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Experimental observation of boundary layer of the turbulent flow over a bluff body inside rectangular diffuser

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Abstract

The turbulent fluid flow with different velocity over a bluff body is important for the analysis and design of structure of high rise buildings as well as flow passage having flow obstruction. The main aim of present work is to investigate experimentally the flow field of air in a rectangular diffuser with different inlet velocity. From experimental results it has been found the displacement thickness and momentum thickness by numerical integration. The flow field considered is the field before and after the bluff body in a rectangular diffuser. The result also contained detailed velocity distributions, which have been investigated thoroughly in the direction normal to the test section at different axial positions. From the experimental results it is concluded that the boundary layer thickness is lower for higher inlet velocity. Displacement thickness is fluctuating at upstream and top of bluff body and at downstream it decreases with increase of inlet velocity. Momentum thickness decreases according to increase inlet velocity. The variation of momentum thickness is higher for high inlet velocity. Near the bluff body, momentum thickness decreases, which denotes maximum momentum transfer and as it becomes negative, it corresponds to recirculation zone. The recirculation length and height increases with increase inlet velocity.

Keywords: Bluff body; turbulence; re-circulation; boundary layer; displacement thickness; momentum thickness.

Nomenclature

g	acceleration due to gravity (m/s^2)
h	difference of height of two points (m)
l_{stag}	stagnation pressure readings of the manometer (m)
l_{stat}	static pressure readings of the manometer (m)
n	No. of points
P_1	main scale reading of barometer
R	gas constant (kg-m/kg ^{0}k)
R_{eX}	Reynolds number
T	absolute temperature (^{0}k)
V.C.	vernier constant
V.S.	vernier scale reading
V	velocity of air at a particular height (m/s)
V_∞	maximum velocity of air (m/s)
w	specific weight of mercury (kg/m^3)
x	distance of the stations measured from the blower outlet end (m)
x_0	initial height (m)

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1.1. Experimental set up and procedure

A complete description of the experimental set-up is shown below. The components of the set up are as follows

(i) Rectangular diffuser with 15^0 inclination in axial direction (ii) Blower with controlling system (iii) Bluff body of dimension 0.2×0.1×0.075m (iv) Inclined tube Manometer (v) Bevel Protractor (vi) Stagnation tube (vii) Hose pipe (viii) Sealing material (ix) Static tube (x) Scale (xi) Digital Velocity Meter (xii) DC Variac (xiii) Speed Sensor (xiv) Thermometer. Experiments have been carried out at 1000 RPM, 1500 RPM and 2000 RPM of blower speed.

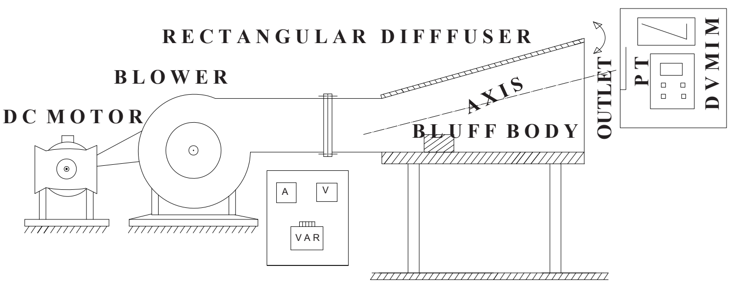

Fig. 1. Schematic diagram of experimental set-up

A blower with controlling system was connected at the inlet of a 15^0 inclined rectangular diffuser. A bluff body of 0.2x0.1x0.075m dimension, 0.24m from the inlet is set within the diffuser. Inclined tube manometer with 5^0 inclinations is connected to stagnation tube and static tube by a long hose pipe. The Manometric fluid used was kerosene and the measurements were taken in middle plane of the diffuser. Stagnation tube has been used to measure stagnation pressure and static tube was for static pressure. The upper wall of diffuser has holes throughout the axial length. The stagnation and static tube are set at different station by this hole. After entering the tube within diffuser through upper wall holes it is properly sealed by using sealing material. The heights at which a pitot tube has been raised are measured with a centimetre calibrated scale. The pressure has been read throughout the station. All the measurements have been taken at 1000 RPM, 1500 RPM and 2000 RPM of blower speed at nine different stations. Distances of stations from the blower end are chosen conveniently as 0.115m, 0.18m, 0.24m, 0.29m, 0.36 m, 0.48m, 0.725m, 1.185m and 1.39m respectively. The experiments were conducted very carefully with measurements taken for short times so that there are no appreciable changes in density of the air flowing through the diffuser.

