<u>BOUNDARY LAYER SIMULATION USING WIND TUNNEL</u>

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF

Bachelor of Technology
In
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By

ANIRUDH KUMAR

Department of Civil Engineering

National Institute of Technology

Rourkela

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National Institute Of Technology, Rourkela

CERTIFICATE

This is to certify that the thesis entitled "**Boundary Layer Simulation using Wind Tunnel**" submitted by Anirudh Kumar in partial fulfillment for the requirement for the award of Bachelor in Technology degree in Civil Engineering at National Institute of Technology, Rourkela, is an authentic work carried out by him under my supervision and guidance. To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any degree or Diploma.

Prof. Awadhesh Kumar

Dept. of Civil Engineering

National Institute of Technology

Rourkela-769008

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Finally, I would like to thank my parents for their immense love and care for me.

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Anirudh Kumar

Roll No.108CE046

Dept. of Civil Engineering

ABSTRACT

For understanding the effect of vertical strips (varying configuration viz. c/c spacing and height) placed on the upstream of the surface under taken for studies on the growth of boundary layer, the experiments were carried in the laboratory using Wind tunnel. The variables include vertical strips of heights 20 cm, 30 cm and 40 cm with fixed central spacing of 8 cm c/c. and then 30 cm strips at varying central spacing at 6.5 cm and 14 cm c/c. The wall clearance in each case was kept 2 cm from both sides. The growth of boundary layer was found to be significantly affected on strips configuration. The boundary layer thickness increases with increase in height of the vertical in the range of the experiment. Also, the boundary layer thickness has been found to decrease with increase in c/c spacing of the strips.

In the different section of wind tunnel reading of Boundary layer were taken with main stream velocity (U) which varies 10 to 12 m/s. With the concept of 99% (U) velocity profile is plotted at different location of working section length and the corresponding height is measured for the determination of Boundary layer.

The velocity of fluid increases from zero velocity on the stationary boundary to the free stream velocity of the fluid in the direction normal to the Boundary. This variation in velocity normally takes place in the vicinity of solid Boundary, and this narrow region is termed as Boundary layer. So our main aim is to enhance the Boundary layer thickness which is achieved by using many passive devices like spire, cube as roughness elements and vertical strips of different sizes.

My experiment is based on use of different size of vertical strips. Basically two things occur due to use of strips, one is it allows the formation of Vortex and consequent turbulence and second is it allows the air flow preferably on the upper part of the tunnel (main stream velocity).

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CHAPTER 1

INTRODUCTION

INTRODUCTION:

Boundary layer is such type of layer which is very adjacent to surface and also viscous forces plays important role near it. When a real fluid flows on the solid body or solid wall then fluid adhere to the boundary surface because there is no relative motion so condition of no slip occurs. This indicates that velocity close to the surface is same as the velocity of Boundary. If the boundary is not moving then velocity at boundary is zero. But away from the boundary velocity increases gradually due to which velocity variation and velocity gradient will exist. The velocity of fluid increases from zero velocity on the stationary boundary to the main stream velocity of fluid in the direction normal to boundary.

The extent of atmospheric boundary layer (ABL) thickness is quite high and all types of structures lies with atmospheric boundary layer thickness. To conduct wind tunnel experiments on the small scale replica of a structure (civil, mechanical or any), it is necessary that the models should lie with in boundary layer zone. But, in wind tunnel, the boundary layer thickness is very small and hence constant attempts have been made by different researchers to increase boundary layer thickness by different means.

In the first part of experiment, the study was based on the fact that reading was taken without any obstruction in approaching flow. With these reading velocity profile were plotted and then growth of boundary layer were also drawn. In the second part of experiment reading were taken in presence of vertical strip of different sizes and dimension and the thickness of Boundary layer is increased in comparison to previous case.

This is because obstruction helps in the generation of vortex formation and consequent turbulence. Secondly, the air flow preferably on the upper part of tunnel (main stream velocity)

CHAPTER 2

LITERATURE REVIEW

2.1 BOUNDARY LAYER THICKNESS

A very small consideration shows that boundary layer thickness, as the thickness where velocity approaches to main stream velocity, is not an entirely acceptable concept. Since the velocity in boundary layer increases in asymptotic manner so the distance 'y' depends upon measurement of accuracy.

To conduct wind tunnel experiments on different structural models, it is necessary that the models should lie with in boundary layer zone. But, in wind tunnel, the boundary layer thickness is very small and hence constant attempts have been made by different researchers to increase boundary layer thickness by different means. Irwin [1] has used triangular spires of different dimensions to study the boundary layer formation. Counihan[2] proposed collection of castellated barrier wall which provides generation of vortex and turbulence .Cermak[3] uses quarter-elliptic wedge for generation of vortex and turbulence.

