Investigation of Flow over bluff bodies with patterned surface using Laser-Doppler Anemometry

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Abstract

Patterned cylinders made by bending and welding patterned steel sheets were tested in a subsonic Wind tunnel to observe the effect of these hexagonal patterns on the flow of air.

The length of the patterned sheet to form a cylinder was calculated by taking into account the dimensions of the patterns to insure their continuity over the circumference of the cylinder. These patterns are hexagonal in shape with wrench size of 33 mm and depth of 3 mm

Cylinders are formed in such a way that the effect of patterns on the flow could be investigated in four different orientations i.e. hexagons pressed towards outside, hexagons pressed towards inside, hexagons parallel to the free stream flow, hexagons perpendicular to the free stream flow.

The results of investigations on all these orientations were compared with a smooth cylinder. Investigations were done for Reynolds numbers (based on the diameter of the cylinder and free stream velocity) ranging from 3.14E+04 to 2.77E+05. The results show that these patterns reduce the total drag of the cylinder. Patterns pressed towards outside and parallel to the free stream velocity give the highest drag reduction. The drag of the patterned cylinder is about 0.65 times the drag of the smooth cylinder. This phenomenon of drag reduction is related to the positions of flow separation points on the surface of the cylinder which are clarified from the measurement of the wakes of all cylinders with the help of LDA and flow visualization using light sheet.

INTRODUCTION

Aerodynamics of the bluff bodies has been of great interest for scientists and engineers especially in the automotive industry, Aerospace and Sports industry. Various methods have been adopted by many researchers to achieve a reduction in Drag of Bluff bodies. Y.triogi et all (2009) have achieved a 48% drag reduction for a Cylinder by installing a much smaller cylinder in the upstream direction of Flow, Yamagischi (2004) shows a clear reduction in Drag of a Cylinder with circular Grooves for a particular Reynolds numbers. Choi et all (2006) has explicitly explained the mechanism of drag reduction for a dimpled sphere. According to Choi et all (2006) a shear layer instability caused by the successive dimples on the surface of a bluff body delays the separation of the boundary layer. This delayed separation of the boundary layer is ultimately responsible for reduction in Drag.

In this paper flow over hexagonal patterns has been investigated. Investigations were performed in a subsonic Wind Tunnel. The Motivation behind these tests was to study the effects of the above mentioned hexagonal structures on the Flow of air and their contribution in reducing the Drag of the body. The Cylinders to be investigated were made by bending and welding patterned steel sheets once with facing the patters outwards and second the patterns facing inwards. The Orientation (Fig. 1) of these patterns towards the free stream of air was also changed during the Investigations and hence the investigations could be performed over five different configurations.

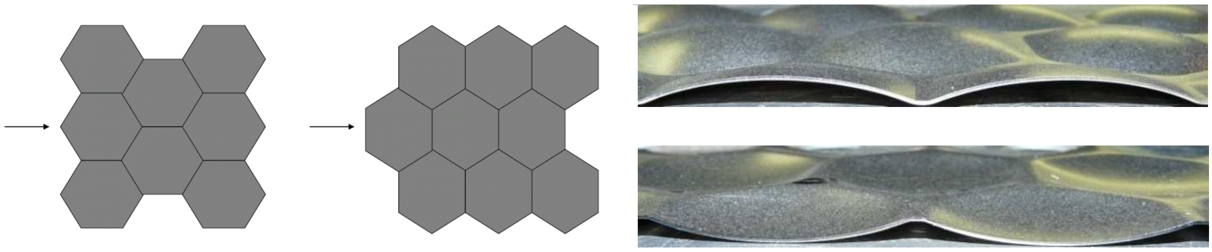

Fig 1: 90°(left) 0°(right), outwards(top), inwards (bottom)

The Idea is to influence the pressure distribution around the Cylinder with shear layers over the patterened surface, coming from the upstream Cylinder in such a way that the shear layer becomes instable dramatically delaying the separation process. A delayed separation and a smaller wake region behind the cylinder are responsible for reduced Aerodynamic forces.