To measure velocity of flow of air by stagnation tube and static tube we considered the equation

$$P_{stag} = \rho_{oil} \times g \times \sin\theta \times l_{stag} \quad (1)$$

$$P_{stat} = \rho_{oil} \times g \times \sin\theta \times l_{stat} \quad (2)$$

In the above equations P_{stag} and P_{stat} are the stagnation and static pressure respectively. ρ_{oil} is the density of Kerosene which is 800 kg/m^3.

Using Bernoulli's Theorem, we get the velocity, which is

$$V = \sqrt{\frac{2\rho_{oil} g \sin\theta (l_{stag} - l_{stat})}{\rho_{air}}}\, m/s \quad (3)$$

We found the term ρ_{air} which is density of air and it is found from equation (4)

$$\rho_{air} = \frac{(P + V.C \times V.S)2.54w}{R \times T \times 100} Kg/m^3 \quad (4)$$

Our main aim is to determine Displacement thickness and Momentum thickness. Reynolds no is an important parameter for this calculation and it can be obtained as

$$R_{eX} = \frac{\rho_{air} \times V \times x}{\mu_{air}} \quad (5)$$

Where μ_{air} is the viscosity of air.

For Numerical calculation of Displacement thickness and Momentum thickness we used one third Simpson rule [1].

$$\int_{x_0}^{x_0+nh} ydx = \frac{h}{3}(y_0 + 4y_1 + 2y_2 + 4y_3 + 2y_4 + \cdots + 2y_{n-2} + 4y_{n-1} + y_n) \quad (6)$$

For first six stations h=0.01m and for last three stations h=0.02m, x_0 is the initial height and n is the number of points.

For Displacement thickness $y = \int_0^\infty (1 - \frac{V}{V_\infty})dy$

For Momentum thickness $y = \int_0^\infty \frac{V}{V_\infty}(1 - \frac{V}{V_\infty})dy$

2. Results and discussion

The velocity distributions in the rectangular diffuser along the mid plane of different heights are plotted for different stations. The velocity distributions are obtained at three different inlet velocity of the diffuser with 75 mm high bluff body and corresponding speeds of Blower are 1000RPM, 1500 RPM and 2000 RPM.

The following graphs are plotted from the data obtained from the performed experiments and they are shown below.

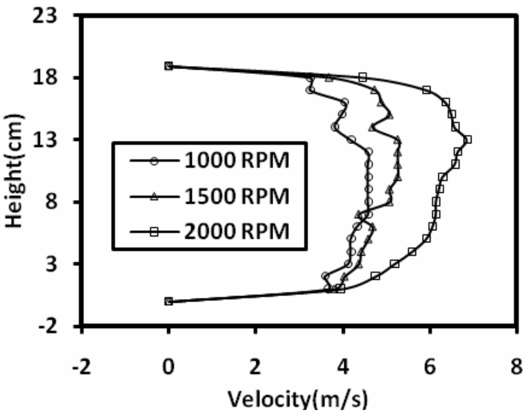

Fig. 2. Comparison of velocity distribution at x=11.5cm for variable inlet velocity

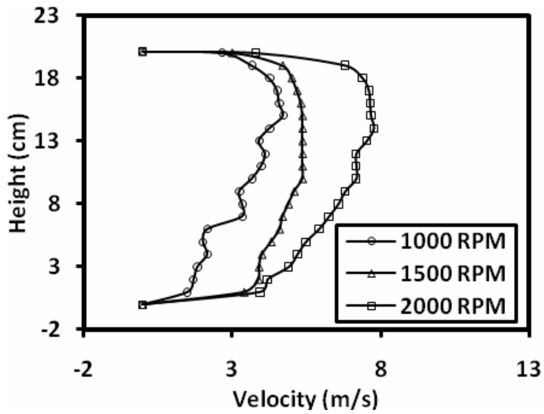

Fig. 3. Comparison of velocity distribution at x=18cm for variable inlet velocity

