A Project Report on Study of Velocity Profiles over Parabolic Surfaces

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CERTIFICATE

This is certify that the thesis entitled, **"Study of velocity profile over parabolic surfaces"** submitted by **Mr. Rajesh Singh** in partial fulfillment of the requirements for the award of master of technology degree in **Civil Engineering** with specialization in **Water Resource Engineering** at the National Institute of Technology Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in thesis has not been submitted to any other university/Institute for the award of any degree or diploma.

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Rajesh Singh

ABSTRACT

An extensive experimental study of velocity profile on parabolic surfaces has been carried out. The study has been carried out using different parabolic surfaces (four numbers) and under four different values of free stream velocities inside the wind tunnel. This analysis has been carried out to understand the changes in velocity profile by changing the characteristic of parabola. In daily life we can see there are a lot of bodies around us which have parabolic shapes. Many High speed trains have parabolic leading head. The headlight of vehicles, aircraft nose etc. is also of parabolic shapes. Keeping in mind the aerodynamic significance of parabola, an attempt has been made to understand the variation of velocity profiles with the parabolic parameter and also along the longitudinal direction under different free stream velocities. For this purpose, four arbitrary parabolic surfaces of different characteristic and made up of wood have been chosen. Velocity profile along the normal direction is strong function of free stream velocity. There are two major factors:

(i) Characteristic of parabola, and

(ii) Free stream velocity which affects the Velocity profile.

Changing these two factors on different parabolas at different sections (we picked 12cm long parabolas and divided them in four sections at equal spacing of 3cm. The studies of velocity variation have been carried out in two ways. Once the free stream velocity was kept constant and the variation in the nature velocity profile was studied at different sections in the longitudinal direction. Secondly, the change in velocity profile at a particular section was studies under varying free stream velocities. To better confirmation, the studies were carried out at different sections. The experimental studies and observations have revealed that, there the velocity profile varies significantly with the surface of the different parabola, main stream velocities and the position of the section from leading edge i.e. from leading to trailing ends.

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Chapter 1

INTRODUCTION

Design of a body has significant importance in the field of aerodynamics. To make a model efficient and economic it is necessary that model has such shape which creates least resistance against fluid movement. high speed trains, Germany's trans rapid TR 09 which is design to achieve 500km/h speed, similarly France's Tgv Reseau train, South Korea's KTX2, Shangai's magnetic levitation (maglev train) etc. Not only high speed trains but also there are some aircrafts which are designed in a aerodynamic fashion. These aircraft body faces least air resistance due to its design. Ex-A380 air bus nose shape is aerodynamic. Making it aerodynamic there is low friction resistance between outer surface of air bus and the immediate layer of air. Few years back, for designing purpose we had simple shapes like circle, rectangle, quadrilateral etc. Designers had done a lot of work on these shapes but future is seeking more intricate shapes as parabola, ellipse etc. As we can see currently science is putting its feet in the world of parabola, ellipse for optimum designing purpose. These shapes are more efficient than earlier shapes. So it becomes very important to work on these shapes and observe play of air over these surfaces to find out the changes in the aerodynamics properties. Here we picked parabola and did brief study of velocity over parabolic surface at different free stream velocity. There is a definite pattern of velocity profile in the normal direction of surface. Now we are able to say the changes in velocity profile on increasing –decreasing or changing the characteristic of parabola.

1.1. **Wind Tunnels**

A wind tunnel is like a tool used in aerodynamics research to study the effects of air moving past solid objects. A wind tunnel consists of a closed tubular or square passage in which object is mounted in the middle of the passage. Air passes through the object by a powerful fan; the fan is consisting straightening vanes so that airflow remains smooth. The forces generated by airflow over the testing object can measure by sensitive balance for visualization of air flow lines we can inject smoke or other substance by which flow lines around the object is visible.

In the earlier days large wind tunnel is used during world war second. In 1871 the earliest enclosed wind tunnels were invented. For the development of supersonic aircraft and missiles Wind tunnel testing was considered of strategic importance during the Cold War. Full scale aircraft, vehicle etc are sometime tested in large wind tunnels but these facilities are expensive to operate so some large facilities have been dismantled. Now a days advances in computational fluid dynamics (CFD) modelling on high speed digital computers have reduced the demand for wind tunnel testing. Wind tunnel not only used for the study of vehicles, aircraft. In addition, wind tunnels are used to study the airflow around large structures such as bridges and office buildings.

In the beginning era of wind tunnel it is proposed as a means of studying vehicles (primarily airplanes) in free flight. The wind tunnel was envisioned as a means of reversing the usual paradigm: instead of the air's standing still and the aircraft moving at speed through it, the same effect would be obtained if the aircraft stood still and the air moved at speed past the object. In this way, a stationary observer is able to study the aircraft in action, and can measure the aerodynamic forces being imposed on the aircraft.

Later on, wind tunnel study came into its own roll, the effects of wind on artificial structures or objects needed to be studied when buildings became tall to present large surfaces to the wind, and the resulting forces on the building had to be resisted by the building's internal structure. Determining such forces is required before building codes could specify the required strength of such tall buildings and such tests continue to be used for large or unusual buildings. On later days, wind-tunnel testing was applied to automobiles, to reduce the power requirement to move the vehicle on roadways at a given speed, not so much to determine aerodynamic forces per sec acting on the body. In this type of studies, the interaction between the surface of road and the vehicle plays a significant role, and this interaction must be taken into consideration when someone interpret the test results. In an real situation the roadway is moving relative to the vehicle but the air is stationary relative to the roadway, but in the wind tunnel things are other way round, air is moving relative to the roadway, while the roadway is stationary relative to the test vehicle.

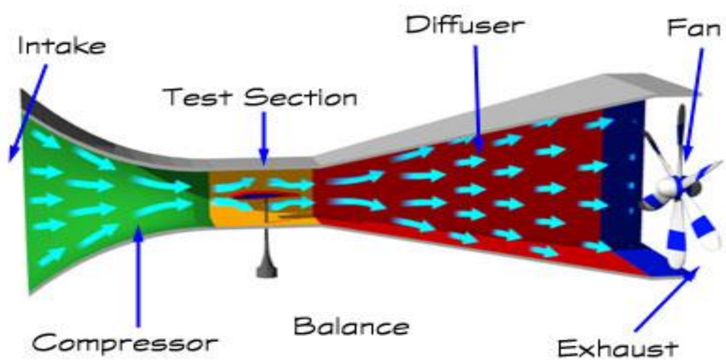


Fig.1.1 Wind tunnel

There are several ways to measure air velocity and pressures inside wind tunnels. By Bernoulli's Principal we can determine air velocity through the test section. For compressible flow only, we can measure dynamic pressure, the static pressure, and the temperature rise in the airflow. By attaching the tuff of yarn to the aerodynamic surfaces the direction of airflow around a model can be determined. The direction of airflow approaching a testing surface can be visualized by mounting threads in the airflow ahead of and aft of the testing models. To visualize the flow behavior smoke or bubbles of liquid can be introduced into the airflow upstream of the test model, and their path around the model can be photographed easily. Several times aerodynamic forces on the test model are measured with beam balances, connected to the test models with beams strings, or cables.

The pressure distributions around the test models have historically been measured by making many small holes along the airflow path on the surface, and using multi-tube manometers to measure the pressure at each hole and usually we used low specific gravity liquid for higher sensitivity. There are also other ways to measure pressure distributions conveniently be measured by the use of pressure-sensitive paints, in which paint is painted on the body according to the pressure distribution, higher local pressure is indicated by lowered fluorescence of the paint at that point. There are also some other methods, pressure distributions can also be conveniently measured by the use of pressure-sensitive pressure belts, a recent development in which multiple ultra-miniaturized pressure sensor modules are integrated into a flexible strip. The strip is attached to the aerodynamic surface with tape, and it sends signals depicting the pressure distribution along its surface.

1.2. Parabolic surface

Parabola: The parabola is the locus of points in the plane that are equidistant from both the directrix and the focus.

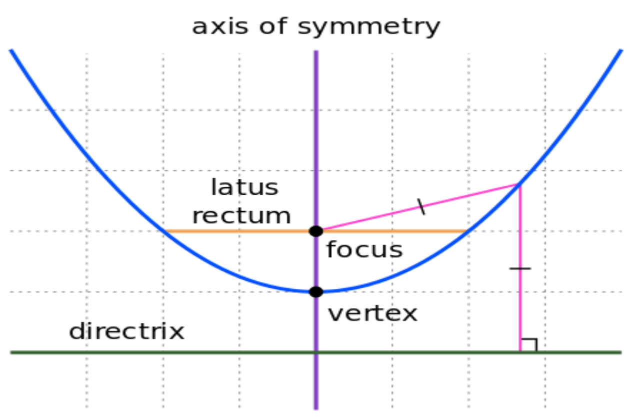


Fig.1.2 parabola

Surface produce by revolving the above parabola around its vertical axis called parabolic surface and whole three dimensional geometry is call paraboloid.

Equation of parabola in Cartesian coordinates:

Let the equation of diretrix is $x = -a$ and co-ordinate of the foci (a, 0).we know definition of parabola according to Pappus's If (*x*, *y*) is a point on the parabola then, its normal on the diretrix from the parabolic point is equal in length to the line which is formed by simply joining the parabolic point to the foci of parabola.

In mathematical way:

$$x + a = \sqrt{\left\{(x-a)^2 + y^2\right\}}$$

$$y^2 = 4ax$$

If one interchanges the roles of *x* and *y* one's obtains the corresponding equation of a parabola with a vertical axis as

$$x^2 = 4ay$$

to generate generalize equation of parabola, we need to shift the parabola vertex (translational shifting w.r.t original co-ordinates) in Cartesian plane , say new vertex co-ordinate *(h,k)*. Then equation of a parabola with a vertical axis becomes

$$(x-h)^2 = 4a(y-k)$$

This equation can be written in the form

$$y = ax^2 + bx + c$$

More generally, we can define parabola in Cartesian plane by an irreducible equation:

it should not be product of two distinct linear equations — of the general conic form

$$Ax^2 + Bxy + Cy^2 + Dx + Ey + F = 0$$

And

$$B^2 = 4AC$$

The equation is irreducible if and only if the determinant of the 3×3 matrix is non-zero

$$\begin{pmatrix} A & B/2 & D/2 \\ B/2 & C & E/2 \\ D/2 & E/2 & F \end{pmatrix}$$

$$(AC - B^2/4)\,F + BED/4 - CD^2/4 - AE^2/4 \neq 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

If this becomes equal to zero it is called degenerative case, it'll give us a pair of parallel lines, possibly coinciding lines, possibly imaginary lines and possibly real lines.

Parabola in physical world:

In Nature, application of paraboloids and parabolas are found in several diverse situations. As trajectory of body/particle in conservative force field without air resistance. For example if we through a stone in vacuum, it will trace parabolic path.

In 17th century, Galileo was the person who did experiment in inclined planes with rolling balls. Later on he proved it mathematically in his book "Dialogue Concerning Two New Sciences". In the physical world trajectory is approximation of parabola for low speed. In high speed, shape of body becomes distorted due to air resistance and it does resemble trajectory of parabola. Many objects which are in space, such as a jumping of diver from diving board, object resembles a complex body motion throughout its jumping.But center of mass of the object make a parabolic trajectory. The shapes of the main cables on a simple suspension bridge are also approximations of parabolas. These main cables are an intermediate curve between a parabola and a catenary. But in practice curve is nearer to parabola. Under the influence of a uniform load such as a horizontal suspended deck, catenary shaped cable is deformed in the shape parabola. A freely hanging spring of unstressed length takes the shape of a parabola ,unlike an inelastic chain.

In parabolic reflector which act like a mirror or similar reflective device that concentrates light or other forms of electromagnetic radiation to a common focal point arise in several physical situations as well. Conversely, collimation of light from a point source at the focus into a parallel beam is also done by paraboloid mirror.

a parabolic reflector also reflects sound in parabolic microphones, but it is not necessary that is also reflect electromagnetic radiation.it is usually used to focus sound onto a microphone and it gives it highly directional performance.

We can also see in a cylinder which is partially filled with water and rotates around its central axis make a parabolid. The centrifugal force is the cause of liquid to climb onto the walls of the container.

Chapter2

LITERATURE REVIEW

Parabolic structures are used for many purposes throw-out the years. **N.Naenee and M. Yaghoubi** (2006) worked on parabolic solar collector in which they traced the sunlight to collect solar power, due to the large structure of parabolic collector it becomes necessary to stabilize the structure against strong wind. They provided different wind velocity at different collector angle and investigated various circulation regions in leeward and forward directions. Pressure and force is maximum when collector is in opposing direction to the wind and minimum when it is along the wind direction.

David Stack, Hector R. Bravo (March 2009) had studied on flow separation behind ellipse at Reynold number less than 10. For Reynold number less than 1, there is linear relationship between Reynold number and critical aspect ratio for separation. When Reynold number is less than 1 critical aspect ratio decreases more quickly when it approaches 0. Flow separation around two dimensional body ellipse is investigated. For laminar flow behind the ellipse, fluctuation in the value of stream function is found the function of Reynold number and critical value of aspect ratio.

Josue Njock Libii (2010) had studied study pressure distribution around a bluff body (in the case of circular cylinder) . he found out pressure is maximum around leading and rare part of the cylinder while it is minimum at the top and the bottom of the cylinder. And velocity becomes twice the free stream velocity at top most and bottom most point. He further investigated the results with real fluid there are some change occurs due to the viscosity consideration and boundary layer development. For cylinder C_p & theta graph is investigated for higher free steam velocity curve departed from low free stream velocity. However in real fluid flow fluid particle that moves in the vicinity of the surface of the body is within the viscous boundary layer the inside pressure will be same as the existion outside the boundary layer. Due to constant pressure there is no conversion of pressure into velocity head. Its decreases its kinetic energy. When particle reached in the downstream half of the cylinder its kinetic energy will be smaller than it would have been in ideal fluid flow.

Ronit K. Singh, M. Rafiuddin Ahmed, Mohammad Asid Zullah, Young-Ho Lee (2012)had studied design of a low Reynolds number airfoil for small horizontal axis wind turbines for better start up and low wind speed performance a low Reynold number airfoil was designed for applications in small horizontal axis wind turbine. This experiment was completed on the improved airfoil AF300 at different Reynold numbers. At different angle of attack pressure distribution, lift, drag is calculated. They basically worked on low Reynold number airfoil which operates Reynolds number range of 38,000e205, 000 which is experienced by small wind turbine rotors near the root to the outward section of the turbine blade. The AF300 airfoil was optimized from existing low Re airfoils through x foil code. They perfomed to evaluate characteristic of air foil when air flow over it in wind tunnel tests at different low Reynold number. To gain insight into the flow, Together with experimentation, Ansys CFX, PIV tests and smoke flow visualization of the airfoil were conducted. Experimental, Ansys CFX plots and xfoils of pressure distribution showed good agreement with each other. At low Reynold number the airfoil performed good lift characteristics and maintained fully attached flow at an angle of attack as high as 14. Delaying flow separation is improved by the flat back trailing edge of the AF300 airfoil and the aerodynamic properties by delaying flow separation and increasing CL as well as the adding strength to the airfoil structure. The structural strength added by the thick trailing edge of the airfoil would require lighter and less expensive materials for the blades, decreasing the inertia and improving startup and letting the rotors operate at lower cut-in wind speeds. Without being in danger of stalling and losing rotor efficiency a high stall angle of 14 is given it means that the rotor would be able to operate at a wider range of angle of attack

A.A Hachicha, I Rodriguez, J.Castro, A Oliva (2013) had study numerical simulation of wind flow around a parabolic trough solar collector a numerical aerodynamic and large eddy simulation modelling is done firstly on cylindrical body then on parabolic solar collector. The time averaged flow is analyzed around the collector. A brief study is done on velocity, pressure and temperature field.