2.2 EFFECT OF PRESSURE GRADIENT

If the free stream is accelerating or decelerating, substantial changes take place in the boundary layer development. For an accelerating free stream the pressure falls in the direction of flow , the pressure gradient being given by differentiating Bernoulli's Equation in the free stream as ,

$$dp/dx = -\rho U \, du/dx$$

The boundary layer grows less rapidly than in zero pressure gradient and transition to turbulence is inhibited. For the decelerating free stream, the reverse effects are observed. The boundary layer grows more rapidly and the shape factor increases in the downstream direction.

The pressure rises in the direction of flow, and this pressure rise tends to retard the fluid in the boundary layer more severely than that in the main stream since it is moving less quickly. Energy diffuses from the free stream through the outer part of the boundary layer down towards the surface to maintain the forward movement against the rising pressure.

However, if the pressure gradient is sufficiently steep, the diffusion is insufficient to sustain the forward movement, and the flow along the surface reverses, forcing the main stream to separate. It is this separation, or stall as it is sometimes called, which leads to the main component of drag on bluff bodies and to the collapse of the lift force on an aerofoil when the angle of incidence is excessive.

2.3 VERTICAL STRIPS

This is the passive elements namely roughness elements mainly used as obstruction in wind tunnel so that generation of vortex and consequent turbulence takes place. I used wooden strips of dimension (20 cm x5cmx 2cm, 30cmx5cmx 2cm, 40cmx5cmx2cm) for the experiment purpose. These play an important role in the wind tunnel for the obstruction purpose so that generation of turbulence takes place which increases the thickness of Boundary layer.

Figure 2.1 : vertical strips of different dimensions

CHAPTER 3

EFFECT OF TEMPERATURE

3.1 Effect on Reynolds number

The Reynolds number, non-dimensionless velocity is defined as the ratio of dynamic pressure to the shearing stress and can be expressed as

$$Re=\frac{UL}{V}$$

Where v= kinematic viscosity (m^2/s)

μ = dynamic viscosity (Ns/m^2)

L = characteristic length (m)

We can say that Reynolds is inversely proportional to the kinematic viscosity, and kinematic viscosity increases on increasing the temperature so Reynolds number decreases on increasing the temperature.

3.2 Effect on kinematic viscosity

On increasing temperature kinematic viscosity increases but in our project the effect of this factor was not considered due to fact that there is very little increase in kinematic viscosity for low temperature range between (300.15 k 306.15 k)

CHAPTER 4

TEST APPRATUS

4.1 TELESCOPIC PROBE VELOCITY METER

Telescope probe meter contains the velocity, temperature and humidity sensors. It measures velocity inside test section of wind tunnel at different height from surface longitudinally and in transverse direction .when using the probe makes sure that sensor window is fully exposed and orientation dimple is facing upstream.

Fig 4.1: Telescopic probe meter

4.2 DIGITAL VELOCI CALICO MODEL A00TSI

This is Digital model having a screen on which velocity appeared in numerical value. It is directly connected to probe meter. It works with battery as well as electrically.

Fig 4.2:Digital veloci calico model A00TSI

4.3 VERTICAL STRIPS OF DIFFERENT SIZES

The magnitude of vortex and turbulence formation depends on the placement of vertical strips in different configuration.

If the spacing between strips is increased then less formation of vortex and turbulence takes place due to which thickness of Boundary layer is less.

But on the other hand if spacing between strips is decreased then formation of vortex and generation of turbulence takes place in much effective way so that boundary layer thickness is much greater. The main objective of putting these passive devices (strips) is for simulation purpose.

Different sizes of vertical strips (c/s 5 cm x 2 cm) used in the experiment are.

(i) 8 nos. of 20 cm height (ii) 8 nos. of 30 cm height, (iii) 8 nos. of 40 cm height, (iv) 10 nos. Of 30 cm height.

The vertical strips of heights 20 cm, 30 cm and 40 cm have been placed with fixed central spacing of 8 cm c/c. and then 30 cm strips at varying central spacing at 6.5 cm and 14 cm c/c. The wall clearance in each case was kept 2 cm from both sides.

4.4 TROLLEY

Trolley basically used in wind tunnel for the movement purposes. From one section to another section reading is required so it's the Trolley which makes work easier.

FIG 4.3 : TROLLEY

CHAPTER 5

TEST PROCEDURE

5.1 PROCEDURE

1. The figure shows the arrangement of test section fitted with velocity probe meter, Digital velocity calico model A00TS1, and Trolley.

2. It is known that the most accurate method to simulate the Boundary layer (BL) in a wind tunnel is to let the air flow through a set of passive devices, normally consisting vertical strips and a group of spires in the beginning of the tunnel

3. In the first part of the experimental study, the objective was to assess the boundary layer growth on at the surface of the wind tunnel (plywood surface) without placing vertical strips.