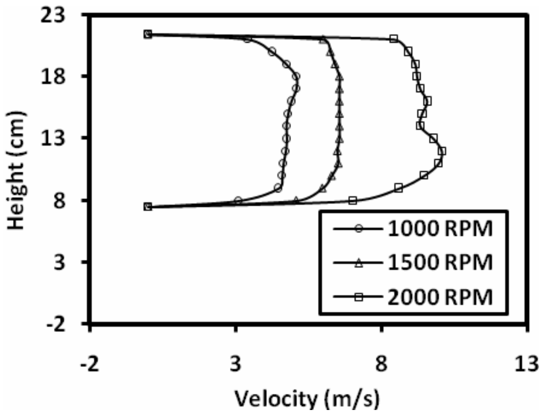

Fig. 4. Comparison of velocity distribution at x=24cm for variable inlet velocity

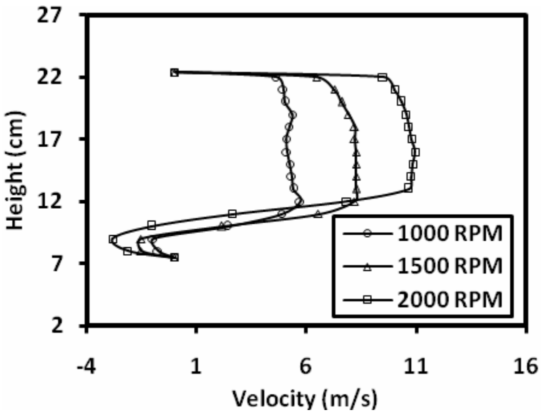

Fig. 5. Comparison of velocity distribution at x=29cm for variable inlet velocity

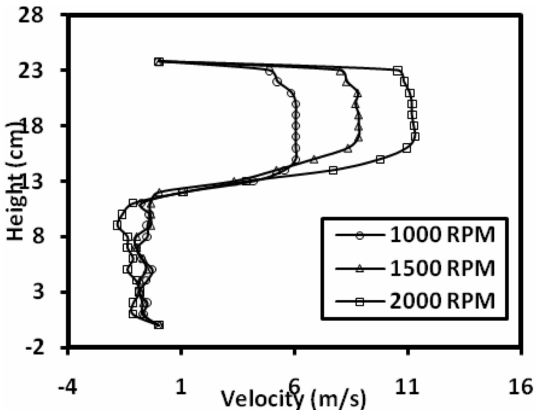

Fig. 6. Comparison of velocity distribution at x=36cm for variable inlet velocity

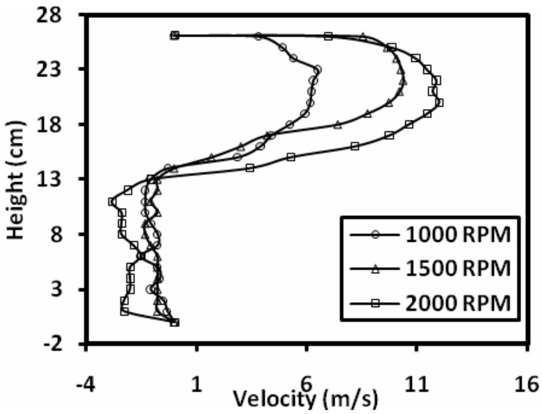

Fig. 7. Comparison of velocity distribution at x=48cm for variable inlet velocity

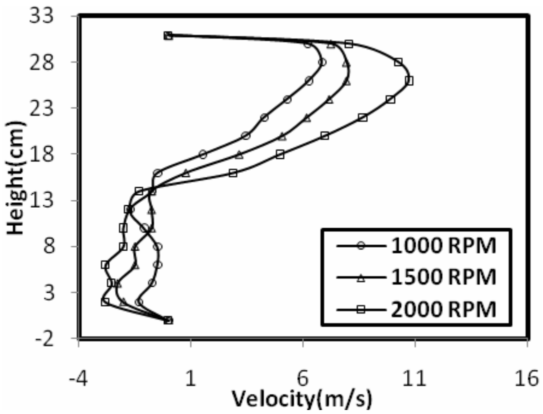

Fig. 8. Comparison of velocity distribution at x=72.5cm for variable inlet velocity

