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LDA-Messungen über sechseckige strukturierte Hohlräum in turbulenter Kanalströmung

LDA measurements over hexagonal structured cavity inside turbulent channel flow

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Keywords: Hexagonal Structures; velocity contour; LDA Measurements

Abstract

The present research focuses on fully developed turbulent channel flow at low Reynolds numbers as one of the canonical forms of wall turbulence. The experimental investigation for the channel flow is carried out within the wind tunnel of the Department of Aerodynamics and Fluid Mechanics of the BTU Cottbus - Senftenberg. The Gottingen-type wind tunnel was designed for high performance up to bulk velocity of 50 m/s with background turbulence intensity less than 0.5% of the incident flow. Two parallel plates with channel height (h) = 50 mm were tested, for structures with fixed depth (k) = 3.1 mm. In these measurements, the ratios of the channel full height (h) to structure height (h/k) were chosen to be 16.1.

LDA measurements over the horizontal x-z plane have been measured starting from y/h = 0.05 to the channel centerline at y/h = 0.5 within the hexagonal structured cavity depression inside turbulent channel flow. These measurements were carried out with a relatively coarse measurement grid spacing with $\Delta x \approx 0.07D$ and $\Delta z \approx 0.07D$ above the hexagonal structured cavity, where D is the diameter of hexagonal structured cavity. The range of the Reynolds number measured was at Re=10900. All LDA measurements have been measured with the origin (x = 0, z = 0) centered at the center hexagonal structured cavity of the 11th row of the structured array as shown in fig.(2), to insure that the flow reached the equilibrium state.

In the present investigation, detailed measurements were carried out to reveal the flow behaviour around a single hexagonal structured cavity and discuss the impact of the structured surface onto the flow.

Introduction

A quest for drag reduction and hence fuel consumption has always provoked researchers to look for new ways to achieve them. In the last two decades, there was an increasing interest in using structure surfaces such as dimples with the aim of reducing the turbulent drag. Early efforts as in the experimental study of (Alekseev et al. 1998) reported significant drag reduction of up to 20% for dimpled surfaces compared with the flat surfaces. However, more recent work like that of (Lienhart et al. 2008), who combined both experimental and numerical studies, reports only small or no drag reduction for dimples in both open and internal boundary layers. No clear reason has been found for the conflict in such results, and on the top that the many parameters that affect the flow over dimples add much to the overall confusion. This is particularly due to the fact that many of these parameters, such as the flow turbulence intensity, are often unreported. The flow structure over the dimples is influenced differently by a various structure geometry and flow parameters. One of the most significant parameters is the dimple depth, which is often non-dimensionalized by the dimple diameter. The effect of ratio of the dimple depth to diameter has been studied extensively in experiments by (Burgess et al. 2005, Ligrani et al. 2001, Merbold et al. 2009) and numerically by (Isaev et al. 2003, Wang et al. 2006). Flow visualizations (Kovaleko et al. 2010, Kwon et al. 2011, Tay et al. 2014) have shown that when ratio of dimples depth to diameter is greater than 10% generation of vertical and streamwise vortices takes place. These vortices, which are sometimes periodic, greatly increase the mixing within the flow. The majority of these studies involve dimples in an internal flow environment such as in a channel or pipe. Numerous empirical relations have been proposed relating to useful parameters such as friction factors with the dimple depth to diameter ratio, Reynolds number, inlet turbulence intensity, channel height, and even the channel aspect ratio (Mahmood et al. 2002, Ligrani et al. 2005, Isaev et al. 2010).

In a study by Butt et. al. 2013 and 2016, investigations have been performed on the flow over a hexagonal structured surfaces including hexagonal structured cylinders, hexagonal structured plates and hexagonal structure turbine blades. It was reported that the drag coefficient of the structured cylinder with convex hexagonal patterns were observed to be lower than the smooth cylinder by 65% .While for the flat plate [fig (2)], the maximum reduction in shear stress coefficient was recorded for concave structured surface of about 19% compared to the smooth surface (Butt et al.2014). The present study focuses on the effect of the flow behaviour around a single hexagonal structured cavity and discuss the impact of the structured surface onto the flow.