4. In the second part of the experiment study, the objective was to assess the boundary layer growth on at the surface of the wind tunnel placing vertical strips.

5. A set of measurements was made using a digital velocity calico model A00TSI.

6. At a particular section, velocity data were taken at small intervals from the surface. The same is repeated at different sections from the position of the vertical strips. The longitudinal sections were marked at 0.5m, 1.2m, 2 m, 3.5m, and 4.5 m from the strips. The same sections were used for the different cases of vertical strips. Velocity profile at every section is plotted and the boundary layer thickness (height from the surface up to 99% of the main stream velocity) was obtained.

Fig 5.1 : Trolley and sensor arrangement

Fig 5.2: Vertical strips

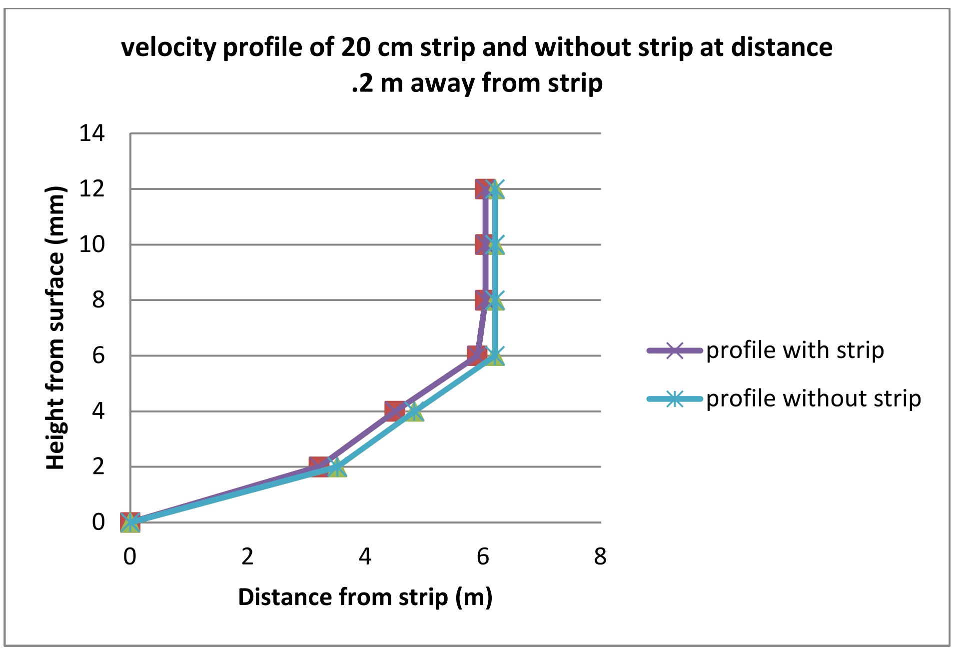
CHAPTER 6

VELOCITY PROFILE AND BOUNDARY LAYER VARIATION

6.1.1 COMPARISON OF VELOCITY PROFILE AT 1.2 M AWAY WHEN 20 CM HEIGHT OF STRIP USED

Height (mm)	speed (m/s)	speed (m/s)
0	0	0
2	3.21	3.52
4	4.5	4.83
6	5.9	6.2
8	6.04	6.2
10	6.04	6.2
12	6.04	6.2

Table 6.1.1.1 : **velocity profile of 20 cm strip and without strip at distance .2 m away from strip**

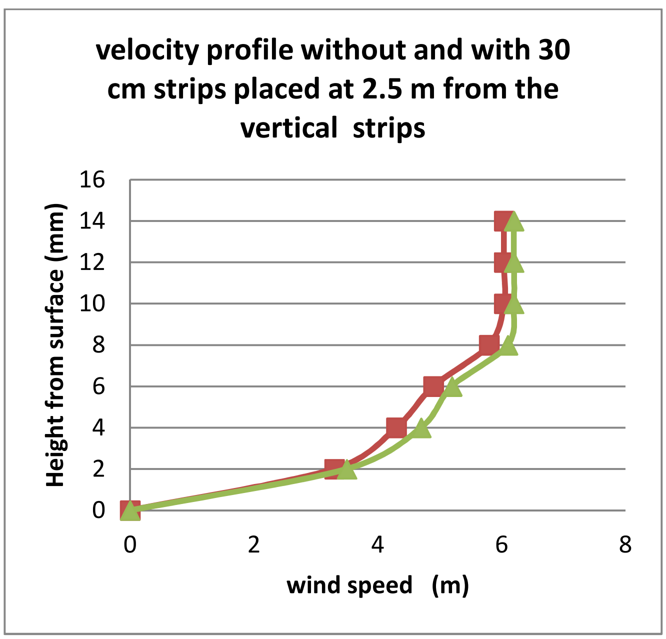


Graph 6.1.1.1: velocity profile of 20 cm strip and without strip at distance .2 m away from strip