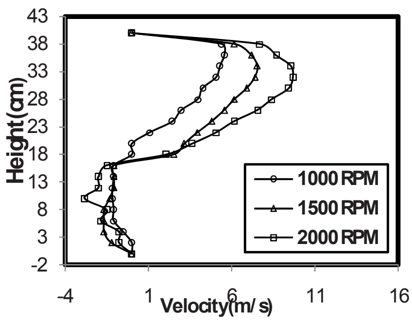

Fig. 9. Comparison of velocity distribution at x=118.5cm for variable inlet velocity

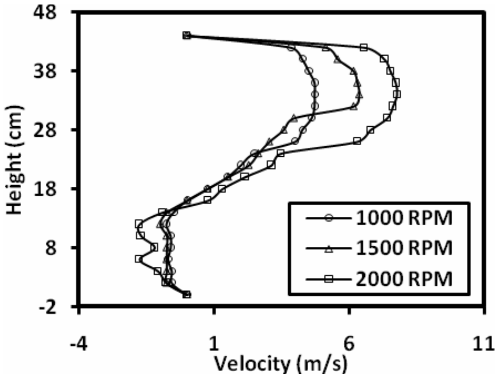

Fig. 10. Comparison of velocity distribution at x=139cm for variable inlet velocity

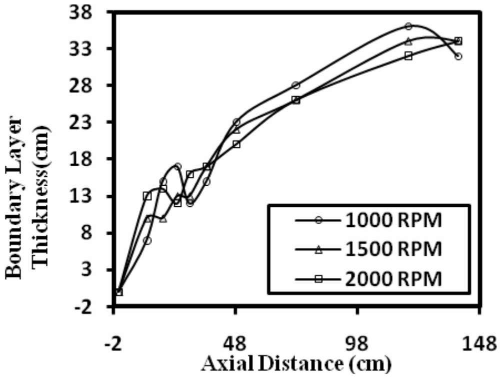

Fig. 11. Comparison of boundary layer thickness for variable inlet velocity

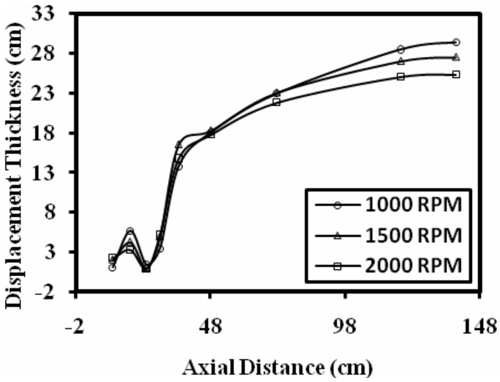

Fig. 12. Comparison of displacement thickness for different axial distances

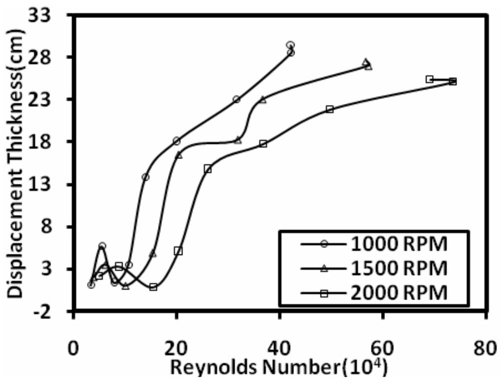

Fig. 13. Comparison of displacement thickness for different Reynolds number

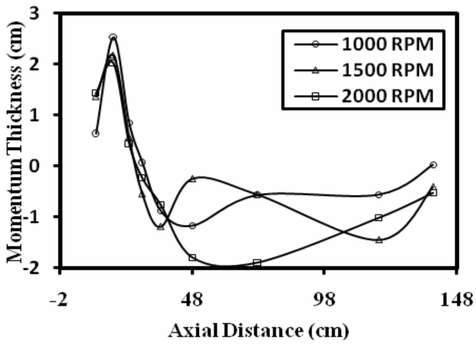

Fig. 14. Comparison of momentum thickness for different axial distances

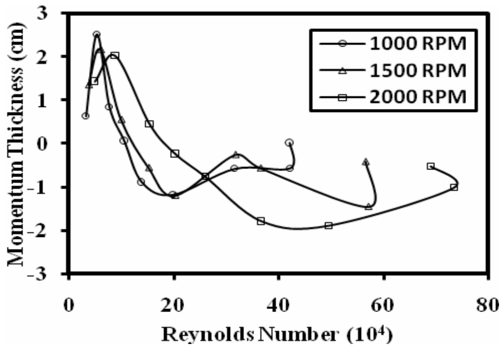

Fig. 15. Comparison of momentum thickness for different Reynolds number

Figures 2 and 3 are indicate the comparison of velocity distribution at position x=0.115m and x=0.18m. Both stations are upstream of the bluff body. From the figure it is clear that no recirculation occurs for any speed. Velocity gradually increases according to the inlet velocity.

The station x=0.24m is the leading edge of the bluff body. The comparison of the velocity distribution at leading edge of the bluff body is shown in Fig. 4. In the leading edge of bluff body there is no recirculation.

The station x=0.29m is the midpoint of the bluff body. From Fig. 5. it is clear that the recirculation occurs above the bluff body and there is a recirculation zone. There is a stagnation point also above of the bluff body.

The stations for x=0.36m, x=0.48m, x=0.725m, x=1.185m and x=1.39m are at the downstream of the bluff body and corresponding comparison of velocity distribution shown in the figure 6 to figure 10. The lower portion of the all stations having recirculation of velocity. There is a recirculation zone present behind the bluff body. The recirculation zone is near to the lower wall. From the velocity comparison, the height and length of recirculation zone are higher for high inlet velocity and vice versa.

It is shown from Fig. 11. that upstream of the bluff body boundary layers increases according to inlet velocity of diffuser. At the top of bluff body boundary layer fluctuate more due to recirculation of flow. Downstream of bluff body, boundary layer is lower for higher inlet velocity and at outlet it is fluctuate for high turbulence.