Chapter 3

METHODOLOGY

Working principal of wind tunnel:

In a duct may be square or in circular shape, air is sucked by series of fans mounted in the end of the duct with viewing ports called window. For large diameter wind tunnels to provide sufficient air flow an array of multiple fans are used in parallel. Sometimes fans are powered by stationary turbofan engine rather than electric motors it depends on requirements of volume and speed of air. The airflow inside duct should be laminar in testing section. To make it laminar it is a wise choice to pick long circular large diameter wind tunnel. Because in square wind tunnel, there is high constrictions in flow around the corners due to viscosity of air. In large diameter, high length type of wind tunnel hydrodynamic entry length is high which makes the flow fully developed. It means there is no variation along the length of testing section. Secondly flow behavior is highly dependent on fan blade motion and orientation of blades. Blades should be closely spaced, it reduces turbulence in flow field. The inside facing of wind tunnel should be smoother otherwise it'll provide drag in the vicinity of surface which can be cause of inaccuracy in reading. And our testing model should be kept near the center of the tunnel. Putting it in the middle of tunnel it'll provide it an empty buffer zone between the object and the tunnel walls. There are many correction factors to co-relate wind tunnel test results with open-air results. The lighting arrangement is usually embedded into the circular walls of the wind tunnel and shines through windows. The light bulb mounted inside wind tunnel (conventional manner) may cause of turbulence as the air blows around it. Observation is usually carried out through transparent port holes into the tunnel rather than simply being flat discs. these lightning and observation windows should be match the cross-section of the tunnel and further reduce turbulence around the window. There are various techniques to study the actual airflow around the different geometry and we can compare it with theoretical results, which are associated with Reynolds number and Mach number for the regime of operation. And for pressure measurement around the body we need pressure taps. Our wind tunnel has following dimensions (wind tunnel at NIR Rourkela)

Component	Length	Size	Power required
Effuser	1.3m	2.1×2.1m at inlet 0.6×0.6m at outlet	
Testing section	8m	0.6×0.6m	
Diffuser	5m	0.6×0.6m at inlet 1.3m dia at outlet	
Fan		1.8m Dia	15hp

Table 3.1: Dimension of wind tunnel (NIT Rourkela)

To analyze the velocity profile over parabolic surface first of all we took four parabolas (arbitrary) in the form of $y^2=ax$, where a is characteristic of parabola.

(i) $y^2=2x$
(ii) $y^2=4x$
(iii) $y^2=6x$
(iv) $y^2=8x$

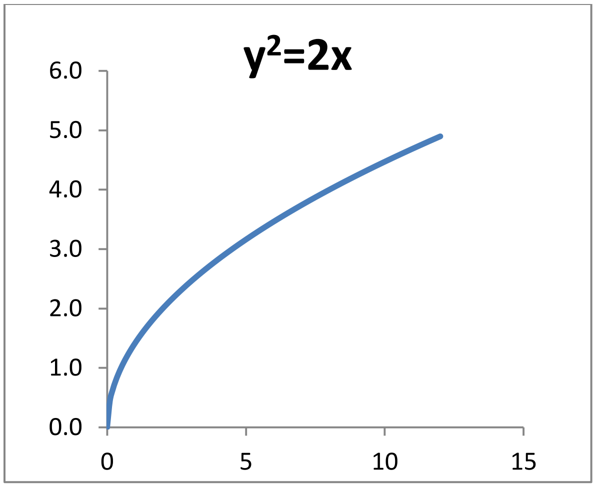


Fig.3.1 (a)

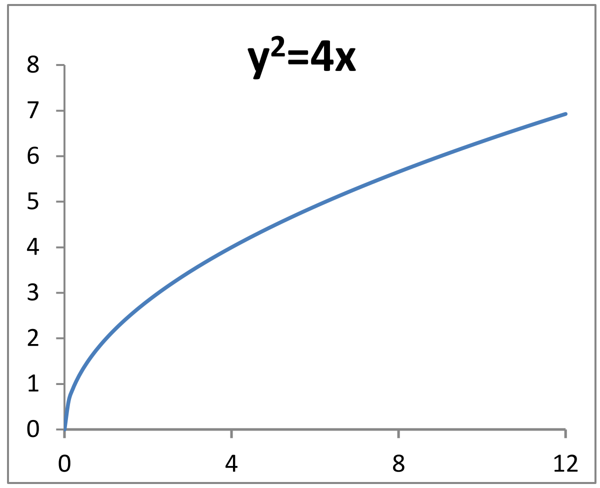


Fig.3.1 (b)

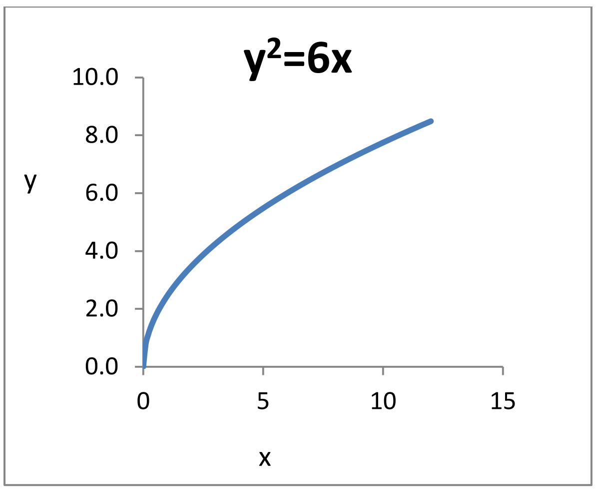


Fig.3.1(c)

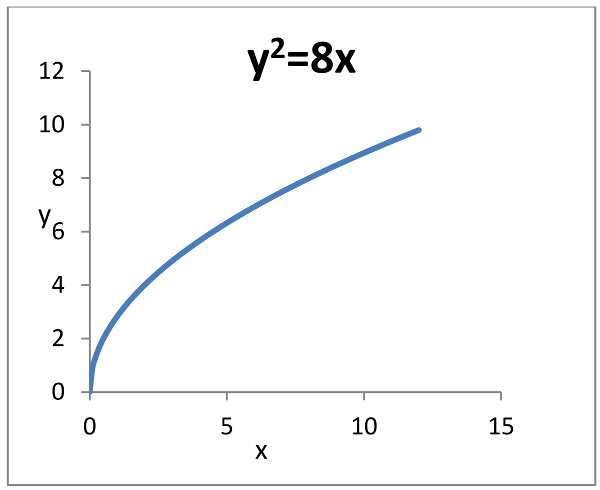


Fig.3.1 (d)

From fig.3.1 (a), fig.3.1 (b), fig.3.1(c) and fig.3.1 (d) is clear increasing the characteristic of parabola curve becomes steeper. Putting these surfaces(surfaces formed by these curves) inside wind tunnel at different free stream velocities 6m/s,8m/s,10m/s,12m/s(arbitrary) we took reading along the normal direction at different sections 3cm,6cm,9cm and 12cm-

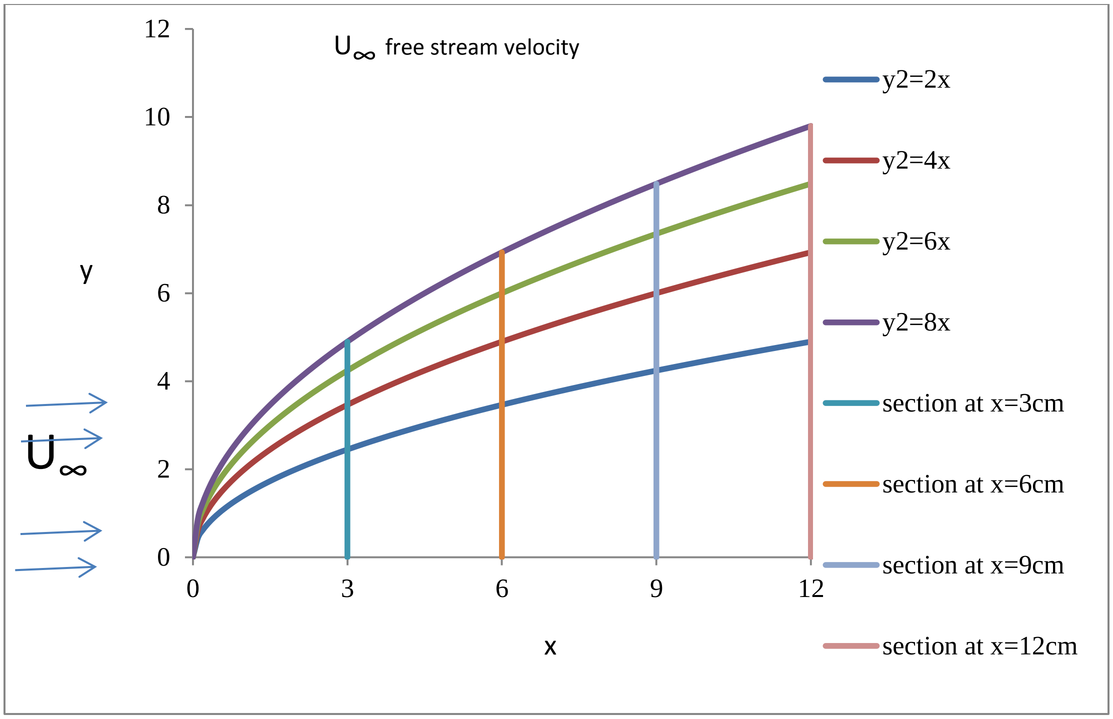


Fig.3.2 Different parabola with different sections

In fig.3.2 vertical lines resembles sections and at the intersections of parabolas and these sections, normal lines are drawn along which readings has been taken. Normal lines are shown in the following fig.3.3.(a),fig.3.3.(b),fig.3.3.(c) and fig.3.3(d)

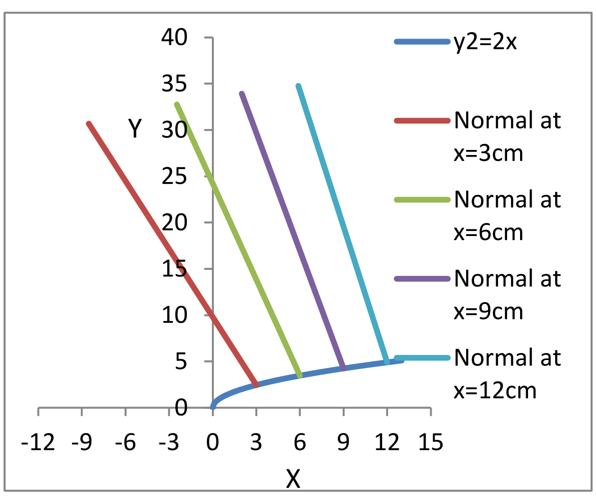


Fig.3.3.(a)

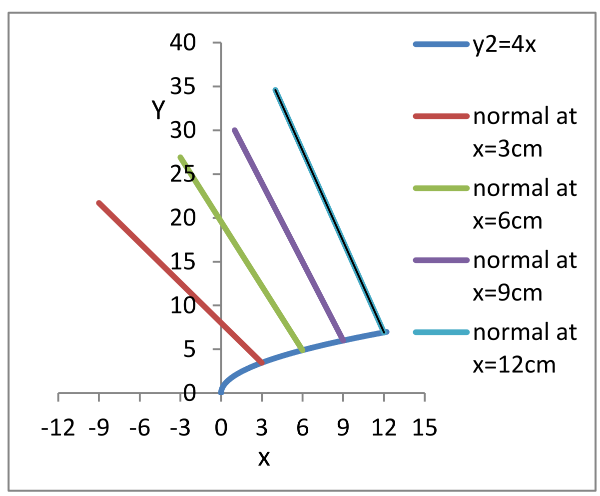


Fig3.3.(b)

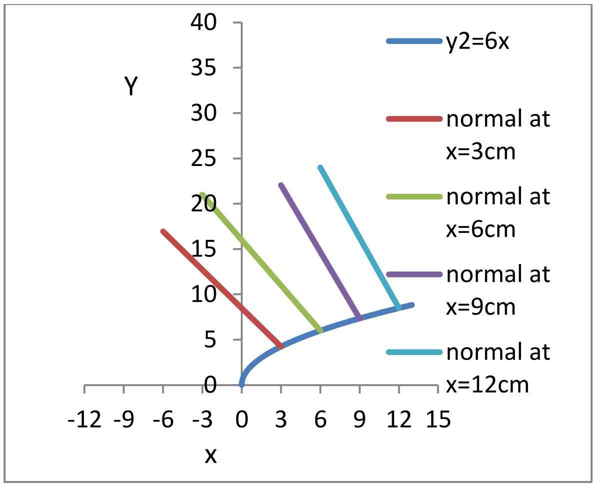


Fig.3.3.(c)