EXPERIMENTAL SET-UP

Figure 3 shows the experimental setup for carrying out experiments in the Wind Tunnel. A smooth Cylinder of diameter 155 mm was taken as a reference. All five configurations have the following properties

Configuration	Diameter	Pattern Shape	Pattern height	Pattern Size
Smooth (A1)	155 mm	hexagonal	3.1 mm	33 mm
Outwards 90°(A2)	156 mm	hexagonal	3.1 mm	33 mm
Outwards 0°(A3)	156 mm	hexagonal	3.1 mm	33 mm
Inwards 90°(A5)	156 mm	hexagonal	3.1 mm	33 mm
Inwards 0°(A4)	156 mm	hexagonal	3.1 mm	33 mm

Fig 2: Configurations

The experiments were performed in a subsonic closed wind Tunnel. The dimensions of the Test chamber (Fig.3) are 585 x 585 x 1300 mm. The free stream turbulence intensity, defined as the ratio of root mean square of the velocity fluctuations to the mean velocity is less than 0.8% for all experiments. The free stream velocities in the wind tunnel were varied from 3 m/s to 27 m/s corresponding to the Reynolds numbers of 3.14E+04 to 2.77E+05. Reynolds number is a dimensionless quantity based on the diameter of the cylinder and the free stream velocity. The length of the cylindrical holder on which the test cylinder was mounted was intentionally made a little larger than the length of the test Chamber to avoid the

Fig 3: Experimental Setup

effects of the finite cylinder length. Hence the body can be considered as an infinitely long cylinder.

The drag coefficient of the Cylinder configuration was measured using a piezoelectric force gauge having an uncertainty of ±0.5 % of the measured value. The least count of the sensor is 0.2 N. The arrangement shown in figure 3 consists of a beam supported on sharp edges on axis parallel to the axis of the cylinder, allowed the drag force to be measured in the form of a compressive force on the force sensor. A Piezoelectric device measures the changes in Voltages caused by the deflection in the piezoelectric material when a force is applied. A calibration is needed ultimately to record the magnitude of force acting accurately.

The velocity profiles in the wake region of all the Cylinder configurations were measured using Laser Doppler Anemometry. A single measurement was recorded for 10 seconds in this case. These measurements were taken in another wind tunnel with closed test chamber having dimensions of 600 x 500 x 600 mm Because of smaller test chamber; measurements could be performed over a length of 300 mm.

Flow visualization was carried out by introducing Fog exactly at the centre of the Test chamber of the Wind Tunnel into the free stream of air with the help of 3 mm diameter tube. A 1200 Watt Fog machine was the source of the Fog. A light sheet above the cylinder illuminated the smoke flow over the cylinder which was captured by a high performance Digital Camera having a Resolution of 8 Mega Pixels at a rate of 4 frames/sec.