Comparison of displacement thickness for different axial distance and Reynolds number are shown in Fig. 12. and Fig. 13. For both comparisons, displacement thickness fluctuates at upstream and top of the bluff body and at downstream it decreases with increase of inlet velocity.

Momentum thickness also fluctuate at upstream of the bluff body. From Fig. 14. and Fig. 15. it is observed that momentum thickness decreases according to increase inlet velocity. The variation of momentum thickness for 2000 RPM is higher, because of the presence of higher recirculation zone compared to other two speeds.

3. Conclusion

The objective of this study was an experimental investigation of the turbulent flow in a diffuser at the presence of bluff body. In this work the detail velocity distribution in the rectangular diffuser have been investigated thoroughly. The comparison of velocity distributions were made by using different inlet velocity with a fixed height bluff body.

From experimental and numerical results, the major conclusions are drawn as

1. For any inlet velocity, there is no recirculation at upstream of bluff body.
2. Recirculation is begin from top of the bluff body and its hold up to outlet of diffuser.
3. The reverse flow occurs near to the lower wall.
4. The maximum velocity occurs near to the upper wall.
5. Recirculation length and height increases with increase inlet velocity.
6. Boundary layer thickness is fluctuated near the bluff body. Downstream of bluff body boundary layer thickness is lower for higher inlet velocity.
7. Displacement thickness is more fluctuate at upstream and top of the bluff body and at downstream it is decreases with increases inlet velocity. For upstream of bluff body displacement thickness is lower for low height bluff body and for downstream of bluff body it is revised.
8. At the upstream of bluff body momentum thickness increases for all inlet velocity and just before of bluff body it rapidly decreases to zero. Again at downstream of bluff body it increases for all velocity and also increases for higher Reynolds number. The variation of momentum thickness is higher for high inlet velocity.

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