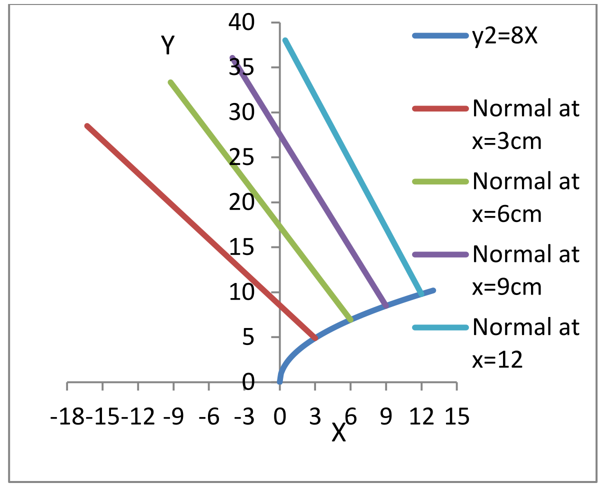


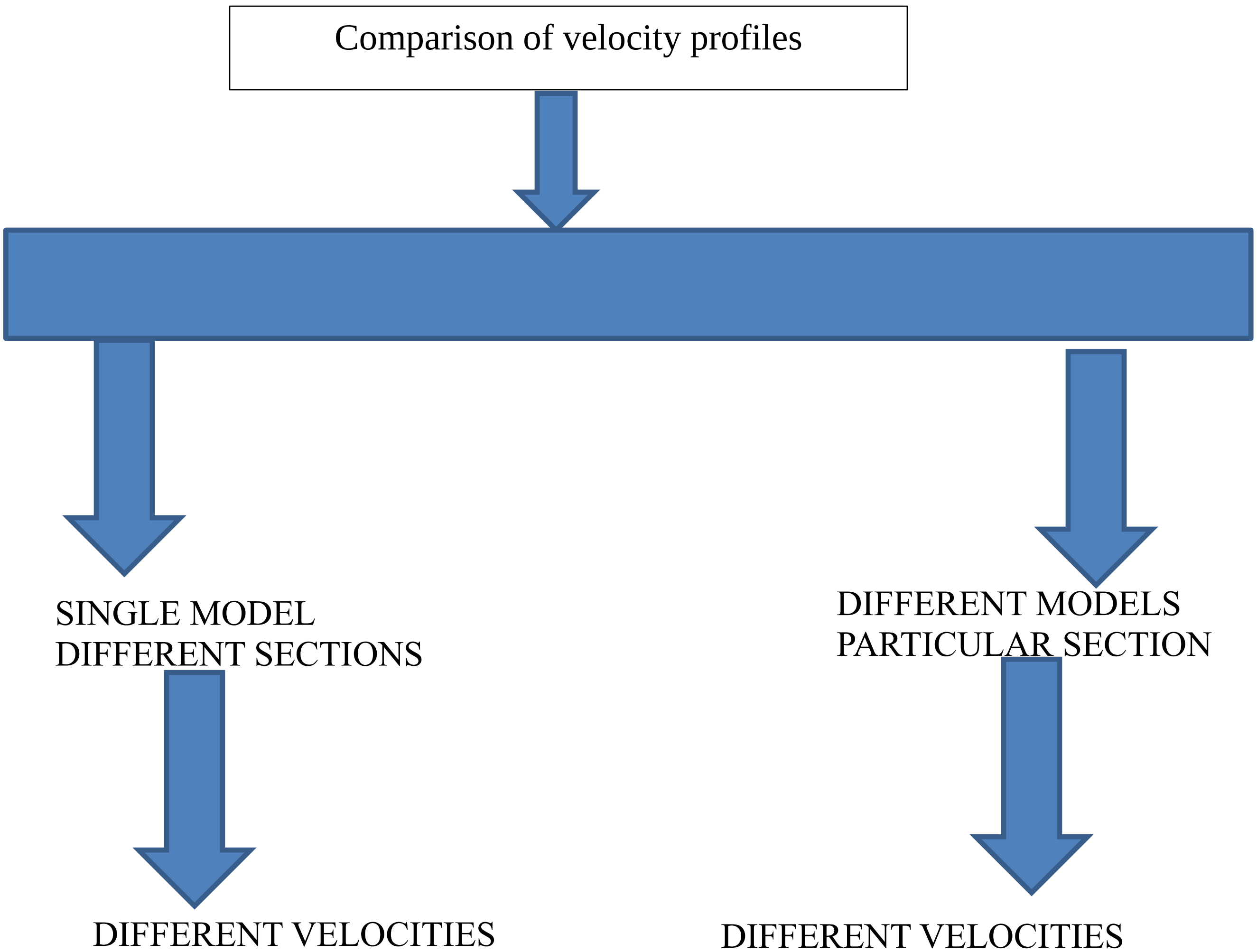
Fig.3.3.(d)

Experimental parabolic bodies-

Fig.3.4

Our experimental parabolas are made of wood which follow the curvature of $y^2=2x$, $y^2=4x$,$y^2=6x$ and $y^2=8x$ which we can see in fig.3.4.Over these parabolas we had drawn standard scale to measure desirable values of air velocity in the vicinity of surface. We placed the pitote tube normal to the surface at different sections to measure the velocity along the outward normal direction of the parabola.

Flow diagram of experiment:



In flow diagram, it is clear there is comparison of velocity profiles in two ways. First we picked a parabola (say $y^2=2x$) and at different free steam velocity 6m/s,8m/s,10m/s and 12m/s the pattern of air flow is investigated over the surface at different sections which are at the distance 3cm from the nose of parabola. We had seen effect on velocity profile on significant increment in the magnitude of free stream velocity.

Secondly, we observed a particular section of all four parabola, and let the air pass over the them at different velocities (6m/s,8m/s,10m/s,12m/s), we saw there are changes when we changed the characteristic of parabola. There are also changes in velocity profiles, in the rare direction of parabola, when we moved from one section to another.

RESULTS AND DISCUSSION

Single model different sections

Variation in velocity profile for model $y^2=8x$ at free stream velocity 6m/s:

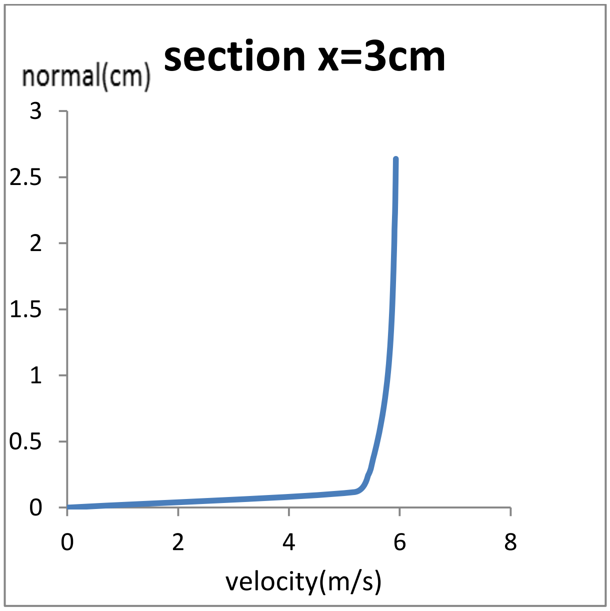


Fig.4.1 (a)

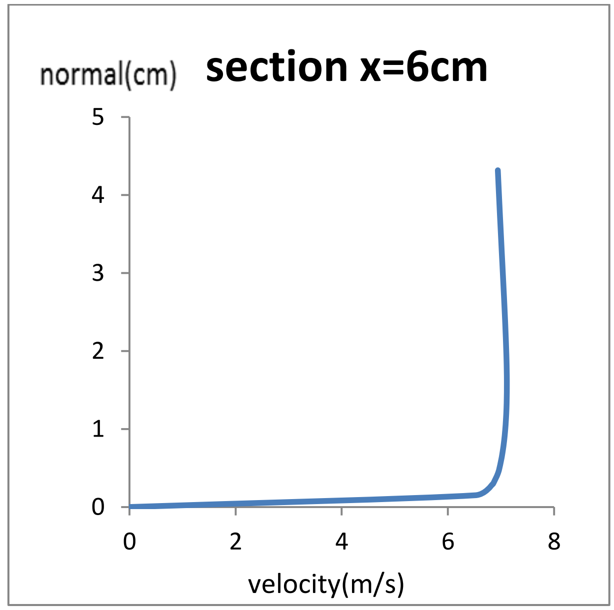


Fig.4.1

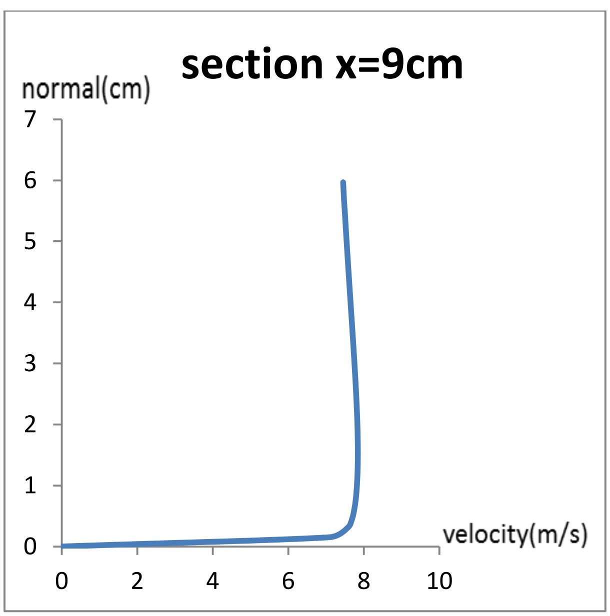


Fig.4.1(c)

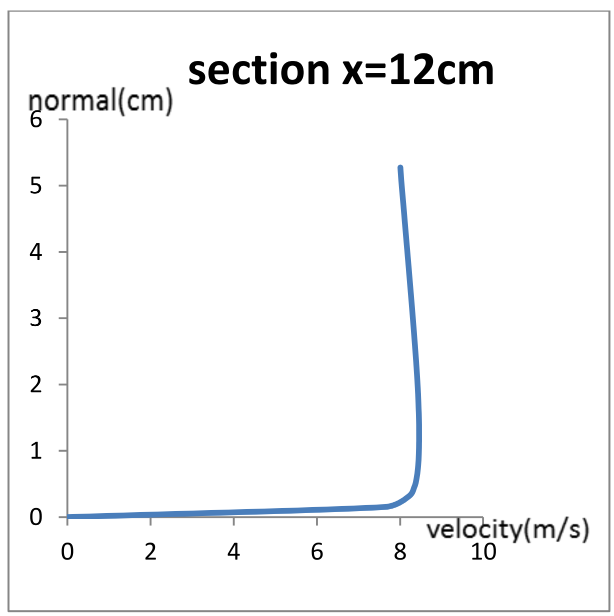


Fig.4.1(d)

Variation in velocity profile for Model y^2=8x at free stream velocity 8m/s:

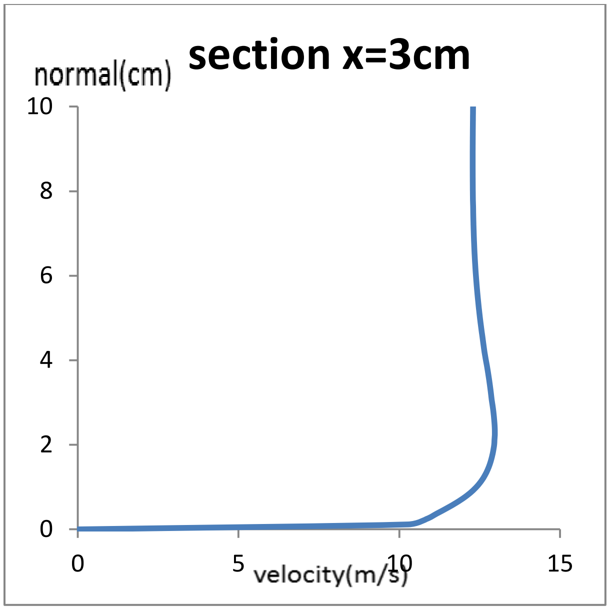


Fig.4.2 (a)

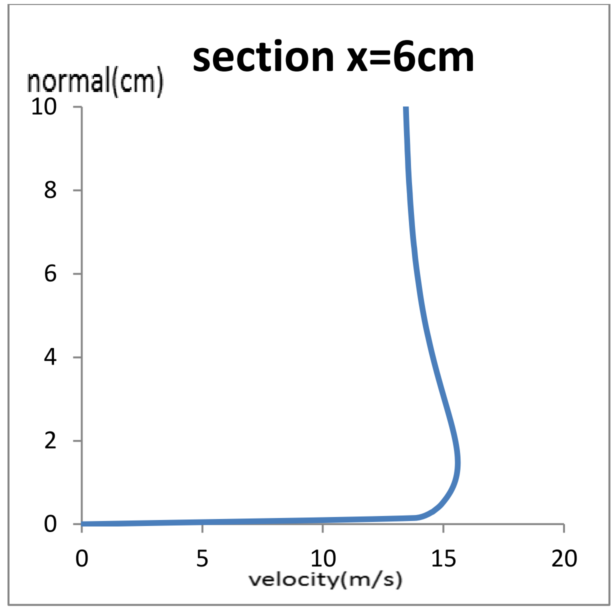


Fig.4.2(b)

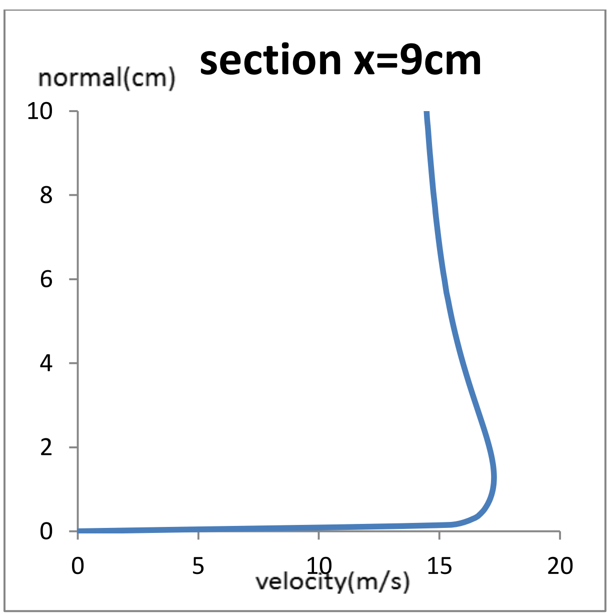


Fig.4.2(c)

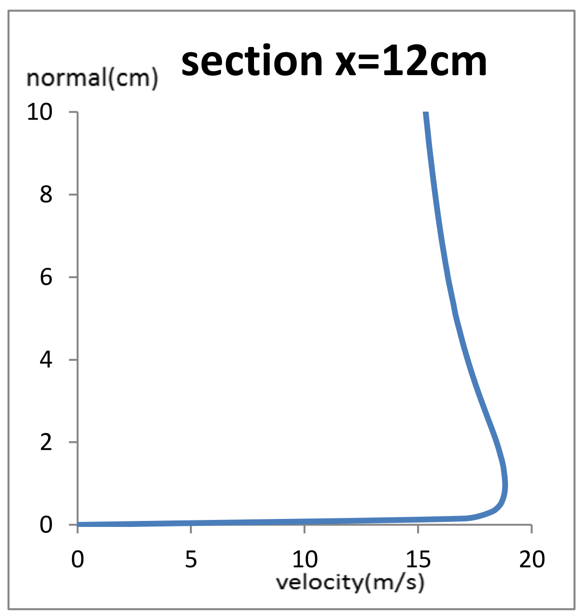


Fig.4.2 (d)

Variation in velocity profile for model $y^2=8x$ at free stream velocity 10m/s:

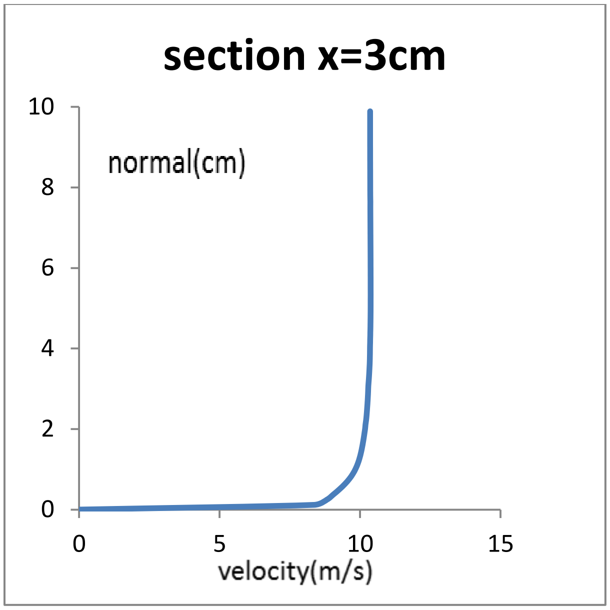


Fig.4.3 (a)