Results and Discussions

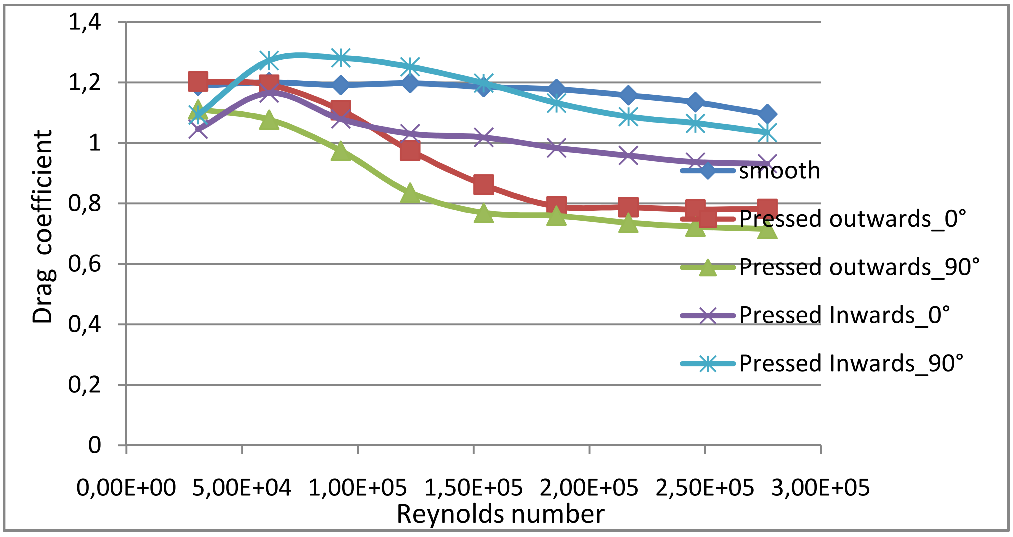

Fig 4: Drag Coefficients vs Reynolds Numbers

Drag Coefficient

The Drag Coefficient measurements are shown in figure 4. It is quite obvious from the Results that the patterned Cylinders offer a less resistance to the flow than the smooth one especially at higher Reynolds numbers. A higher Reynolds number corresponds to a higher velocity as the diameter and the density of air remains constant. The configuration A5 is the only exception which has an even higher drag coefficient at a low Reynolds number with respect to A1. Drag coefficients of the patterned cylinders tend to decrease with increasing Reynolds number or the free stream velocity. The configuration, pressed outwards at 90° to the flow has the lowest drag coefficient at Reynolds number 2.77E+05 which is about 35 % (Fig. 5) less than the smooth cylinder at the same Reynolds number. The difference between the two configurations A2 and A3 is not that remarkable. A3 offers a little higher drag than A2. On the other hand the configurations with patterns pressed inwards show a higher drag coefficient with respect to the configurations pressed outwards. A5 has a drag coefficient very near to that of smooth one whereas the drag coefficient of the configuration pressed inwards at 90° (A4) lies somewhere between A5 and A 3.

