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Effect of mainstream air velocity on velocity profile over a rough flat surface

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ABSTRACT
In turbulent flow, the boundary layer is defined as the thin region on the surface of a body in which viscous effects are important. The boundary layer allows the fluid to stick at the surface and thus having the velocity of the surface and to increase towards the mainstream. Roughness is a component of surface texture. It is quantified by the vertical deviations of a real surface from its ideal form. To study the variations of velocity profiles at boundary layer and their influences especially in turbulence zone, the approaches were done.

KEYWORDS: *Boundary layer, Velocity profile, Turbulence, wind tunnel, laminar zone, turbulent zone, boundary layer parameters, surface roughness.*

I. INTRODUCTION

We experience wind turbulence in everyday life. It affects all the structures and objects within the atmospheric boundary. Turbulence is the chaotic and seemingly random motion of fluid parcels. Turbulence has mechanical and convective origins. Shear forces cause mechanical turbulence while buoyant instabilities (due to the intermingling of fluid parcels with different densities) cause convective turbulence. Atmospheric turbulence differs from turbulence generated in a laboratory or in pipe flow. In the atmosphere, convective turbulence coexists with mechanical turbulence. Roughness is a component of surface texture. It is quantified by the vertical deviations of a real surface from its ideal form. Each of the roughness parameters is calculated using a formula for describing the surface. Although these parameters are generally considered to be "well known" a standard reference describing each in detail is Surfaces and their Measurement. Roughness is often closely related to the friction and wear properties of a surface. In turbulent flow, the boundary layer is defined as the thin region above the surface of a body in which viscous effects are important. The boundary layer allows the fluid to stick at the surface and thus having the velocity of the surface and to increase towards the mainstream.

The study, by K. V. S. Namboodiri, Dileep Puthillam Krishnan et.al (2014), discussed the features of wind turbulence, and surface roughness parameter over the coastal boundary layer of the Peninsular Indian Station, Thumba Equatorial Rocket Launching Station. James Cardillo & Yi Chen, Guillermo Araya (2013) had shown that the dynamic multi-scale approach can be successfully extended to simulations which incorporate surface roughness. They observed that inner peak values of Reynolds stresses increase when considering outer units.

The research of G.R. Spedding, A. Hedenstro¨m, L. C. Johansson (2009) showed that DPIV can measure the background turbulence, and therefore its instantaneous structure. The measurements also reveal certain challenges in investigating the aerodynamic performance of small-scale flying devices. A variety of atmospheric boundary layer parameters are examined as a function of wind direction in both urban and suburban settings in Oklahoma City, Oklahoma, derived from measurements during the Joint Urban 2003 field campaign, by Cheryl Klipp (2007). Shuyang Cao, Tetsuro Tamura (2006) had done Wind tunnel experiments to study the effects of surface roughness on the turbulent boundary layer flow over a two-dimensional steep hill, accompanied by a relatively steady and large separation, sometimes called a separation bubble. Carolyn D. Aubertine, John K. Eaton, Simon Song (2004) studied the effects of wall roughness were examined experimentally for two different rough-wall cases involving flow over a ramp with separation and reattachment. For these cases, the roughness Reynolds number was matched at two different momentum thicknesses Reynolds numbers. Both flow conditions were fully rough. R. A. Antonia, P-A. Krogstad (2000) explained the classical treatment of rough wall turbulent boundary layers consists in determining the effect, the roughness has on the mean velocity profile.

This effect is usually described in terms of the roughness function DU+. The general implication is that different roughness geometries with the same DU+ will have similar turbulence characteristics, at least at a sufficient distance from the roughness elements. The study by Stefan Emeis (1990) had shown the Pressure drag of obstacles in the atmospheric boundary layer is computed with a mesoscale numerical model of the troposphere. Different parts of the drag can be separated from the numerical results: total pressure drag is determined from the surface pressure distribution, hydrostatic drag from the temperature distribution in the atmosphere, and form drag as a residual. The paper of J. Blom, L. Wartena (1969) described the development of a turbulent boundary layer in a neutral atmosphere downwind of an abrupt change of surface roughness. Both a single change and two subsequent changes are treated.