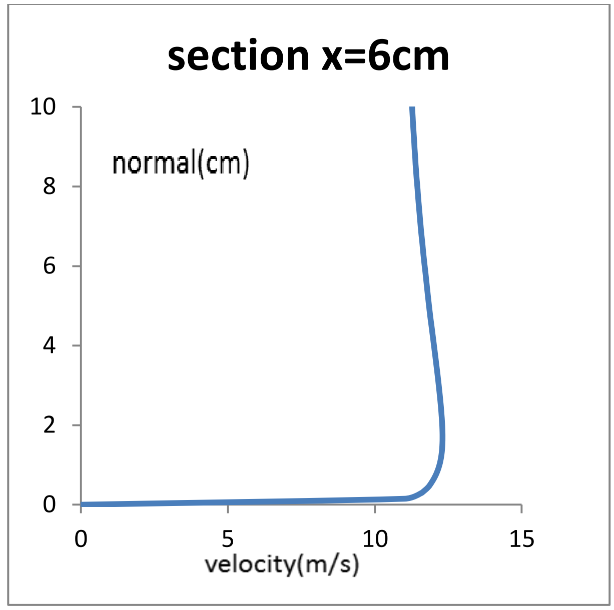


Fig.4.3(b)

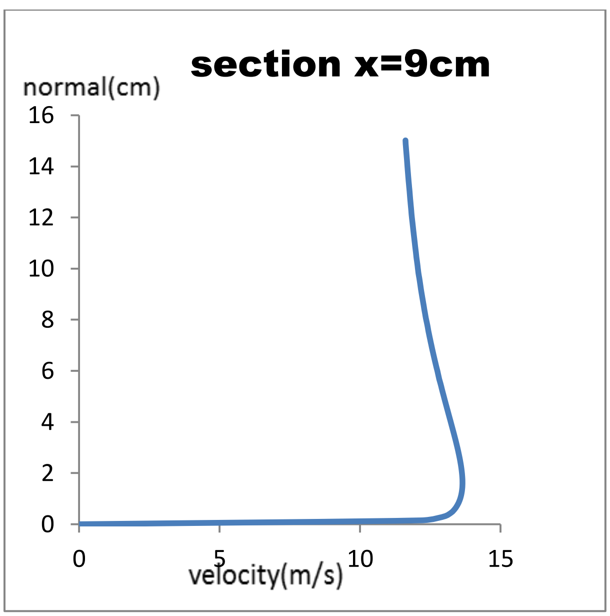


Fig.4.3(c)

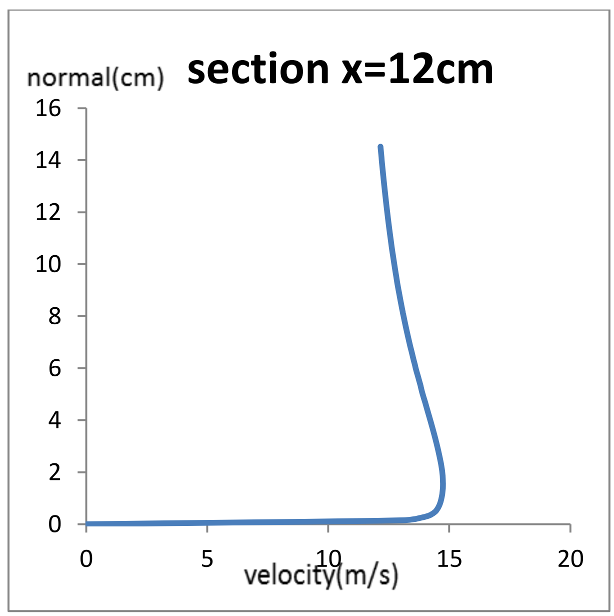


Fig.4.3 (d)

Variation in velocity profile for model y^2=8x at free stream velocity 12m/s:

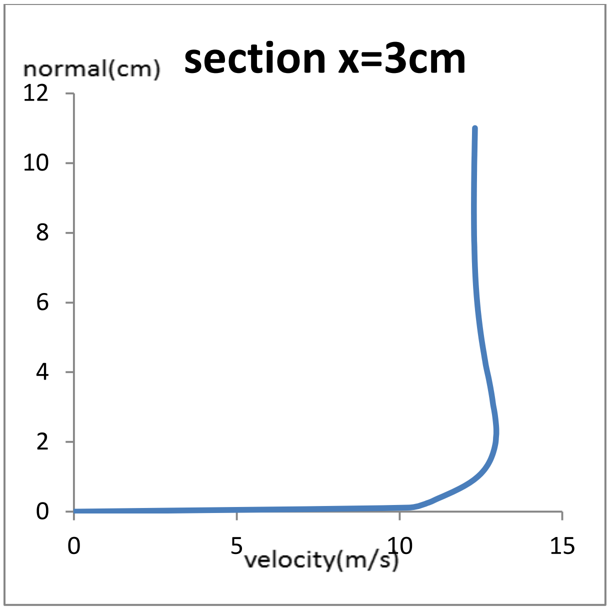


Fig.4.4 (a)

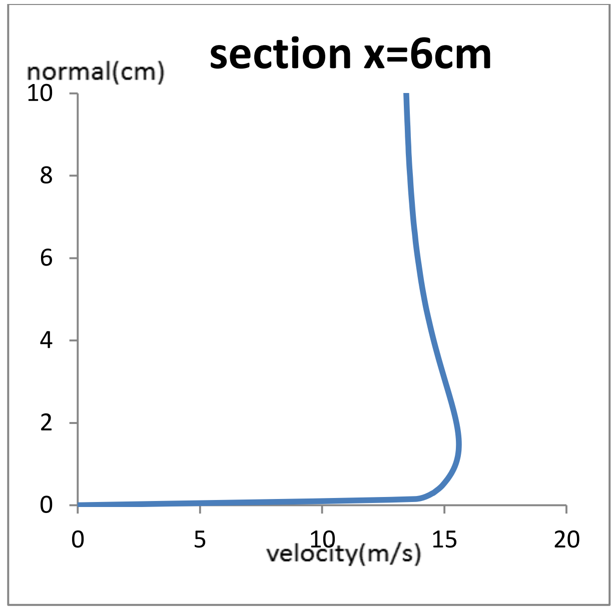


Fig.4.4(b)

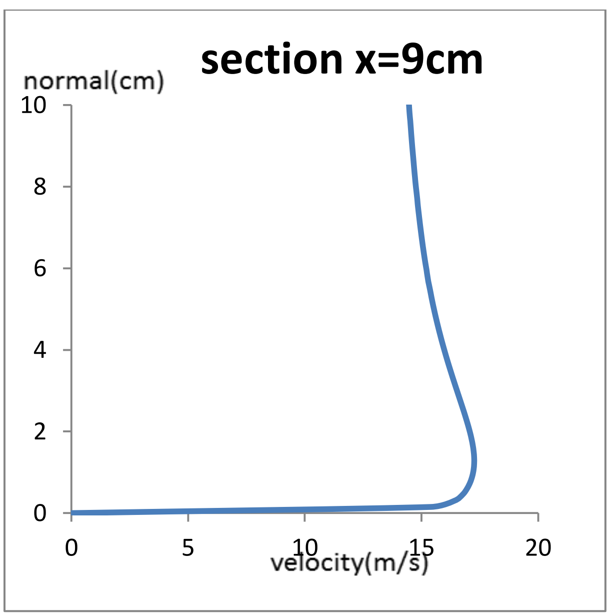


Fig.4.4(c)

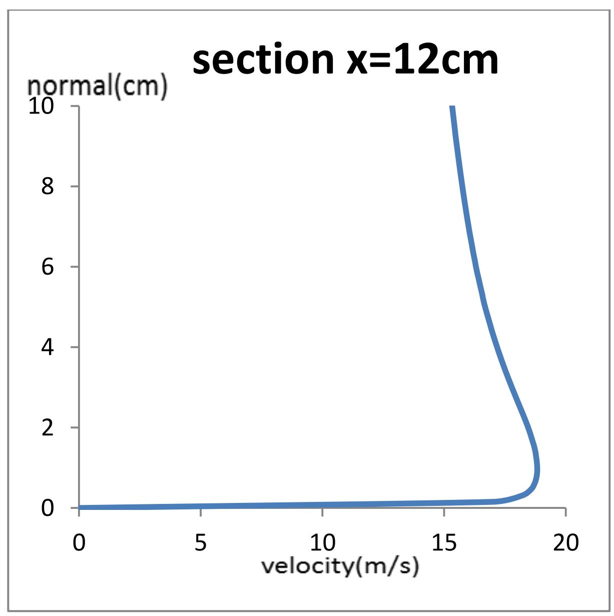


Fig.4.4 (d)

Variation in velocity profile for model $y^2=6x$ at free stream velocity 6m/s

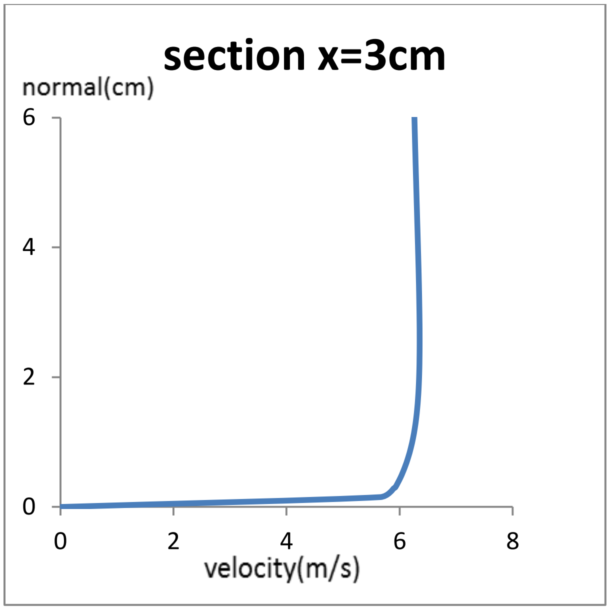


Fig.4.5 (a)

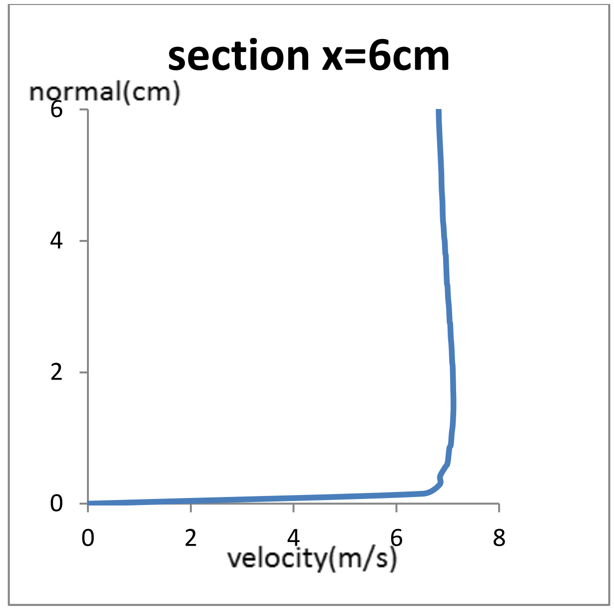


Fig.4.5 (b)

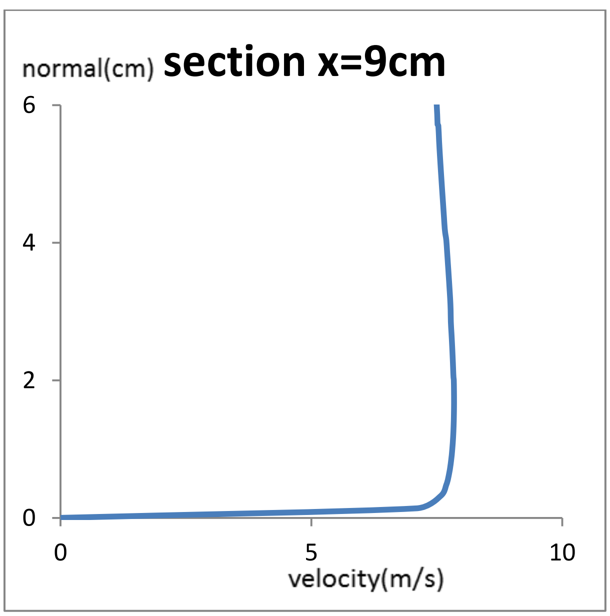


Fig.4.5(c)

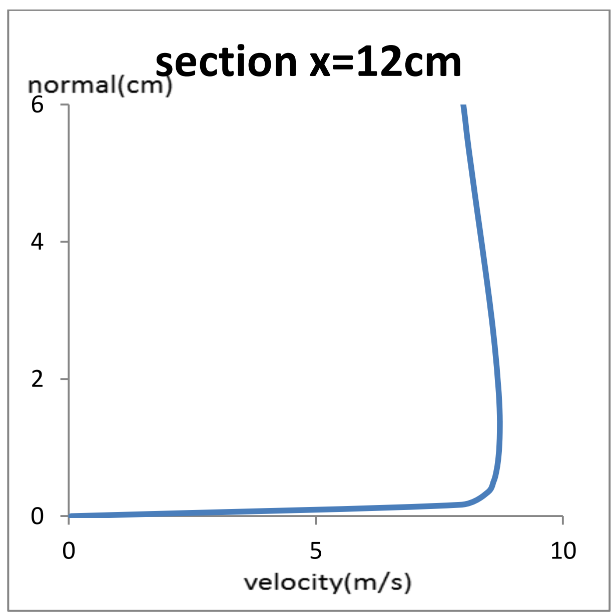


Fig.4.5(d)

Variation in velocity profile for model y^2=6x at free stream velocity 8m/s

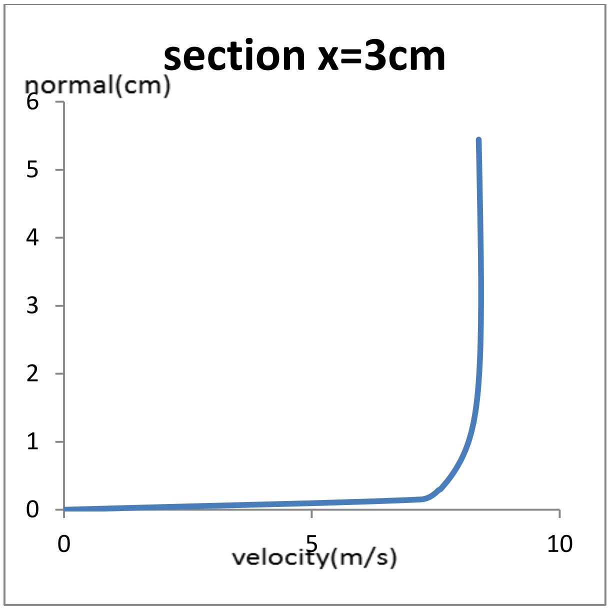


Fig.4.6 (a)