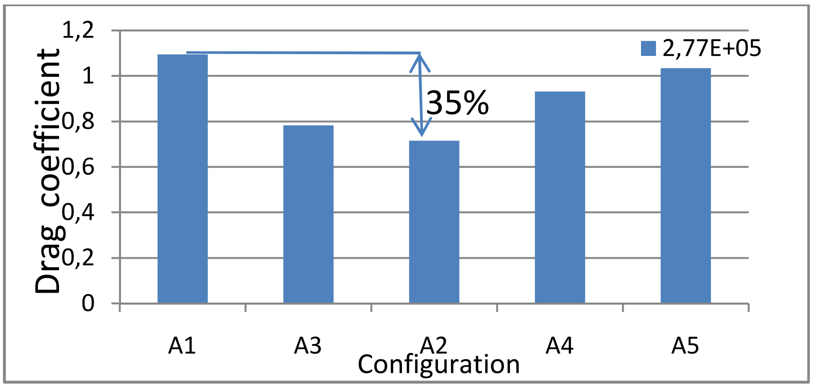

Fig 5: Drag Coefficient vs Configurations

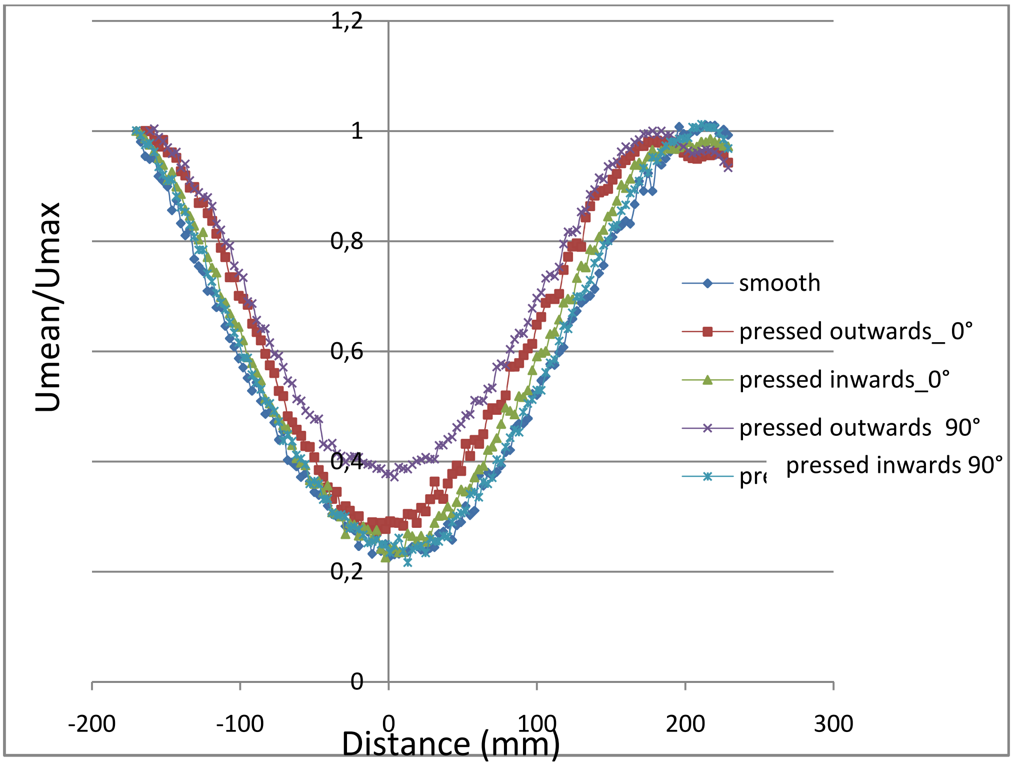

Fig 6: Velocity Ratio vs Distance

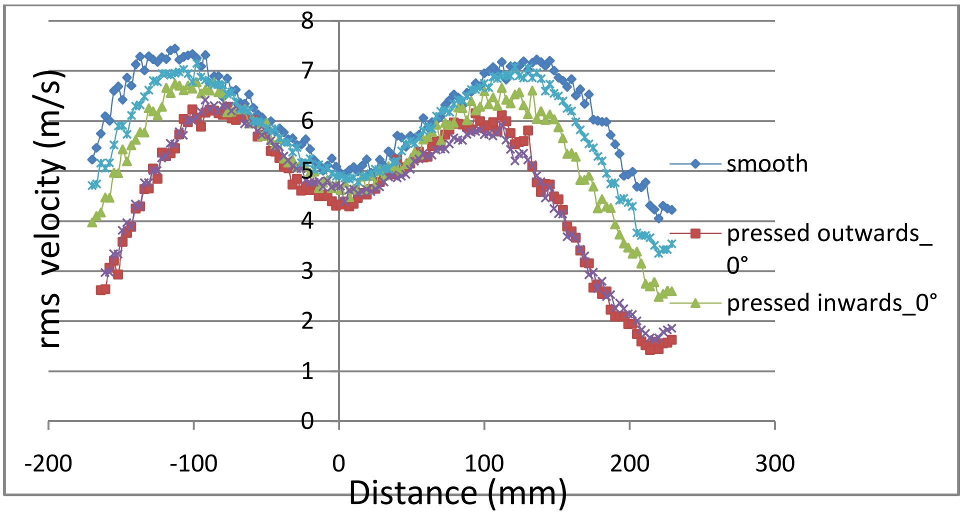

Fig 7: Velocity fluctuations vs Distance

Velocity Profiles

Velocity profiles in the wake region along the line perpendicular to the axes of the cylinder configurations at a distance of about 3 times the diameter of each of the cylinders were obtained using LDA. These measurements were carried out at a Reynolds number of 2.77 E+05. Both the velocity fluctuations (Fig. 7) and the mean velocity variations (Fig. 6) are symmetric indicating that the wakes are symmetric as well. A symmetric wake region indicates that only drag force is acting on all the investigated configurations. Evidence for the behavior seen in Fig 4 and Fig 5 is presented here i.e. the Wake region of all the patterned cylinders is smaller than the wake region of smooth cylinder. A2 has the smallest wake region confirming the lowest measured value of drag coefficient. The pressure distribution around the cylinder is disturbed by the instabilities in the shear layer coming from the upstream of cylinder and hence the separation is delayed. A delayed separation is ultimately responsible for the reduction in aerodynamic forces.