Experimental Setup

The experimental investigation for the channel flow is conducted for Reynolds number $Re = U_b\ d\ /\ v = 10900$ (using bulk velocity U_b, channel half-width $d = h/2$) in wind tunnel of the aerodynamics and fluid mechanics department as shown in fig.(1). The wind tunnel, Gottingen type, was equipped with a cooling system to fix the temperature at 20 ºC. Two Plexiglas plates spanning the whole length of the channel were used as side-walls to allow optical access of the flow. Three strips of tripping device sandpapers were used to trigger the turbulent boundary layer at x/D=0 as in fig (2) to insure that the flow is fully turbulent. The Upper and lower plates are equipped with a wide pocket served as a platform for the structured sheets to be investigated. The test sheets of similar width of the upper and lower plates and smaller in length were placed in the pocket of the plates and fixed with the help of fixing elements on both sides. The surface of the test sheet was setting flush to the surface of the plates to avoid stepping and hence any local separation of the flow as shown in fig.(2). The characteristic dimensions of the channel is 11.9 and 22.4 spanwise and streamwise respectively. For Channels having high aspect ratio ($W/D \geq 10$), the side wall effects on the core flow structure can neglected. (Marusic et. al. 2010)

For better understand the mechanism and reason for the observed drag reduction, further measurements were taken at very high spatial resolution with $\Delta x \approx 0.07D$ and $\Delta z \approx 0.07D$ above the hexagonal structured cavity, double that for the measurements at four different heights at y/h = 0.5 , 0.25, 0.125, and 0.05.

Measurement technique

Laser Doppler Anemometry

All measurements have been conducted over concave hexagonal structured cavity at the 11th row of the tested sheets using two dimensional Laser-Doppler anemometry. The focal length of the LDA during the measurements was 310 mm and the measuring volume was 45 µm. For computing the mean velocity of the local flow measurements at least 20000 samples were acquired at every measuring position. A computer controlled three dimensional high spatial resolution traverse system (Isel Germany AG) was in use for traversing the laser doppler anemometry probe. The traverse is placed on scaled rail to facilitate its movement in streamwise, spanwise, and normalwise directions. The minimum step with the traverse mechanism is 6,35 µm.

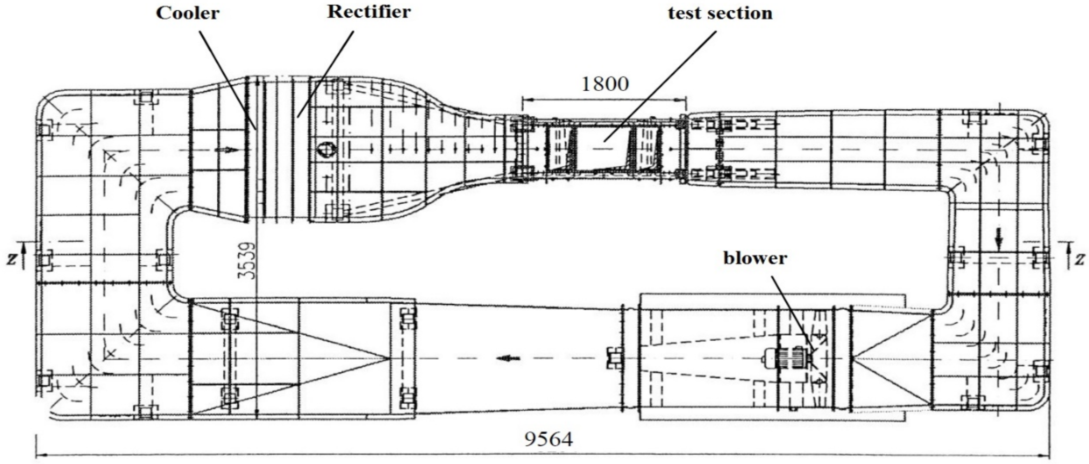

Fig. 1: Sketch for the Gottingen wind tunnel at LAS.