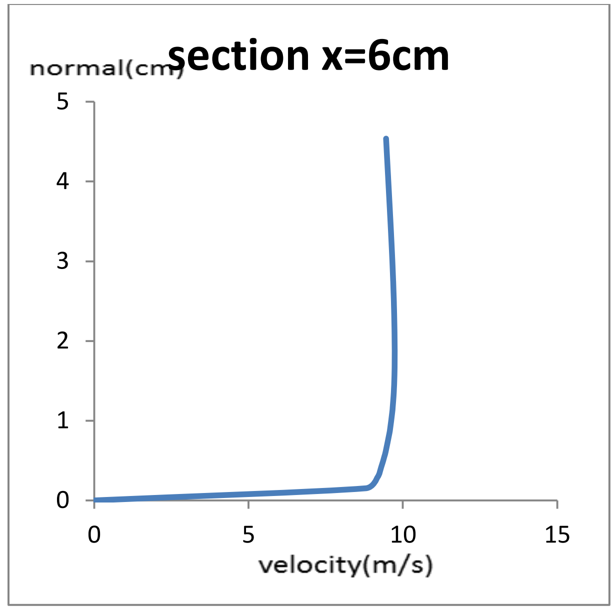


Fig.4.6 (b)

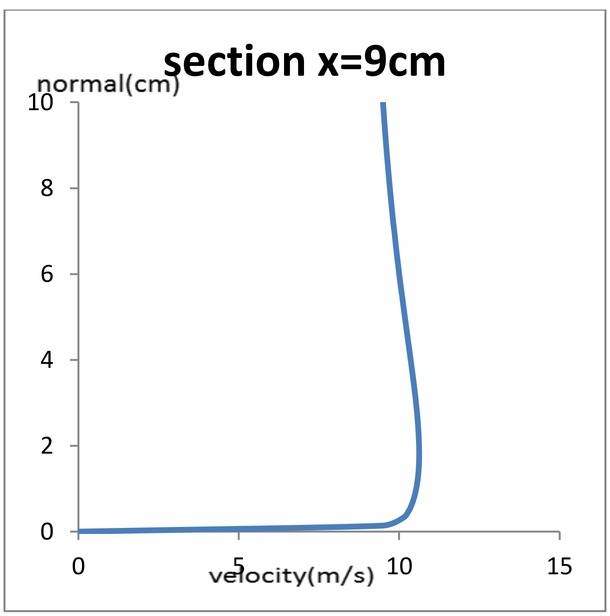


Fig.4.6(c)

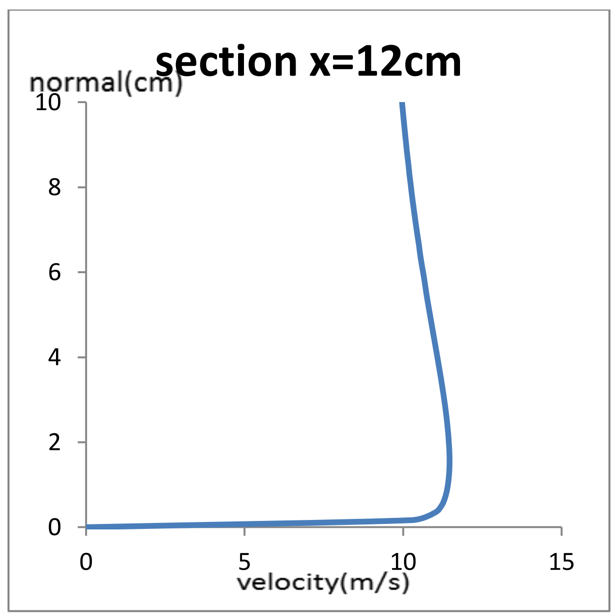


Fig.4.6(d)

Variation in velocity profile for model $y^2=6x$ at free stream velocity 10m/s

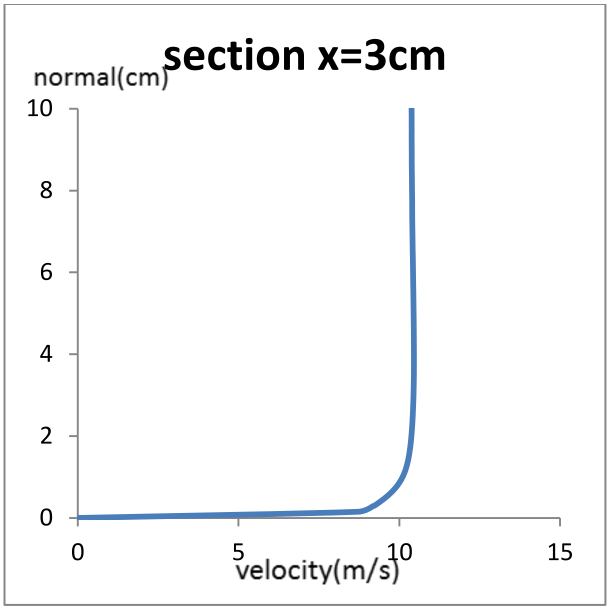


Fig.4.7 (a)

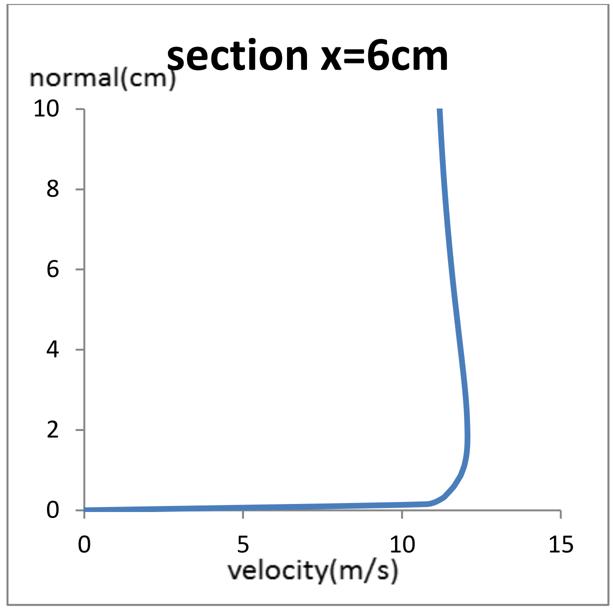


Fig.4.7(b)

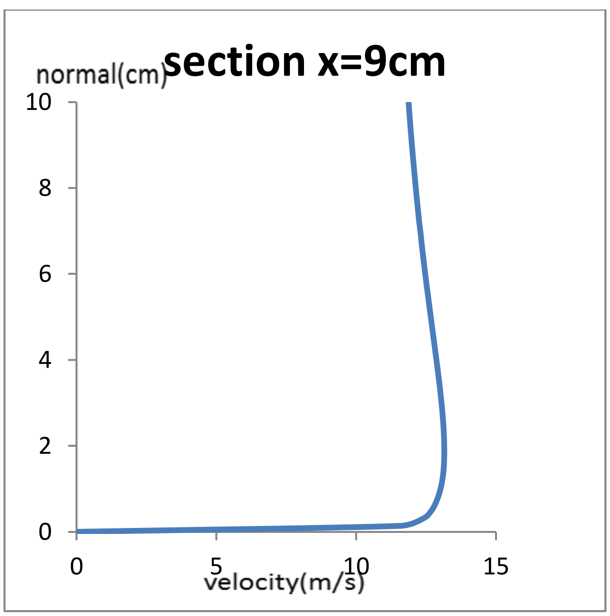


Fig.4.7(c)

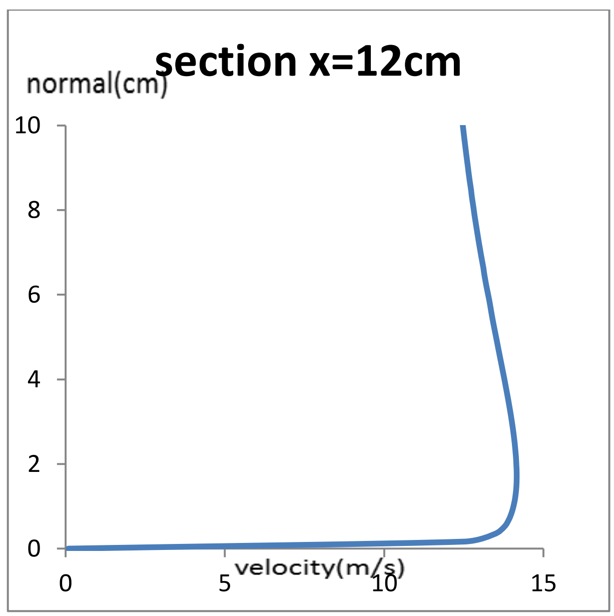


Fig.4.7(d)

Variation in velocity profile for model $y^2=6x$ at free stream velocity 12m/s

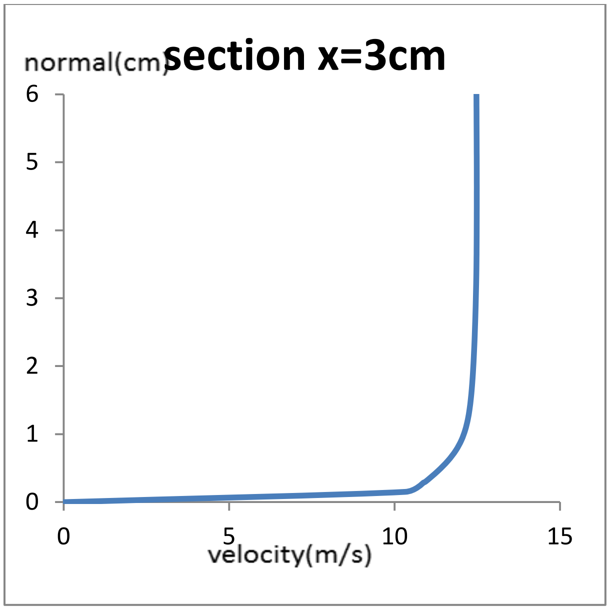


Fig.4.8 (a)

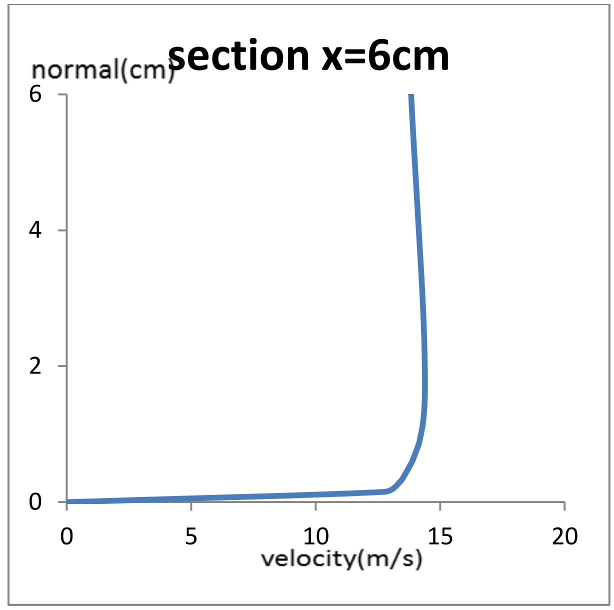


Fig.4.8 (b)

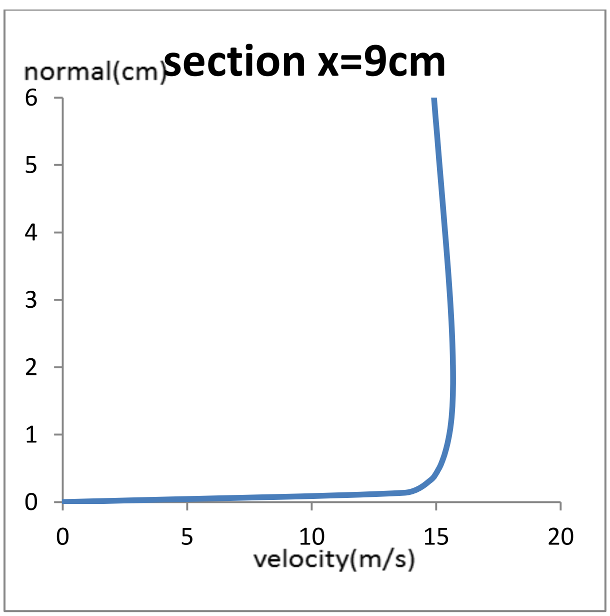


Fig.4.8(c)

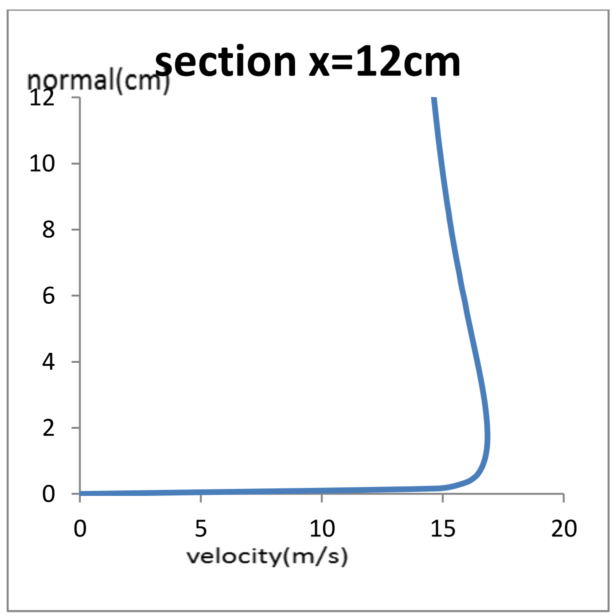


Fig.4.8 (d)

Variation in velocity profile for Model $y^2=4x$ at free stream velocity 6m/s

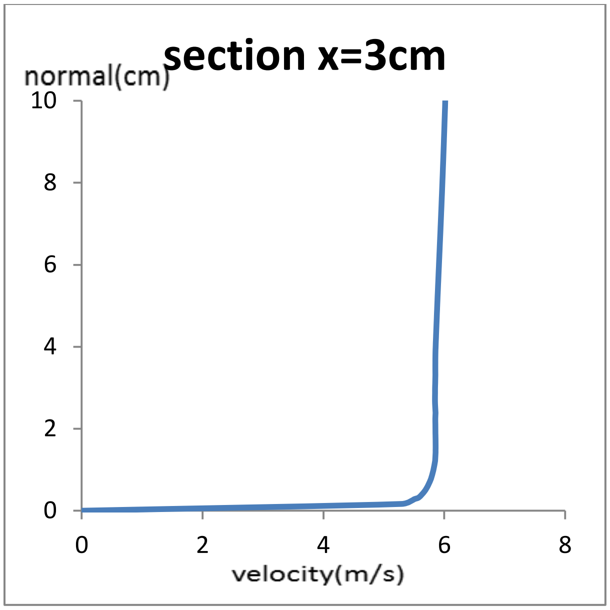


Fig.4.9 (a)