6.1.2 COMPARISON OF VELOCITY PROFILE AT 2.5 M AWAY WHEN 30 CM HEIGHT OF STRIP IS USED

Height (mm)	Speed (m/s)	Speed (m/s)
0	0	0
2	3.3	3.5
4	4.3	4.7
6	4.9	5.2
8	5.8	6.1
10	6.04	6.2
12	6.04	6.2
14	6.04	6.2

Table 6.1.2.1 : **velocity profile without and with 30 cm strips placed at 2.5 m from the vertical strips**

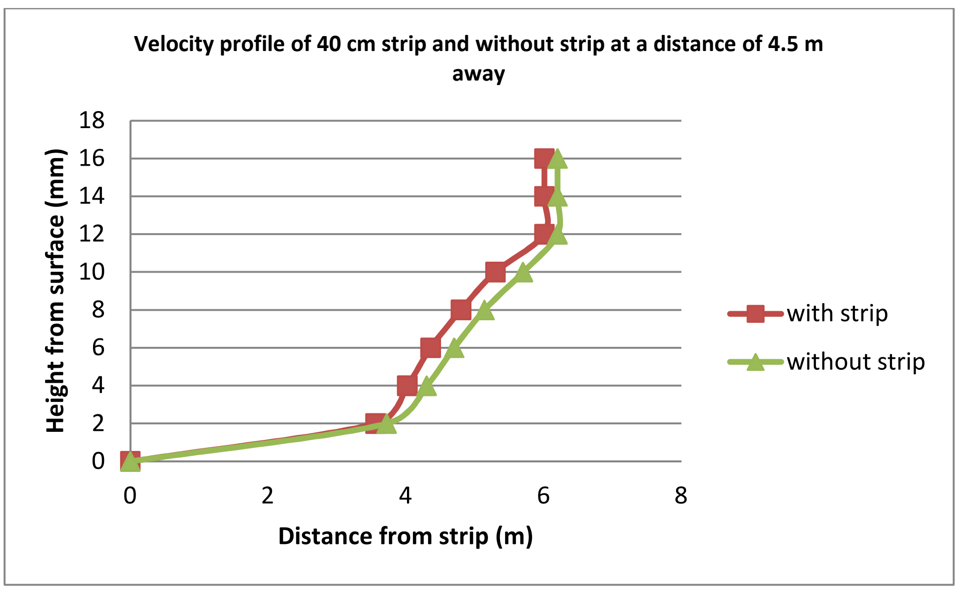


Graph 6.1.2.1: velocity profile without and with 30 cm strips placed at 2.5 m from the vertical strips

6.1.3 COMPARISON OF VELOCITY PROFILE AT 4.5 M AWAY WHEN 40 CM HEIGHT OF STRIP IS USED

Height (mm)	Speed (m/s)	Speed (m/s)
0	0	0
2	3.56	3.72
4	4.02	4.3
6	4.36	4.7
8	4.8	5.14
10	5.3	5.7
12	6.01	6.2
14	6.01	6.2
16	6.01	6.2

Table 6.1.3.1 : **Velocity profile of 40 cm strip and without strip at a distance of 4.5 m away**

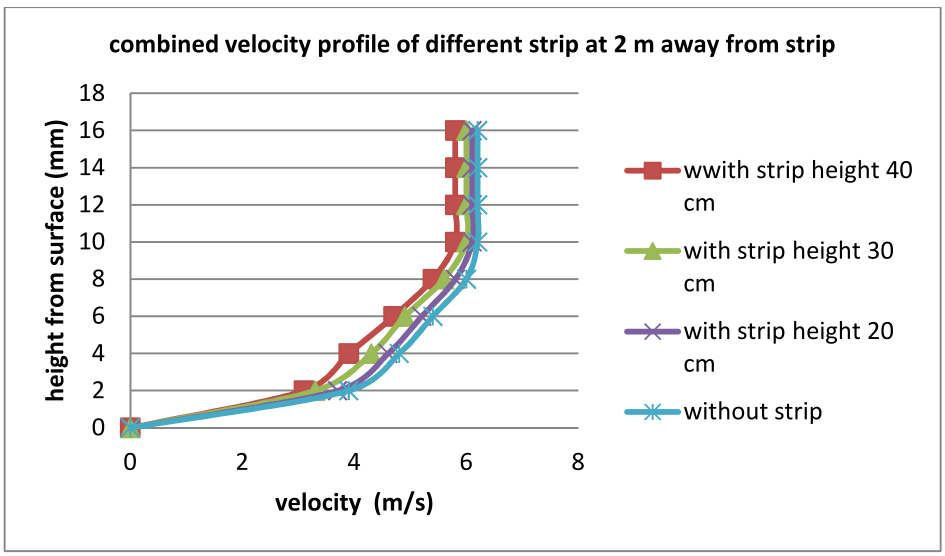


Graph 6.1.3.1: Velocity profile of 40 cm strip and without strip at a distance of 4.5 m away