II. EXPERIMENTALSET-UP

The set-up mainly consists of a wind tunnel which is a large tube with air moving inside. The wind tunnels are used to study the aerodynamic behaviour of an object. Researchers use wind tunnels to learn more about any air moving or wind influenced objects. The wind tunnel used in this project is a low speed wind tunnel in the Hydraulic Machines Laboratory located at National Institute of Technology, Rourkela, Odisha. The wind tunnel is able to produce a wind velocity of up to 45 m/s. The specifications of wind tunnel are tabulated below:

Table 1. Wind tunnel specifications

Components	Length (m)	Inlet (m)	Outlet (m)
Effuser	1.3	2.1×2.1	2.1×2.1
Test section	8	0.6×0.6	0.6×0.6
Diffuser	5	0.6	1.3

The experimental variables include three constant free stream velocities of 12, 12.5 and13.5m/son flat plates of 40 grade roughness. Emery papers of 40 grade to produce a roughness projection of 375μm was used in the experiment. All the experiments were carried out at room temperature (250 to 270C). A total of 17 numbers of sections at the intervals of 5 cm were taken along the centre-line of the flat plate. At a particular section, velocity measurement along vertical height at an interval of 2 mm and up to a height of maximum velocity were recorded in the turbulentregion.The same procedure was repeated for varying sections and varying incoming main stream velocities. The observation data were used for plotting of graphs and further studies. Some of the principal equipments used to carry out the experiment are Rough flat Plates of 40 grade, Digital Veloci Manometer, Telescopic pitot-tube, Special trolley arrangement and Tachometer.

III. RESULTS ANDDISCUSSION

From the experimental data, the graphs of velocity profiles are plotted first. That is obtained by plotting graph of Velocity (v) vs height (y) at different sections for every constant free stream velocities.
Then graphs for velocity vs height at different freestream velocities (V) for each particular turbulent section were shown. At last but not the least, the graphs of velocity (v) vs boundary layer thickness (δ) for different free stream velocities were developed.

3.1VelocityProfiles : Here we observed the regularity and variations in the patterns for increasing velocities with the rise in vertical height at different sections in the zone of turbulence.

