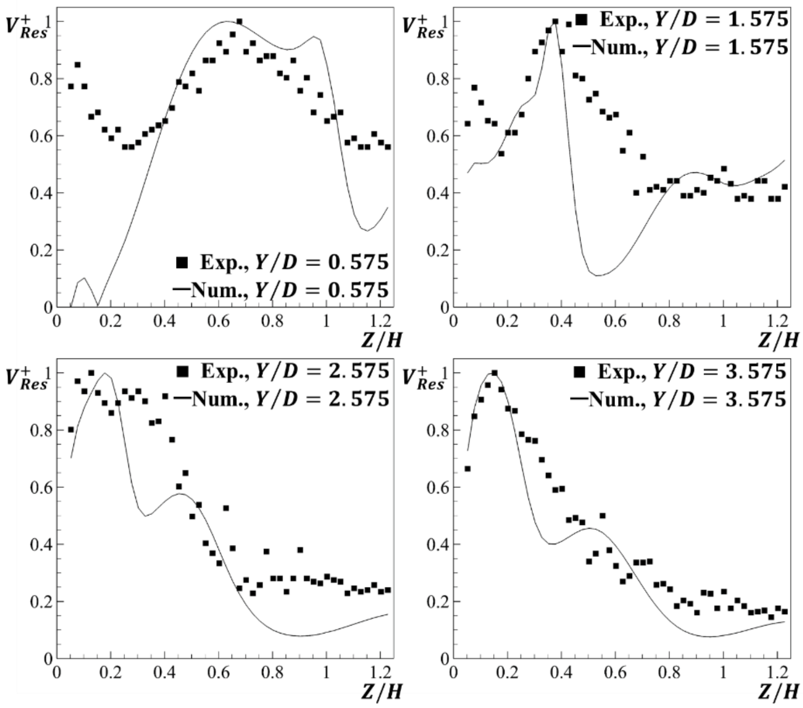

Fig. 2 Dimensionless resulting velocity profiles in the symmetry plane in the downstream region for the Grashof number equals 7.35×10^8.

In present work, the uncertainty analysis method, which states the total uncertainty (w) can be determined from uncertainties of the specified components which influence the experiment, is used [3]. the uncertainty of heat transfer coefficient for different points, which considered in experimental investigation, varies between 2.96% and 7.41%.

5. CONCLUSIONS

To sum up, the certainty and compatibility of experimental apparatus and is equipment for velocity measurement is verified for an adiabatic surface-mounted square cylinder by considering corresponded results of numerical simulation.

REFERENCES

[1] H. Malah, Y.S. Chumakov, E. Sadeghian, The effects of the cross-section shape of the surface-mounted cylinder on the free convective junction flow, *Engineering Science and Technology, an International Journal*, 27 (2022), 101004.

[2] H. Malah, Y.S. Chumakov, Effects of junction flow on the free convection heat transfer of a heated vertical plate, *High Temperature*, 58 (2020), 864-874.

[3] H. Malah, Y.S. Chumakov, Experimental and numerical study of free convection heat transfer around the junction of circular cylinder and heated vertical plate, *Journal of Siberian Federal University Mathematics & Physics*, 13 (2020), 631–643.