6.1.4 COMBINED VELOCITY PROFILE OF DIFFERENT STRIP AT 2 M AWAY FROM WORKING SECTION

Height (mm)	Speed (m/s)	Speed (m/s)	Speed (m/s)	Speed (m/s)
0	0	0	0	0
2	3.1	3.3	3.7	3.9
4	4	4.3	4.6	4.8
6	4.7	4.9	5.2	5.4
8	5.4	5.6	5.8	6
10	5.8	6	6.1	6.2
12	5.8	6	6.1	6.2
14	5.8	6	6.1	6.2
16	5.8	6	6.1	6.2

Table 6.1.4.1 : **combined velocity profile of different strip at 2 m away from strip**

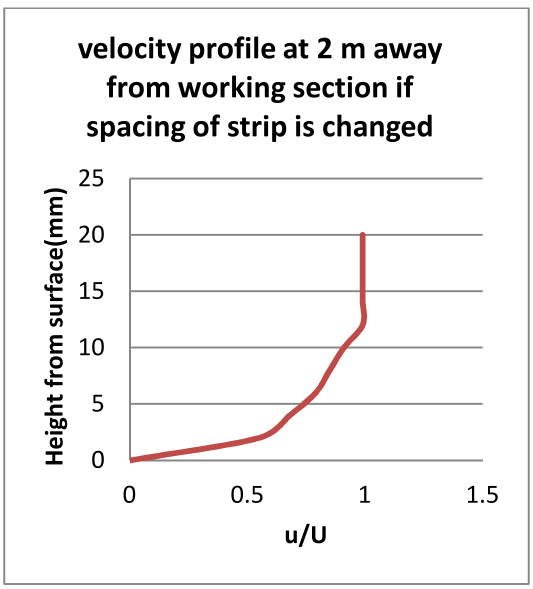


Graph 6.1.4.1: **combined velocity profile of different strip at 2 m away from strip**

6.1.5 VELOCITY PROFILE AT 2 M AWAY OF 30 CM HEIGHT STRIP IF SPACING IS CHANGED

Height (mm)	u/U
0	0
2	0.549
4	0.68
6	0.79
8	0.85
10	0.91
12	0.99
14	0.99
15	0.99

Table 6.1.5.1 : **velocity profile at 2 m away from working section if spacing of strip is changed**

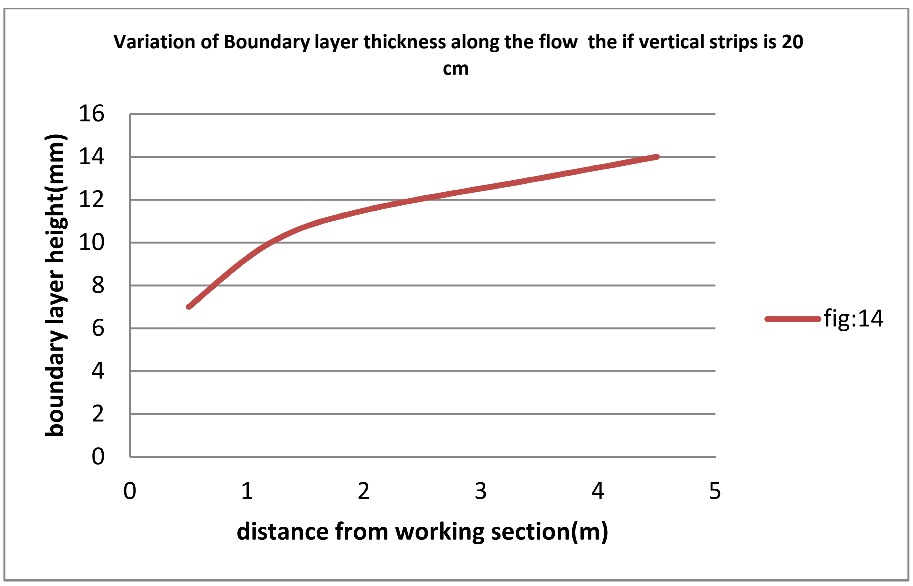


Graph 6.1.5.1: velocity profile at 2 m away from working section if spacing of strip is changed

6.2.1 VARIATION OF BOUNDARY LAYER THICKNESS ALONG THE FLOW FROM THE BEGINNING OF WORKING SECTION IF STRIP HEIGHT IS 20 CM

Distance (m)	Height (mm)
.5	7
1.2	10
2	11.5
3.5	13
4.5	14

Table 6.2.1.1 : Variation of Boundary layer thickness along the flow the if vertical strips is 20 cm