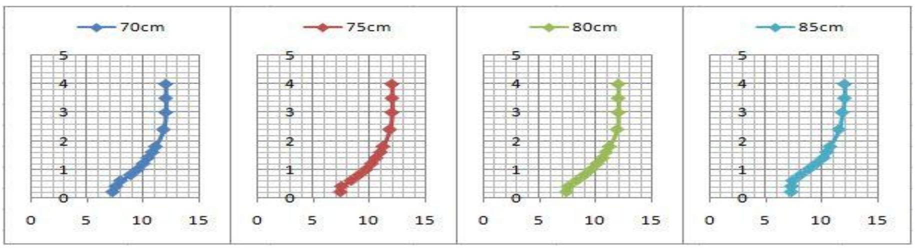

Figure 1.Velocity profiles at various sections for V_1

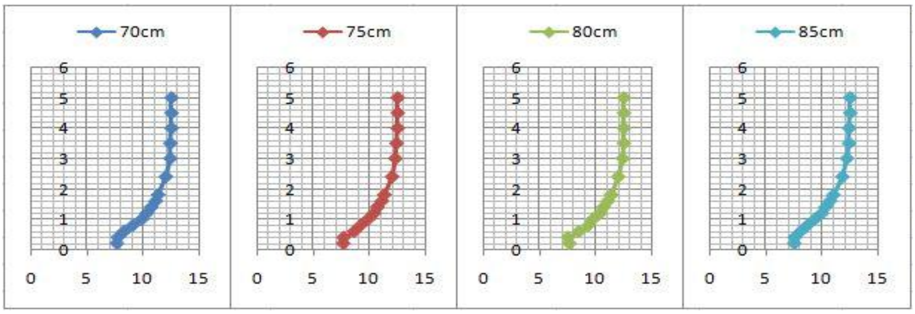

Figure 2.Velocity profiles at various sections for V_2

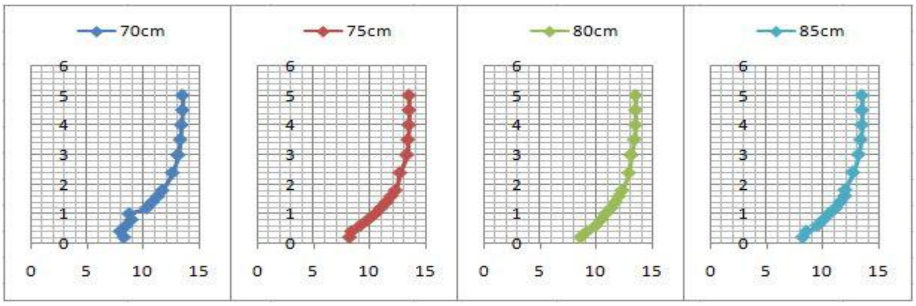

Figure 3.Velocity profiles at various sections for V_3

3.2Velocity Variations at Each Section for Different Main Stream Velocities

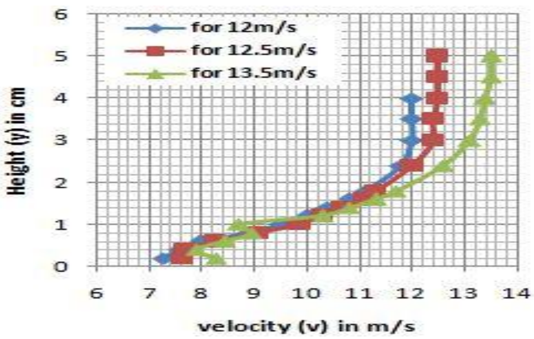

Figure 4.Velocity varriations at 70cmsection for different free streamvelocities.

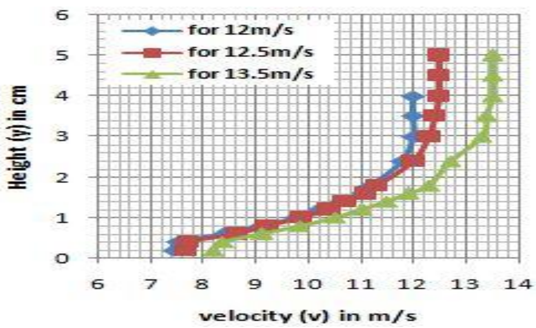

Figure 5.Velocity varriations at 75cmsection for different free streamvelocities.

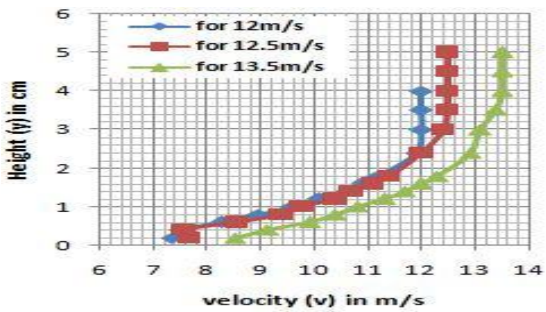

Figure 6.Velocity varriations at 80cmsection for different free streamvelocities.

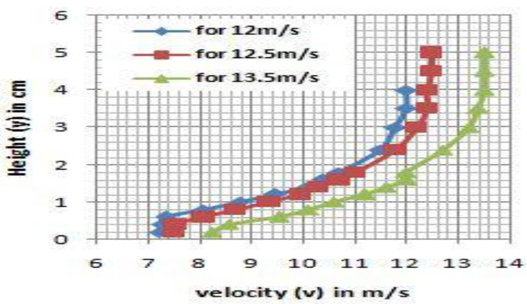

Figure 7.Velocity varriations at 85cmsection for different free streamvelocities.

3.3Plot of Boundary Layer Thicknesses at Different Sections for All the Free Stream Velocities & Vice-Versa

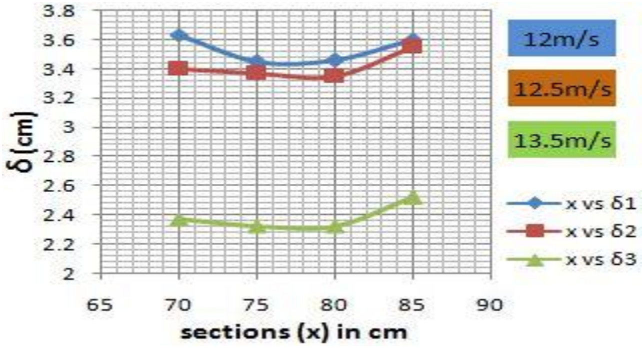

Figure 8.Plot of boundary layer thicknesses at turbulent sections for different free stream velocities.

IV. CONCLUSION

From the analysis of the experimental data and plots, it has been concluded that at a particular location, the velocity is significantly influenced by the incoming free stream velocity. It has been obtained that velocity at a given location above the surface increases with increase in mainstream velocity. Again, it has been found that for a given mainstream velocity, boundary layer thickness increases as the distance from the leading edge increases. Also, it is has been concluded that at a particular section, the boundary layer thickness decreases with increase in mainstream velocity.

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