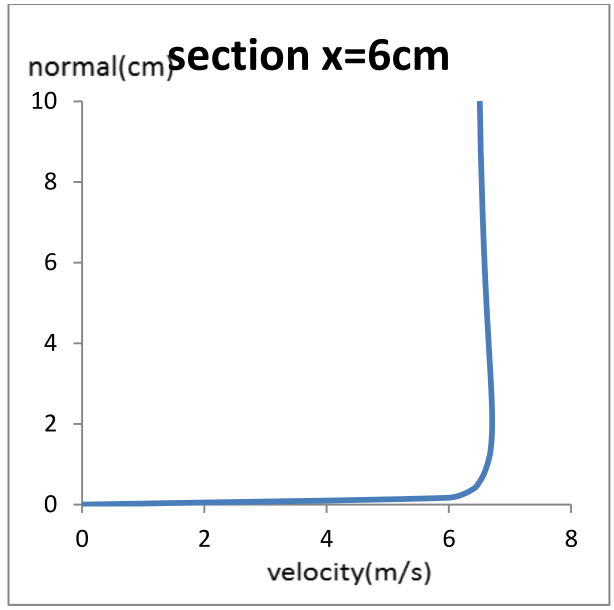


Fig.4.9 (b)

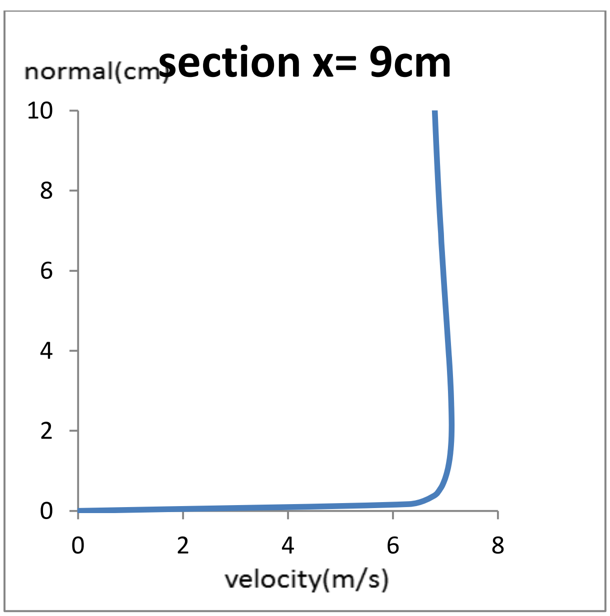


Fig.4.9(c)

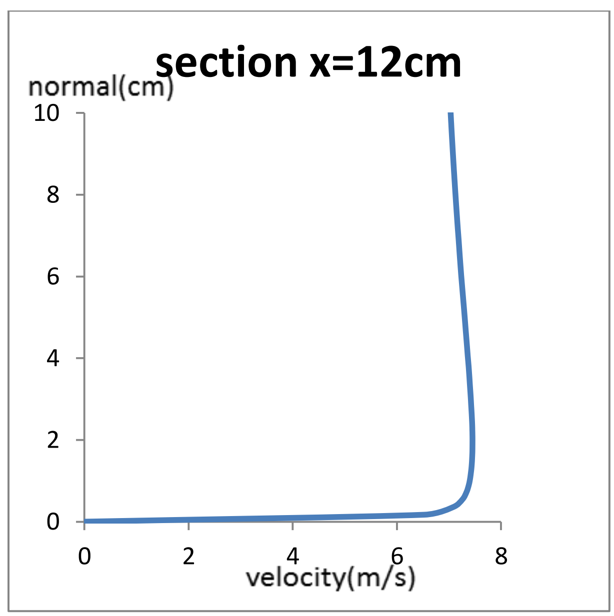


Fig.4.9(d)

Variation in velocity profile for model $y^2=4x$ at free stream velocity 8m/s

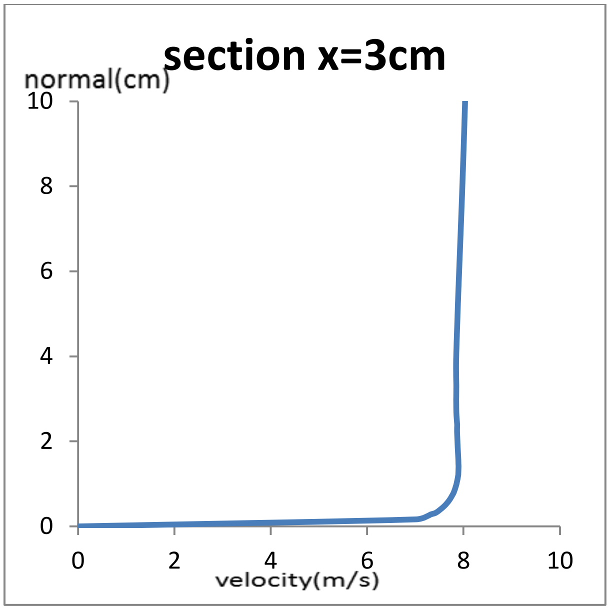


Fig.4.10 (a)

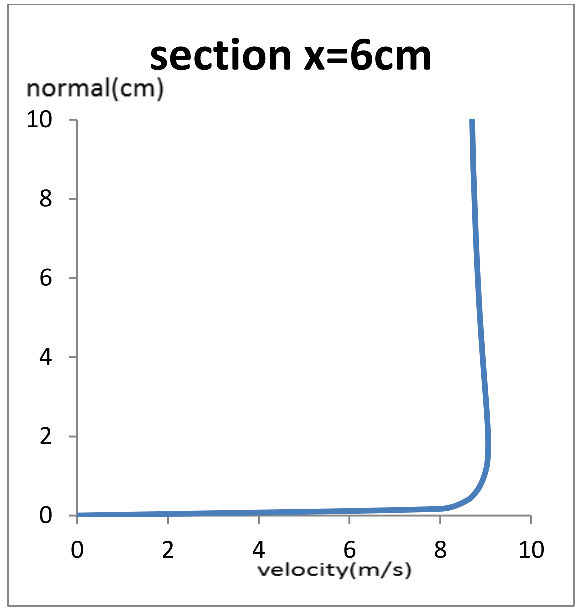


Fig.4.10(b)

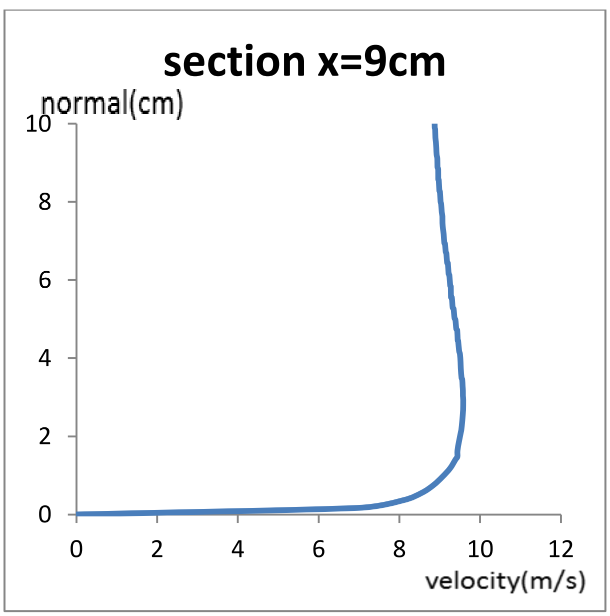


Fig.4.10(c)

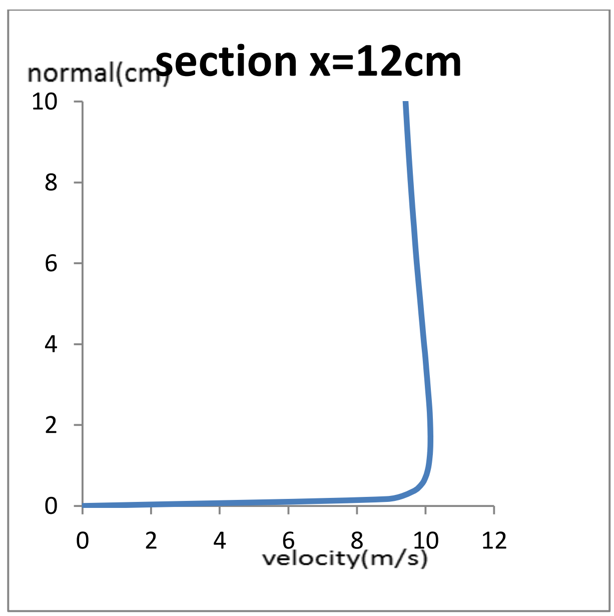


Fig.4.10(c)

Variation in velocity profile for model $y^2=4x$ at free stream velocity 10m/s

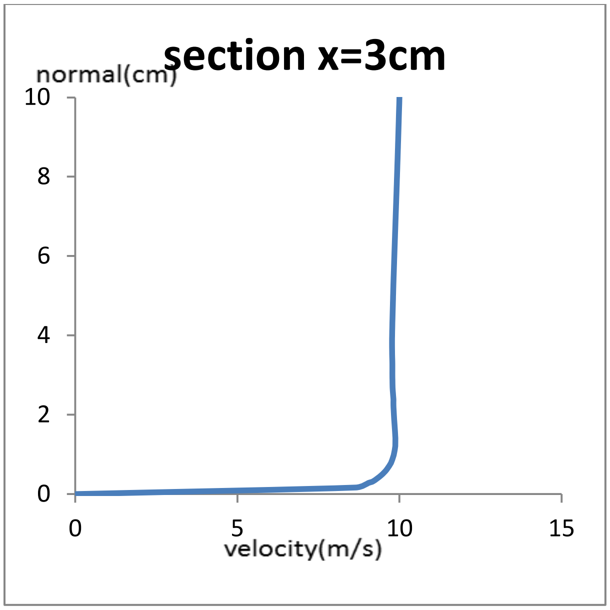


Fig.4.11 (a)

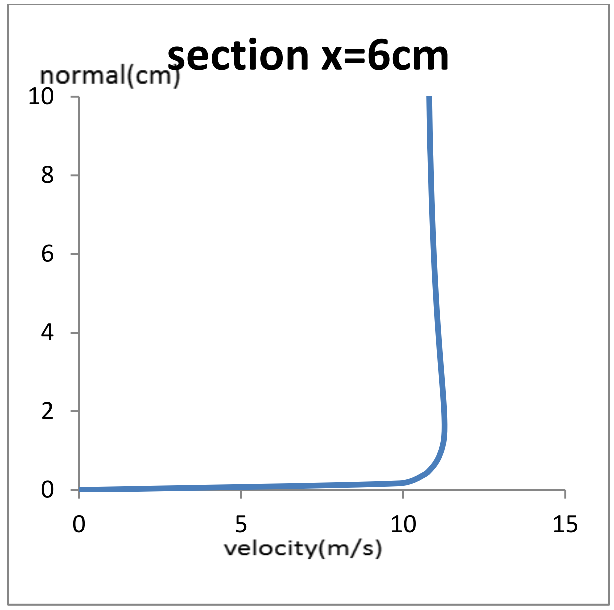


Fig.4.11 (b)

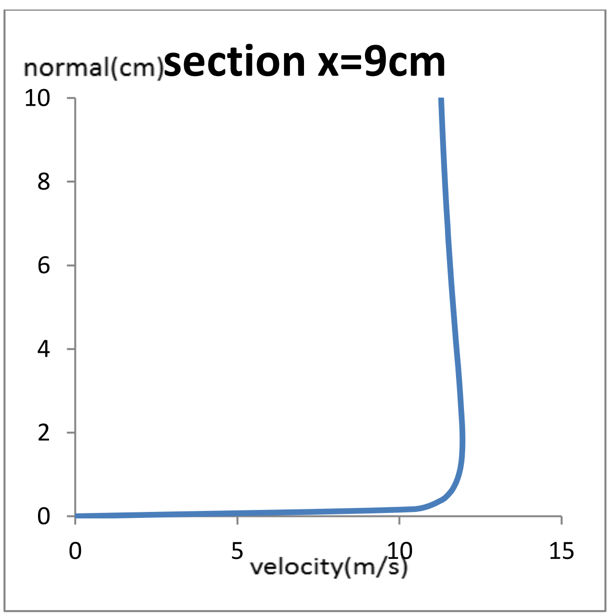


Fig.4.11(c)

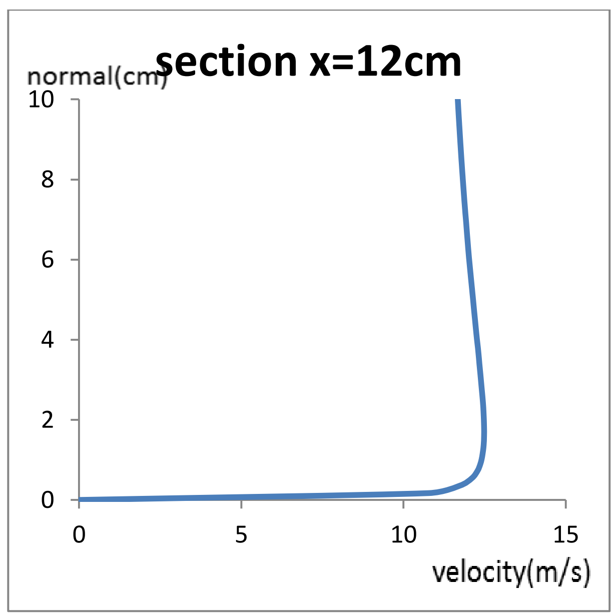


Fig.4.11(d)

Variation in velocity profile for model $y^2=4x$ at free stream velocity 12m/s

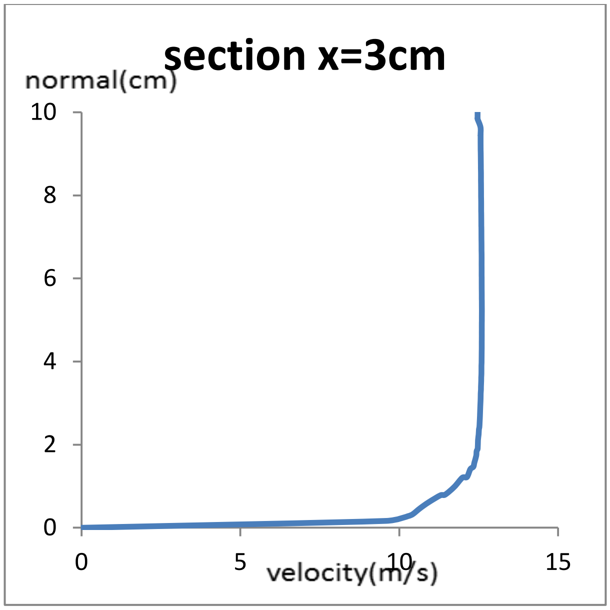


Fig.4.12 (a)