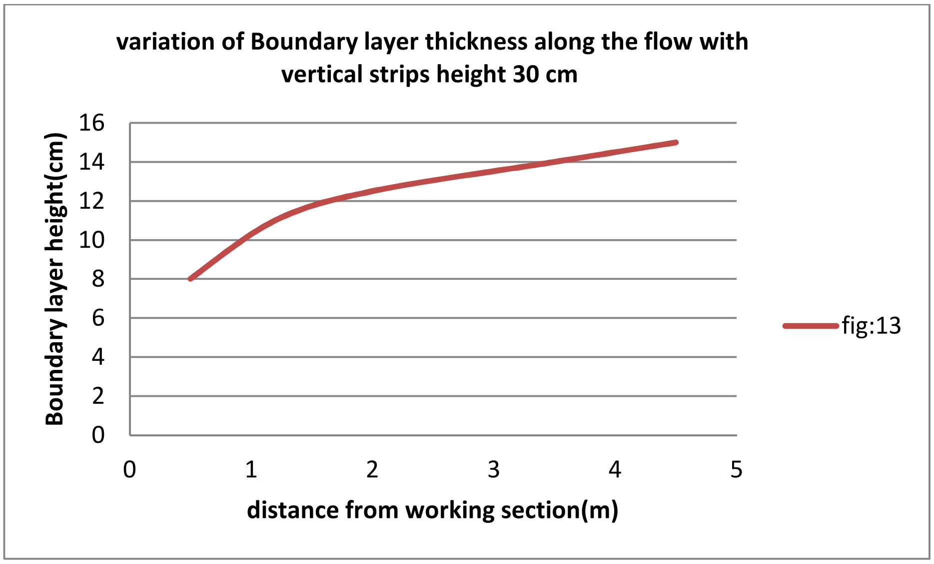


Graph 6.2.1.1: Variation of Boundary layer thickness along the flow the if vertical strips is 20 cm

6.2.2 VARIATION OF BOUNDARY LAYER THICKNESS ALONG THE FLOW FROM THE BEGINNING OF WORKING SECTION IF STRIP HEIGHT IS 30 CM

Distance (m)	Height (mm)
0.5	8
1.2	11
2	12.5
3.5	14
4.5	15

Table 6.2.2.1: variation of Boundary layer thickness along the flow with vertical strips height 30 cm

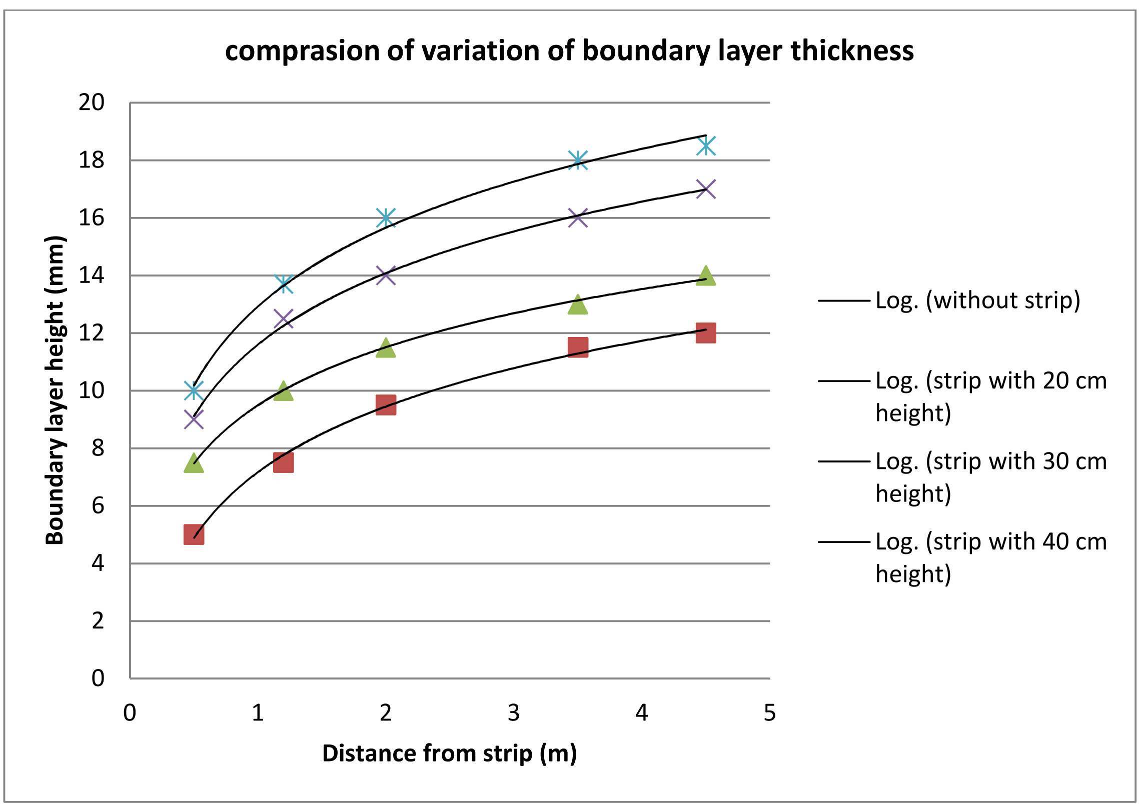


Graph 6.2.2.1: variation of Boundary layer thickness along the flow with vertical strips height 30 cm