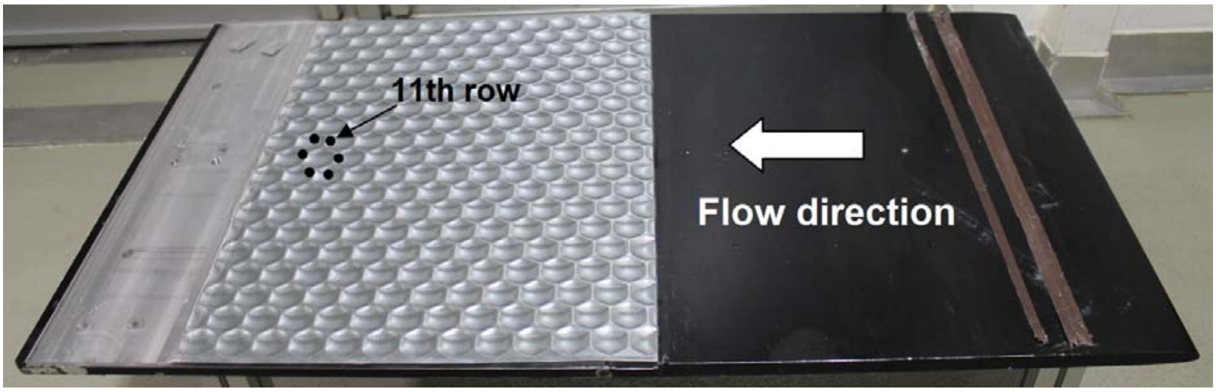

Fig. 2: Structured sheet plate fixed over the lower flat plate. Second plate is mounted above with a separation distance D=50mm.

Results

The effect of the structured patterns serves essentially to introduce streamwise vorticity into the basic flow. This streamwise vorticity arises as the flow enters in and out of the structured pattern resulting in spanwise velocity components near the wall. As depicted in fig. (3) , the streamwise velocity contour showed two high velocity streaks lie on either side of the centerline of the hexagonal cavity and start to vanish as the y/h increase till despair completely at the center of the channel. These repeated contour patterns are support the flow visualization results of Ligrani et al. 2001, Won et al.2005 and Tay et.al. 2015. Tay et.al. reported that the low and high speed streaks are caused by the rotation of the vortices that bring the near-wall low speed fluid up from the center of the structural patterns and the spanwise edges of the structured cavity and the high velocity fluid from high above the wall downwards at the location of the high speed streaks. At the center of the hexagonal structured cavity fig.(3), a recirculation region appears at the falling edge of the hexagonal structure lead to a modified pressure distribution compared with the case of a smooth wall. At both upstream and downstream regions of the hexagonal structure, where the flow either enters or leaves the surface depression, the pressure is slightly decreased. However, the observation is that pressure increases on the rising edge of the hexagonal structure yielding a contribution to the overall drag.

In fig.(4) and (6) , the recirculation area at the center of the hexagonal cavity near the wall lead to higher fluctuation in the streamwise and normal velocities than the flow away from the wall. This could be due to the measurement at y/h=0.05 corresponds to y+=24 and the maximum turbulent kinetic energy occurs at y+=15(Yousry et.al. 2016). This means that the velocity fluctuations below this measurement plane at y/h = 0.05 are higher than that above it.

The normal velocity contour depicted in fig.(5), showed a low velocity at the falling edge and a high velocity at the leading edge of the hexagonal structured cavity. While spanwise flow components disrupt the normal cascading of the turbulent energy to the smaller scales for dissipation. Instead, the energy is being retained at the larger scales, implying greater streamwise coherence and stability of the flow.