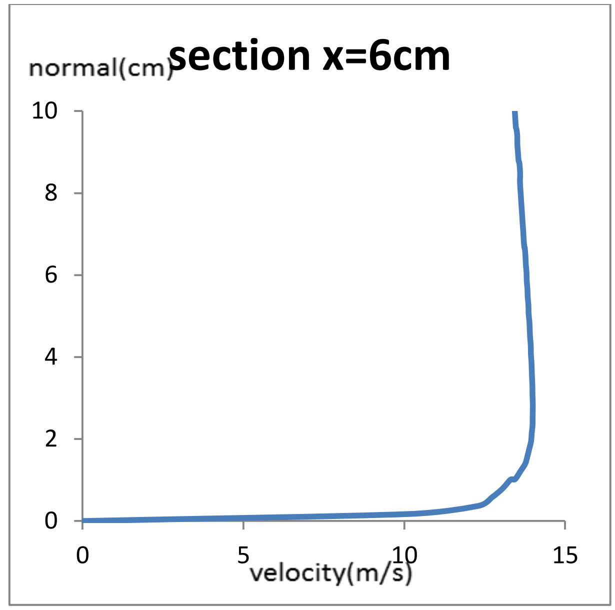


Fig.4.12(b)

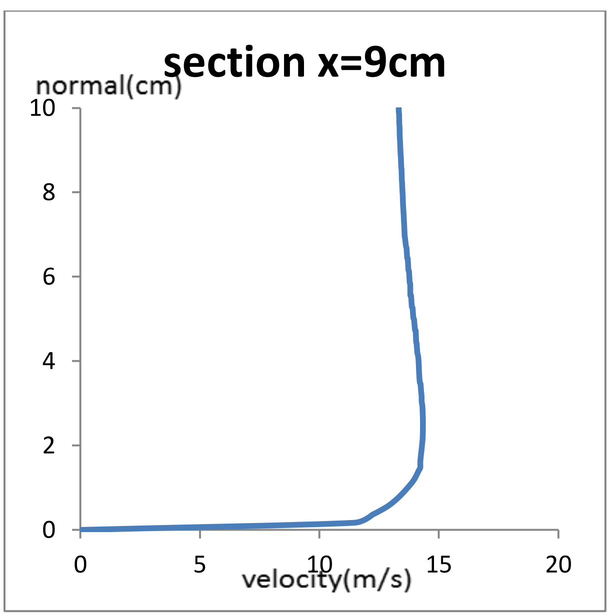


Fig.4.12(c)

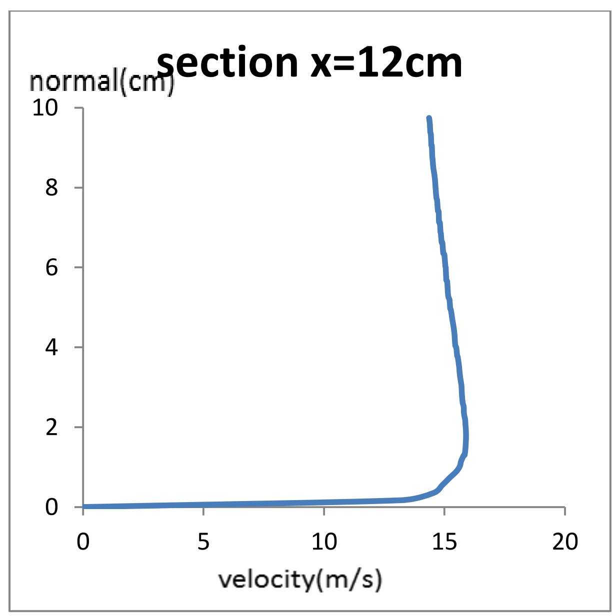


Fig.4.12 (d)

Variation in velocity profile for model $y^2=2x$ at free stream velocity 6m/s

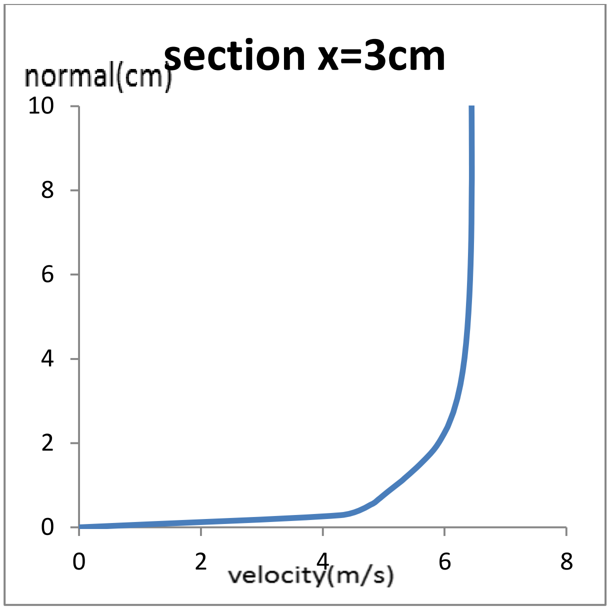


Fig.4.13 (a)

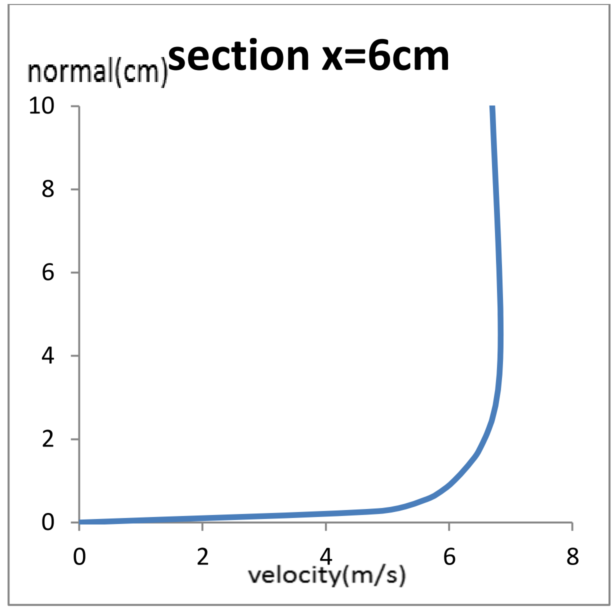


Fig.4.13 (b)

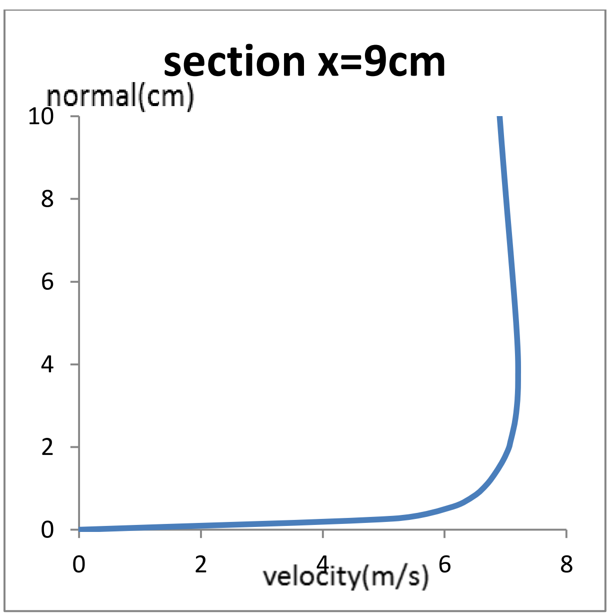


Fig.4.13(c)

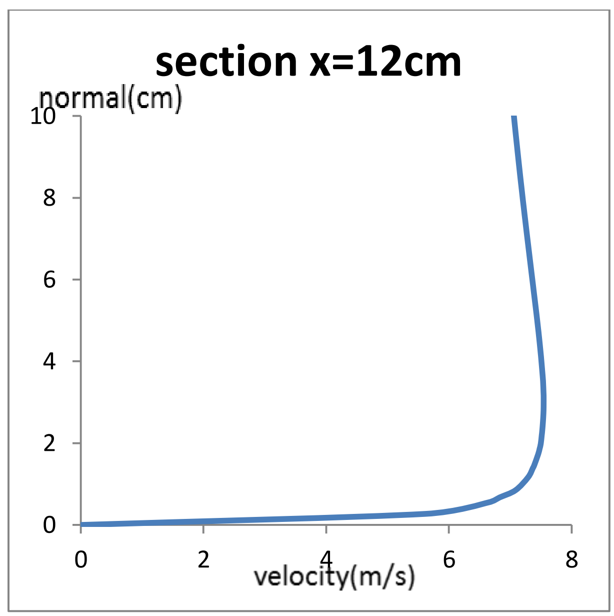


Fig.4.13 (d)

Variation in velocity profile for model $y^2=2x$ at free stream velocity 8m/s

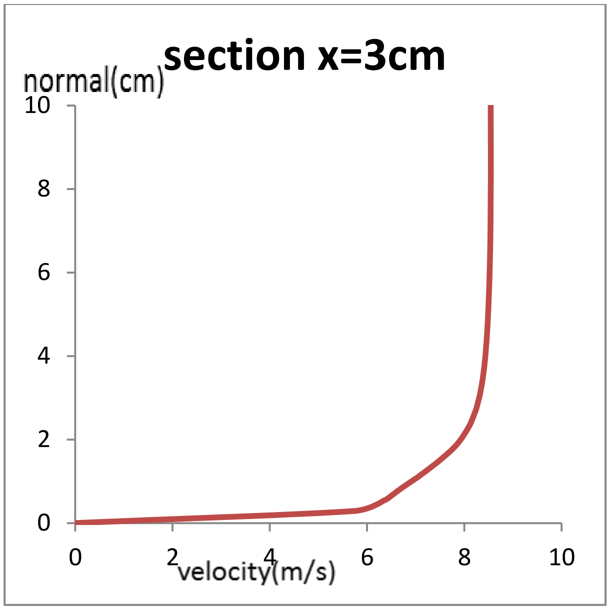


Fig.4.14 (a)

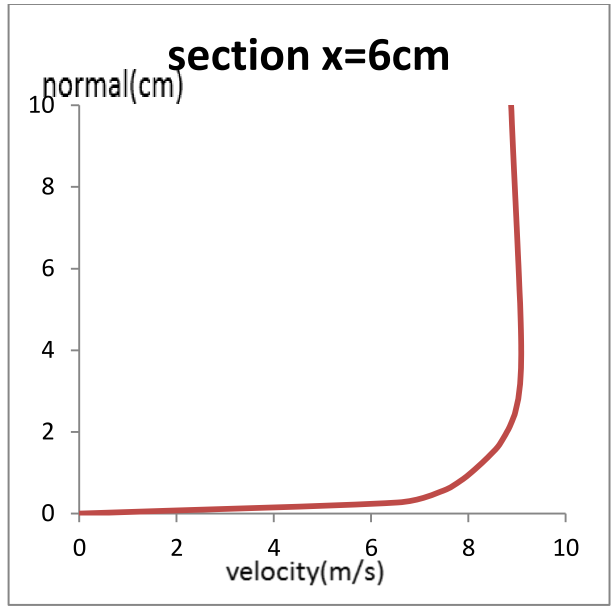


Fig.4.14 (b)

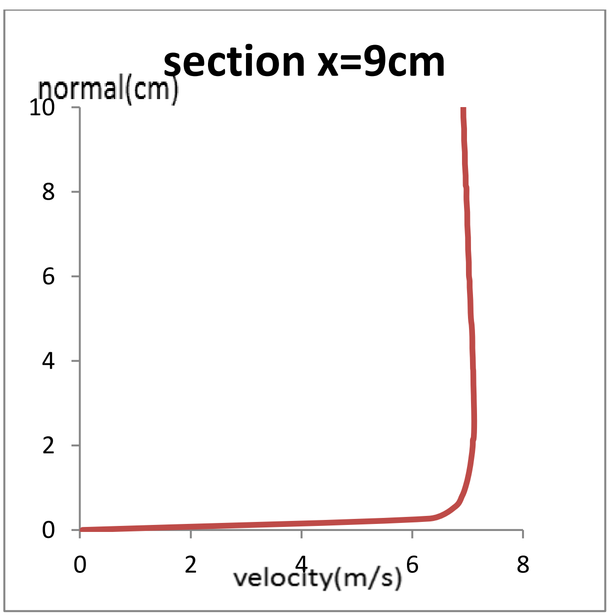


Fig.4.14(c)

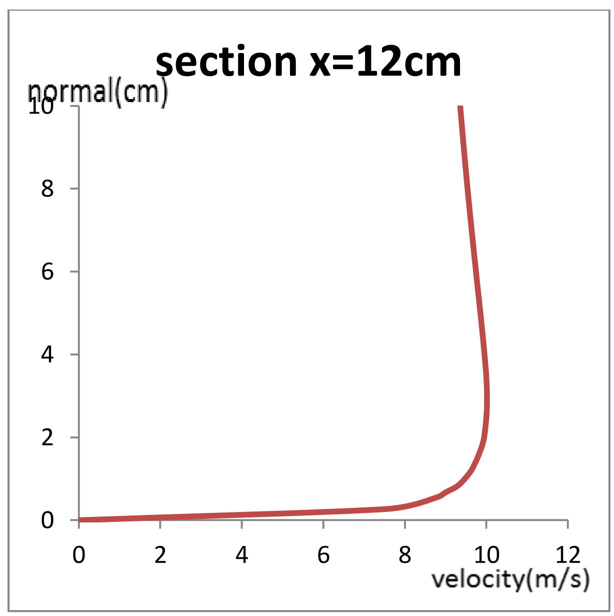


Fig.4.14 (d)