6.2.3 COMPARISON OF BOUNDARY LAYER THICKNESS ALONG THE FLOW WITH SIZE OF VERTICAL STRIP AND WITHOUT STRIP

Distance (m)	Height (mm)	Height (mm)	Height (mm)	Height (mm)
0.5	5	7.5	9	10
1.2	7.5	10	12.5	13.7
2	9.5	11.5	14	16
3.5	11.5	13	16	18
4.5	12	14	17	18.5

Table 6.2.3.1: **comparison of variation of boundary layer thickness**

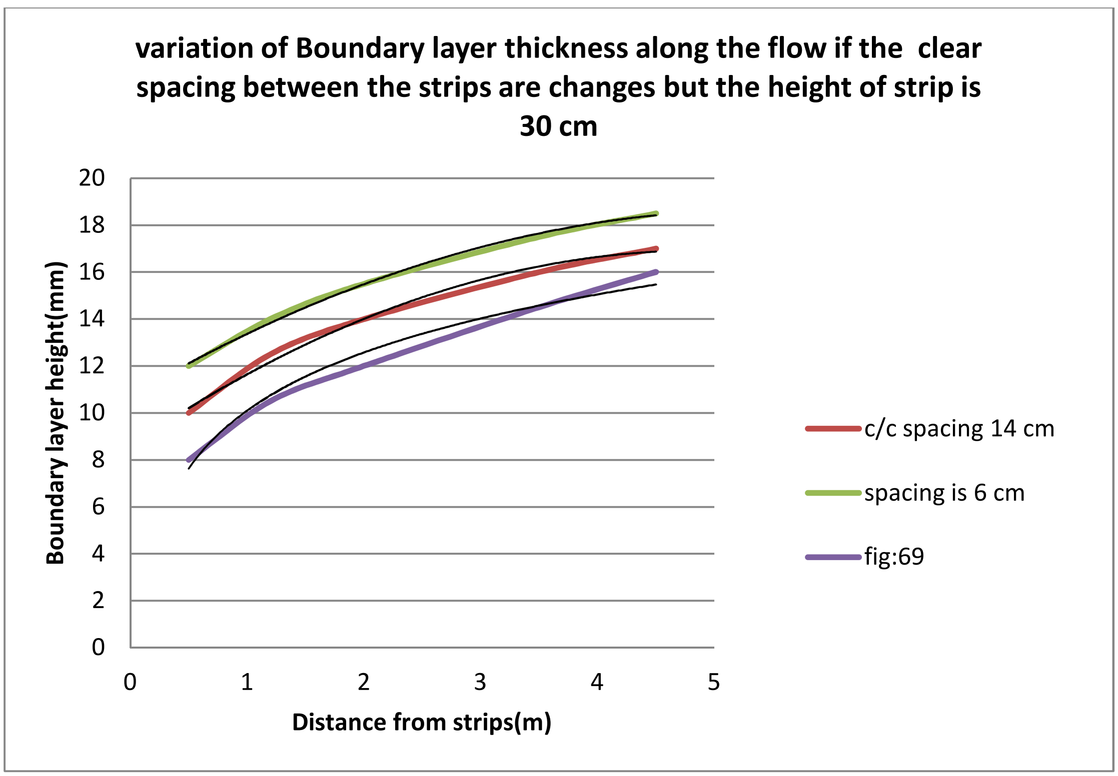


Graph 6.2.3.1: comparison of variation of boundary layer thickness

6.2.4 VARIATION OF BOUNDARY LAYER THICKNESS OF 30 CM HEIGHT STRIP IF SPACING BETWEEN STRIPS ARE CHANGED

distance (m)	Height (mm)	Height (mm)	Height (mm)
0.5	8	10	12
1.2	10.5	12.5	14
2	12	14	15.5
3.5	14.5	16	17.5
4.5	16	17	18.5

Table 6.2.4.1 : **variation of Boundary layer thickness along the flow if the clear spacing between the strips are changes but the height of strip is 30 cm**