Flow Visualization

The results of flow visualization using a light sheet are presented in the Figures 9-13 The flow visualization technique was performed for all the configurations at two different Reynolds numbers 6.17E+04 and 2.46E+05 respectively. A general trend is followed by nearly each configuration i.e. the near wake region is smaller at lower Reynolds number as compared with higher Reynolds number confirming the presence of higher drag at higher Reynolds number. The separation point (shown by an arrow) at higher Reynolds number is slightly delayed for all configurations with the highest delay for A2 and A3 where separation occurs at about 115°. On the other hand the position of separation lies at about 85°. For a delayed separation the boundary layer remains attached to the surface over a larger region and hence reduces the aerodynamic drag acting on the object. The difference among these configurations is minute. Another remarkable observation that is vindicated by theses visualization results is a higher drag coefficient of A5 as compared to the smooth cylinder at low Reynolds number. The figure 13 clearly exhibits that the size of wake region of A5 is larger than A1 yielding a higher drag coefficient.

Re = 6.17E+04 **Re = 2.46E+05**

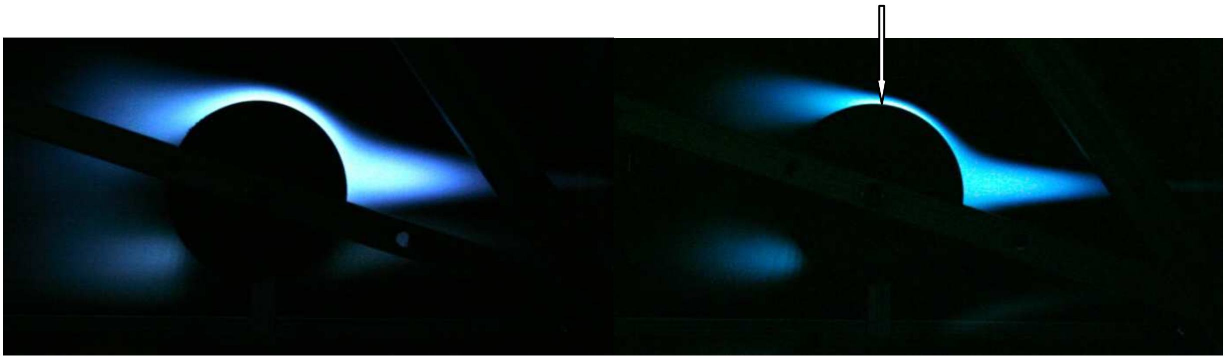

Fig 8: Smooth (A1)

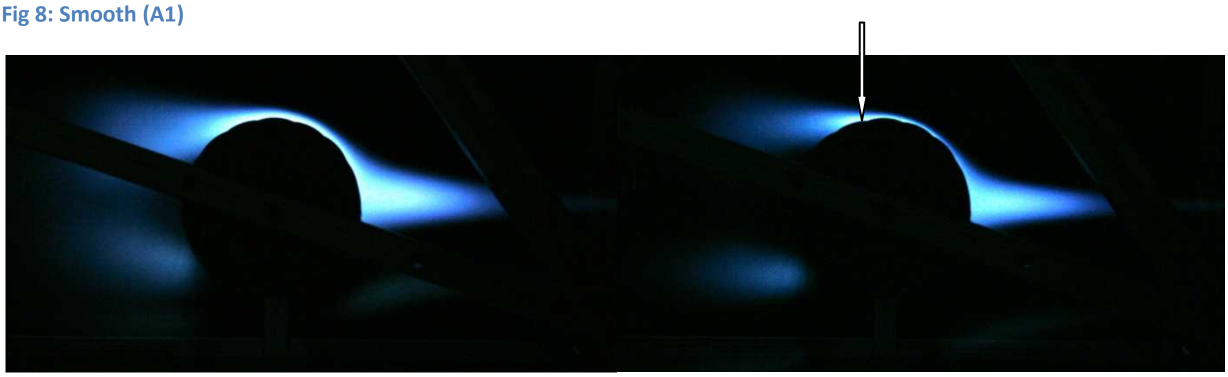

Fig 10: Pressed outwards at 90° to the flow (A2)