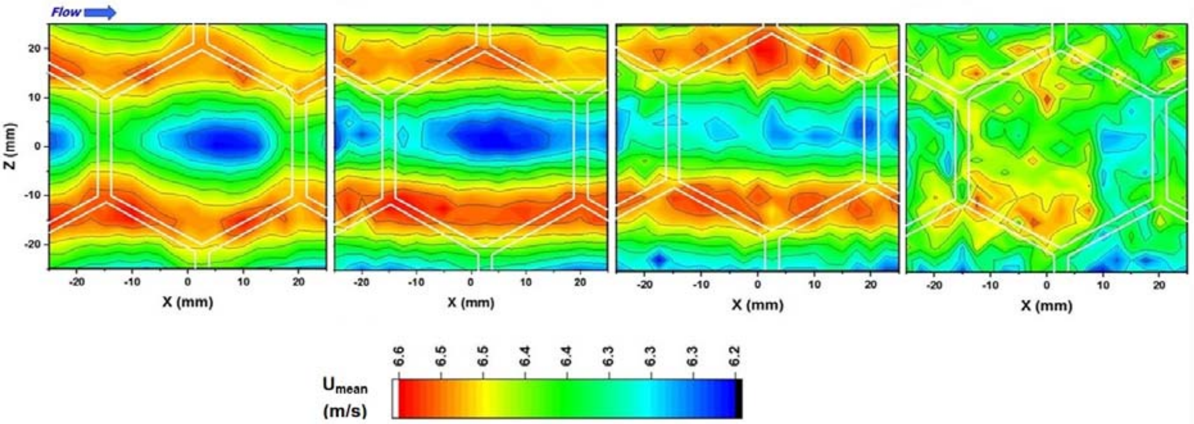

Fig. 3 : Mean streamwise velocity contours at Re = 10900 for y/h = 0.05, 0.125 ,0.25,and 0.5.

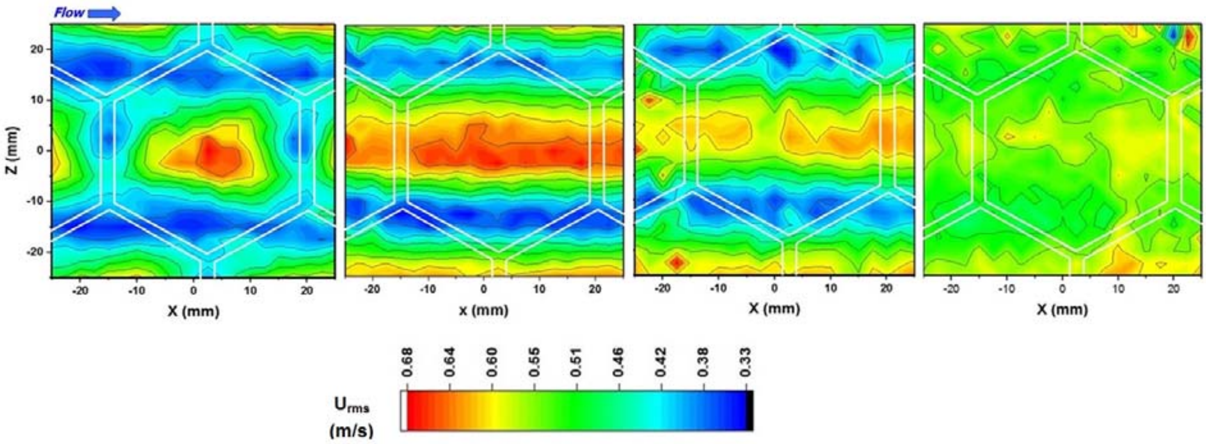

Fig. 4: Fluctuating streamwise velocity contours at Re = 10900 for y/h = 0.05, 0.125, 0.25, and 0.5.