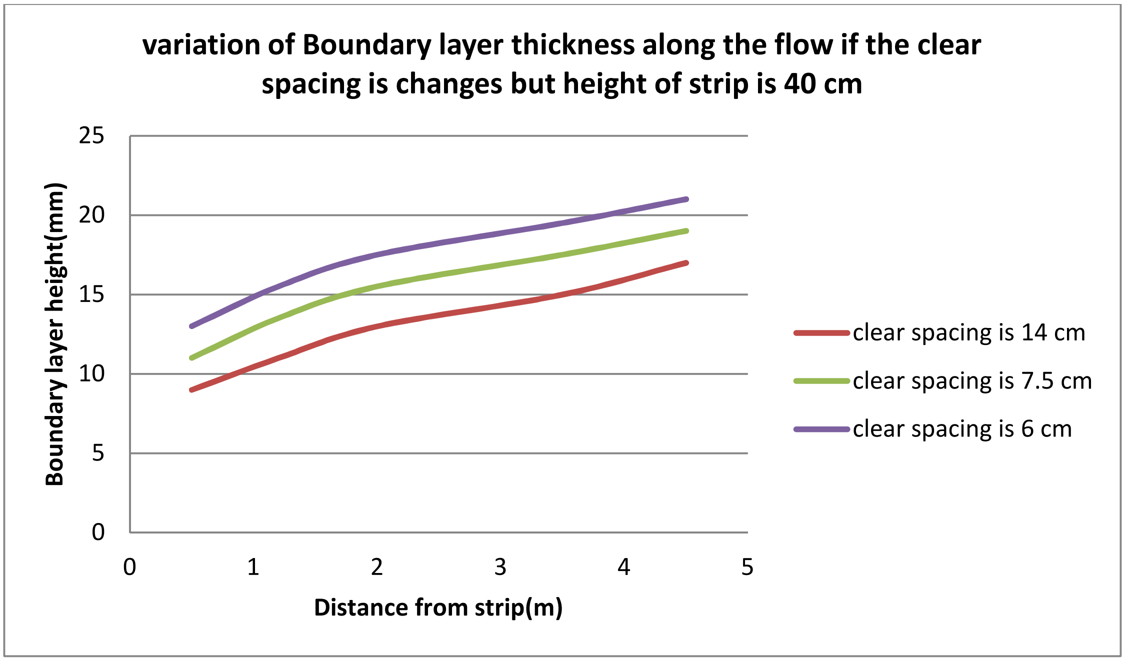


Graph 6.2.4.1: variation of Boundary layer thickness along the flow if the clear spacing between the strips are changes but the height of strip is 30 cm

6.2.5 VARIATION OF BOUNDARY LAYER THICKNESS OF 40 CM HEIGHT STRIP IF SPACING BETWEEN STRIPS ARE CHANGED

Distance (m)	Height (mm)	Height (mm)	Height (mm)
0.5	9	11	13
1.2	11	13.5	15.5
2	13	15.5	17.5
3.5	15	17.5	19.5
4.5	17	19	21

Table 6.2.5.1 : **variation of Boundary layer thickness along the flow if the clear spacing is changes but height of strip is 40 cm**



Graph 6.2.5.1: variation of Boundary layer thickness along the flow if the clear spacing is changes but height of strip is 40 cm

CHAPTER 7

RESULT AND DISCUSSION

RESULT AND DISCUSSION

7.1 Results are shown in above graphs and tables which explain that boundary layer thickness increases if passive devices like strips are used along the flow of air.

7.2 It is observed that Boundary layer thickness increases on increasing the height of strips within the cross section of wind tunnel. It is known that the most accurate method to simulate the Boundary layer (BL) in a wind tunnel is to let the air flow through a set of passive devices, normally consisting vertical strips and a group of spires in the beginning of the tunnel.

7.3 It is also observed that if the c/c spacing between the strips is increases then generation of vortex and turbulence are not so effective so boundary layer thickness decreases.

7.4 If the c/c spacing between the strips is decreases then boundary layer thickness increases due to formation of vortex and high turbulence.

7.5 velocity profile also changes significantly when strips of different sizes are used, velocity profile is more closely arranged to ordinate axis if strip were used .The simulation of Boundary layer (BL) in a short wind tunnel is based on the use of vertical strips in the beginning of the tunnel so that, on one hand, the air flows preferably on the upper part of the tunnel (main stream velocity) and, on the other hand, it allows the generation of vortexes and consequent turbulence.

CHAPTER 8

CONCLUSION

CONCLUSION

8.1 The generation of the BL was achieved by means of a combination between vertical strips in the beginning of the tunnel's working section

8.2 The mean velocity profiles obtained through the simulation of the BL designed for the wind tunnel showed good agreement with the results for the expected power law curve.

8.3 As the height of strips increases the thickness of Boundary layer also increase.

8.4 If the spacing between strips is increased then less effective formation of vortex takes place so Boundary layer thickness will be less as comparison to that strips where spacing is less.

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