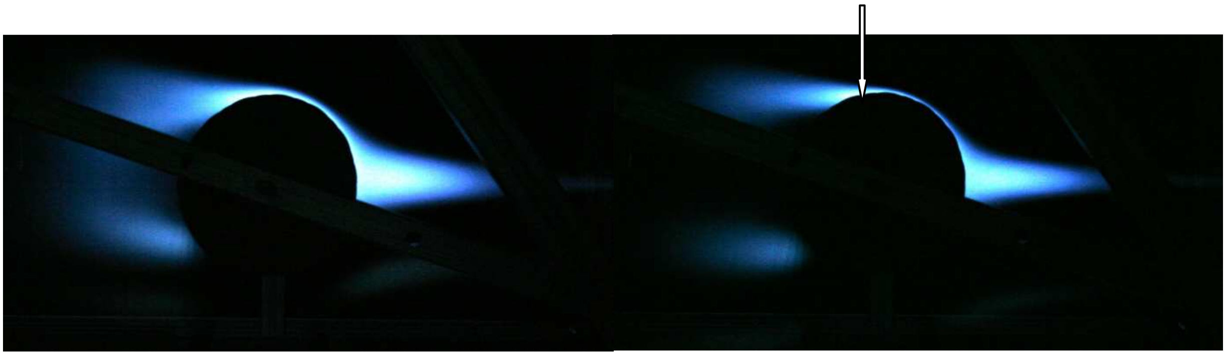

Fig 9: Pressed outwards at 0° to the flow (A3)

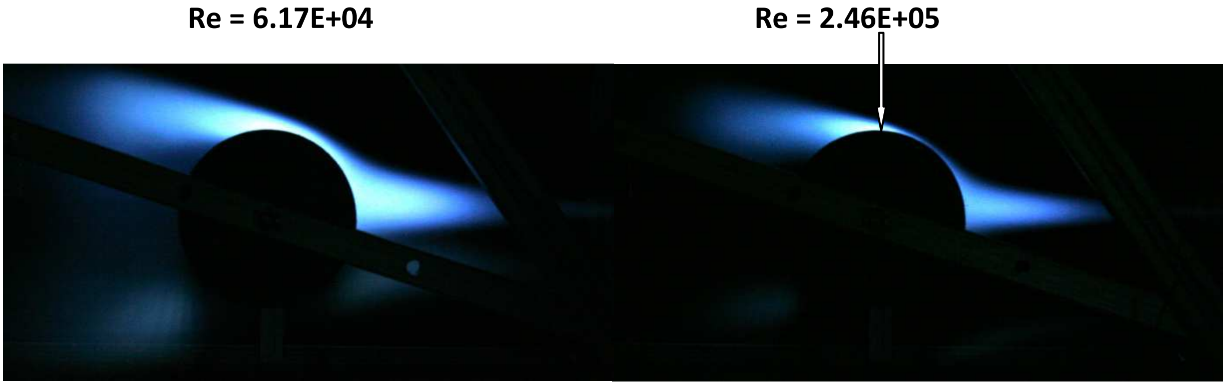

Fig12: Pressed inwards at 90° to the flow (A5)

Fig13: Pressed inwards at 0° to the flow (A4)

Conclusions

In the present study investigations of the Flow over patterned cylinders were conducted for Reynolds numbers ranging from 3.14E+04 to 2.77E+05. The drag coefficient of the cylinder with patterns pressed outwards at 90°to the flow was found to be the lowest of all, 0.65 times of A1 whereas the drag coefficient of the configuration A5 had a value very close to the one of smooth cylinder. The others lie in between.

It was shown with the help of velocity profiles in the wake region and flow visualization over the Cylinders that boundary layer separation is much more delayed for the cylinder with lowest drag coefficient occurring at 115°. The delayed boundary layer separation which disturbs the pressure distribution around the cylinder and a much smaller wake region behind the cylinder are responsible for drag reduction. On the other hand the configuration with patterns pressed inwards bear a drag coefficient closer to the one of smooth cylinder which means that the size of wake region and the position of boundary layer separation are similar to the smooth cylinder. On the basis of these results it can be ratified that the boundary layer separation is mainly responsible for the drag reduction for bluff bodies.

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