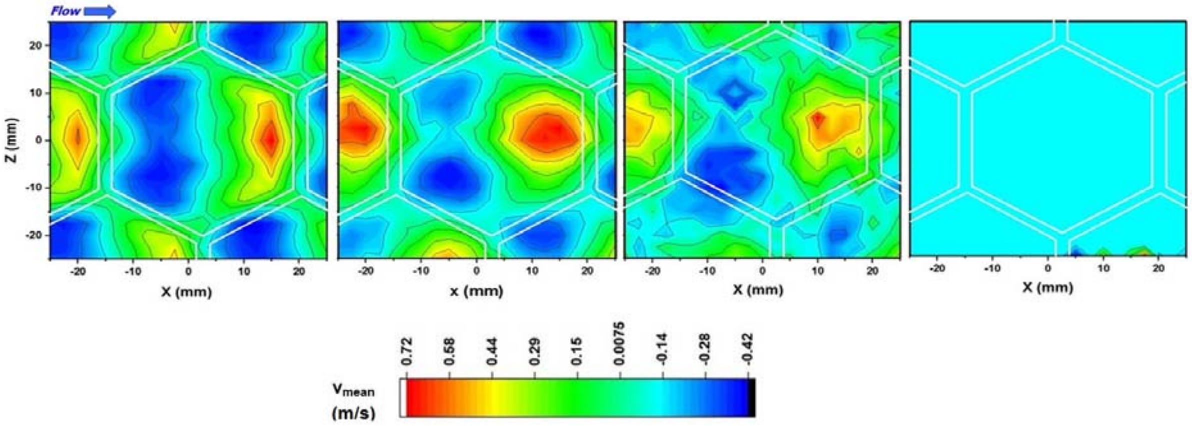

Fig. 5 : Mean normal velocity contours at Re = 10900 for y/h = 0.05, 0.125, 0.25, and 0.5.

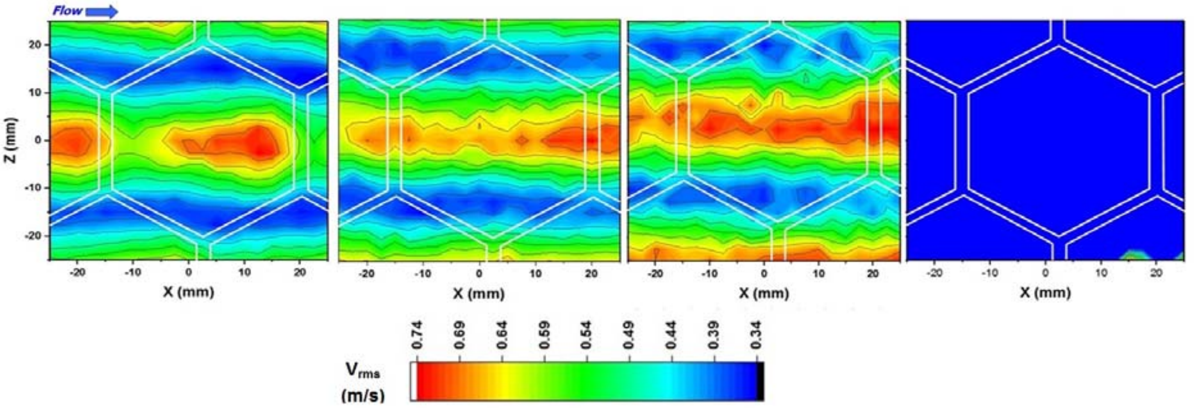

Fig. 6 Fluctuating normal velocity contours at Re = 10900 for y/h = 0.05, 0.125, 0.25, and 0.5.

Conclusion

An experimental investigation has been carried out over hexagonal structured cavity inside fully turbulent channel flow. 2D LDA measurements have been conducted at four different horizontal planes to study the behavior of the flow over the hexagonal structured cavity.

The present study showed that the hexagonal structured cavity introduce streamwise vorticity into the basic flow. The streamwise vorcity appears as two high velocity streaks lie on either side of the centerline of the hexagonal cavity and start to vanish as the y/h increase till they disappear completely at the center of the channel. This behaviour agrees with the behaviour of the flow over dimples as reported by Ligrani et al. 2001, Won et al.2005 and Tay et.al. 2015.

At the center of the hexagonal structured cavity, a recirculation near the wall that lead to higher fluctuation in the streamwise and normal velocities than the flow away from the wall. This could be due to the measurement at y/h=0.05 corresponds to y+=24 and the maximum turbulent kinetic energy occurs at y+=15 . This means that the velocity fluctuations below this measurement plane at y/h = 0.05 are higher than that above it.

Finally, the normal velocity contour, showed a low velocity at the falling edge and a high velocity at the leading edge of the hexagonal structured cavity. While the spanwise flow components disrupt the normal cascading of the turbulent energy to the smaller scales for dissipation. Instead, the energy is being retained at the larger scales, implying greater streamwise coherence and stability of the flow.

Further measurement will be held at different Reylonds numbers in order to better understand the mechanism and reason for the observed drag reduction.

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