Variation in velocity profile for model $y^2=2x$ at free stream velocity 10m/s

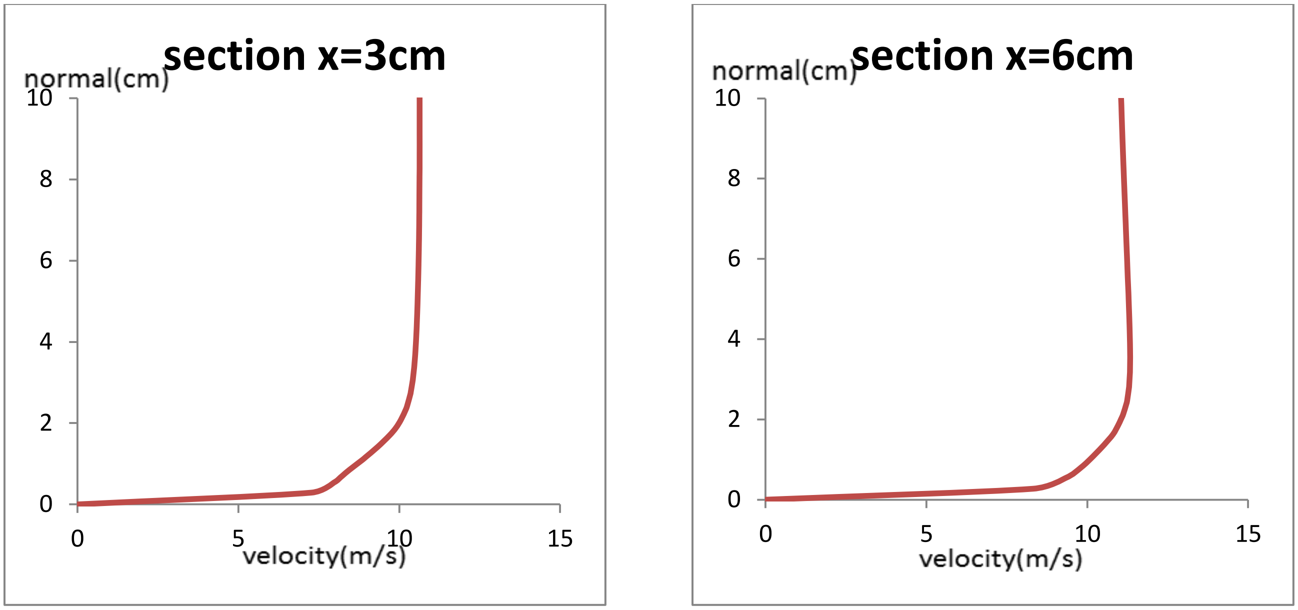


Fig.4.15 (a)

Fig.4.15 (b)

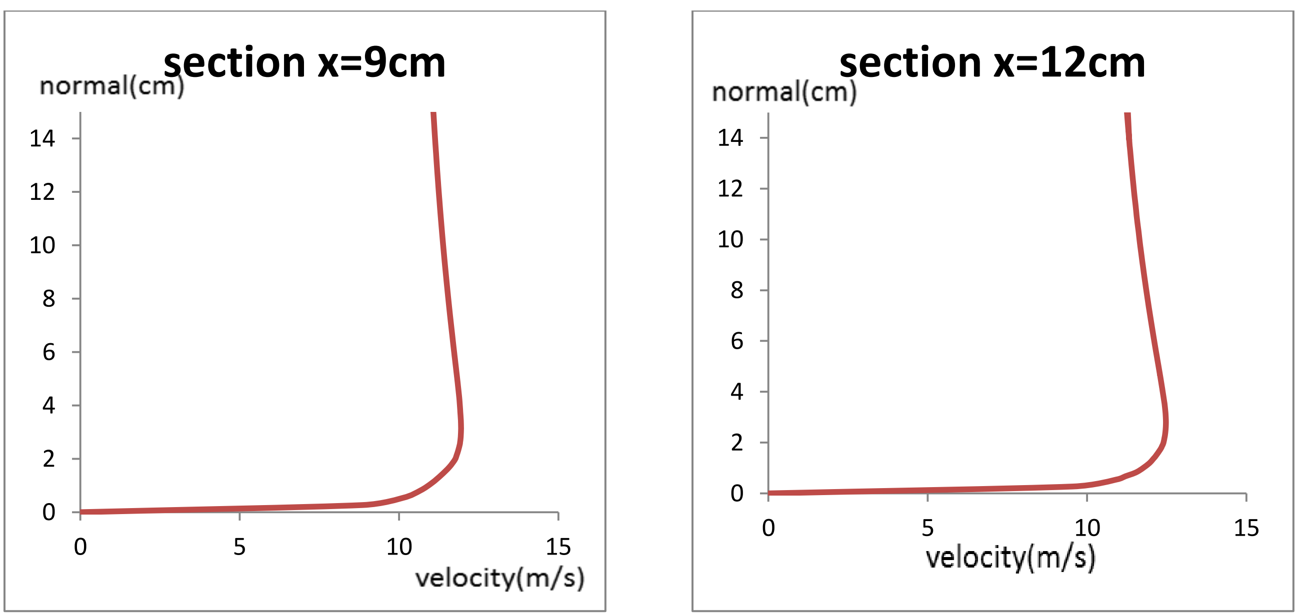


Fig.4.15(c)

Fig.4.15 (d)

Variation of velocity profile for Model $y^2=2x$ at free stream velocity 12m/s

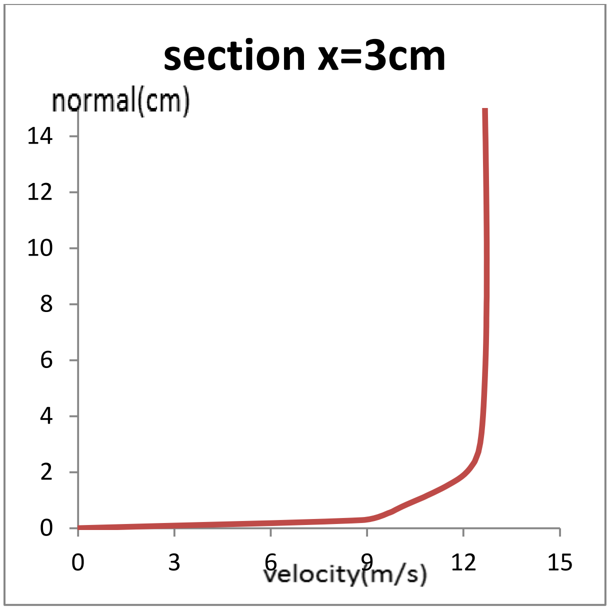


Fig.4.16 (a)

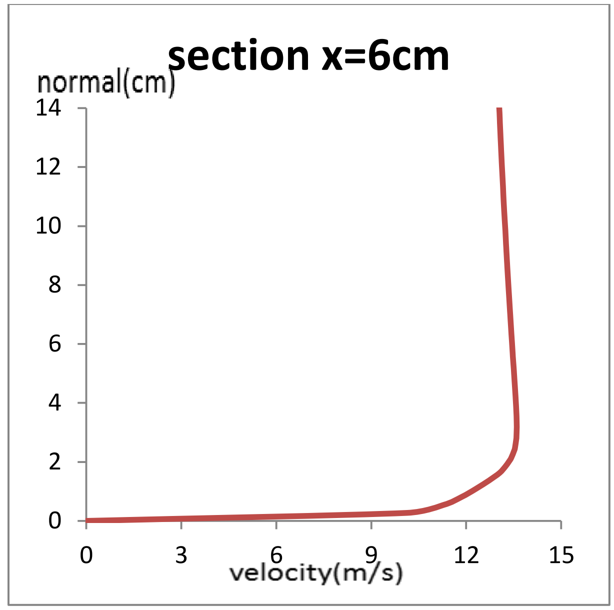


Fig.4.16 (b)

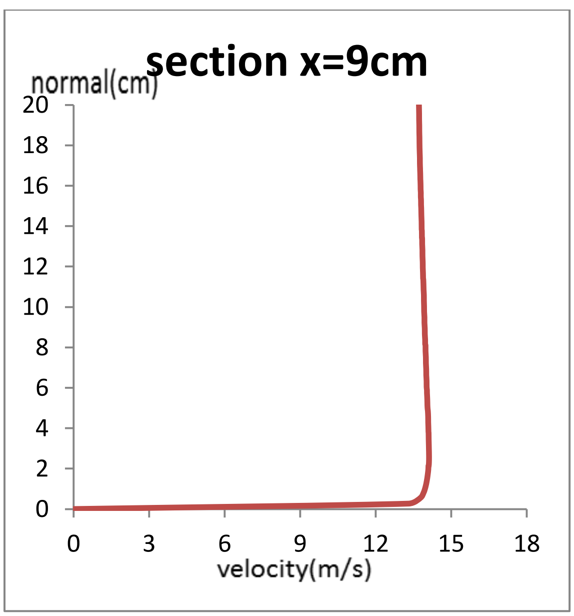


Fig.4.16(c)

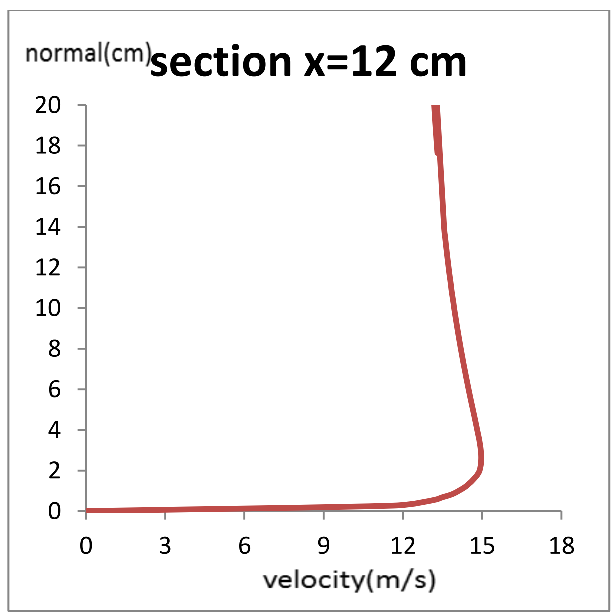


Fig.4.16 (d)

Different models particular section:

Variation in velocity profiles at section x=3cm,at velocity 6m/s

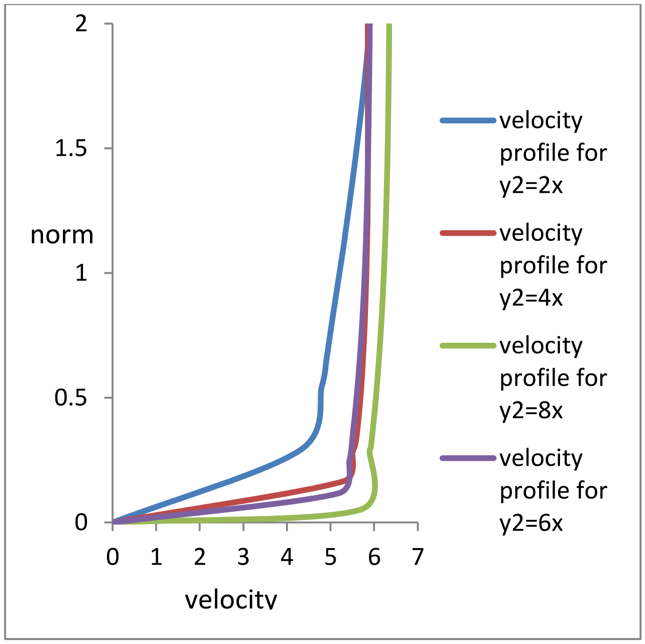


Fig.4.17

Variation in velocity profiles at section x=3cm, at velocity 8m/s

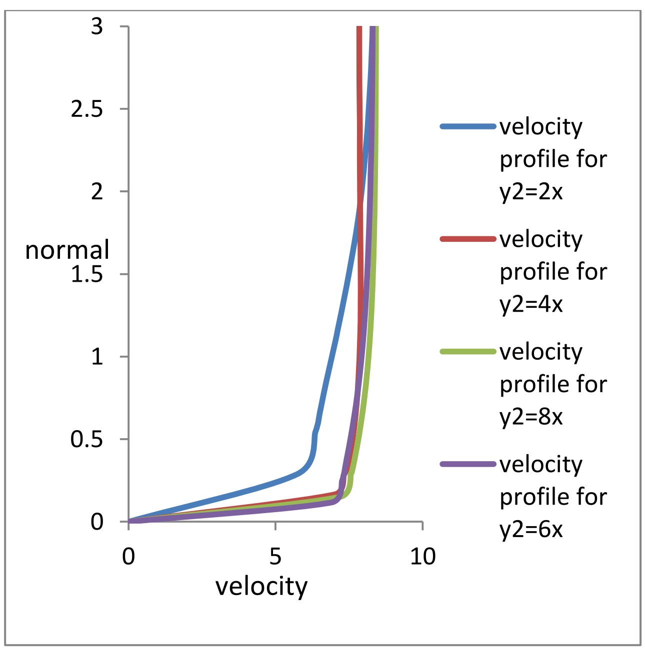


Fig.4.18

Variation in velocity profiles at section x=3cm ,at velocity 10m/s

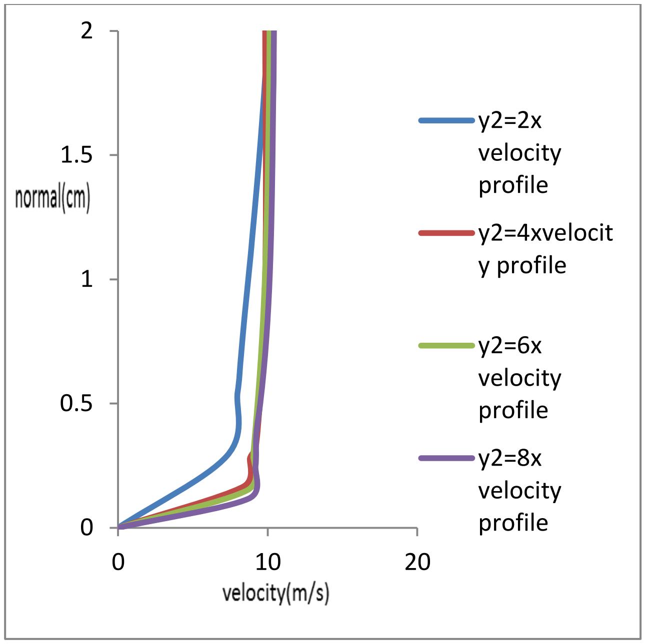


Fig.4.19

Variation in velocity profiles at section x=3cm ,at velocity 12m/s

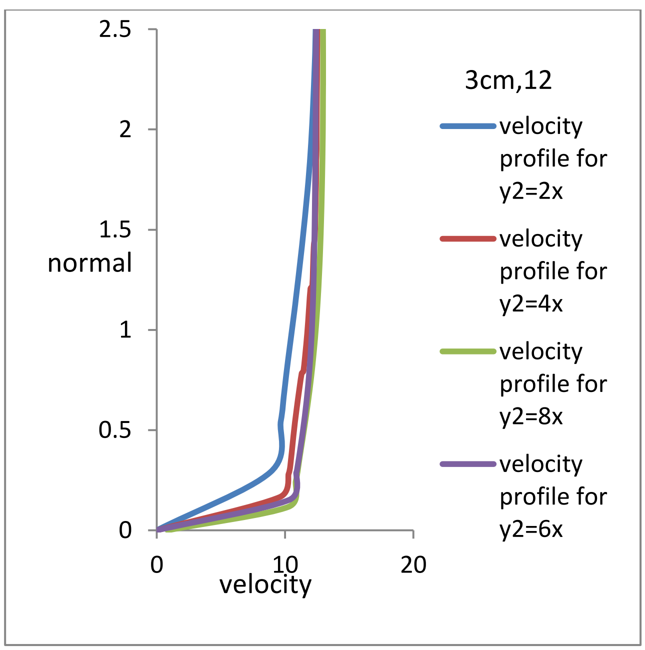


Fig.4.20

Variation in velocity profiles at section x=6cm ,at velocity 6m/s

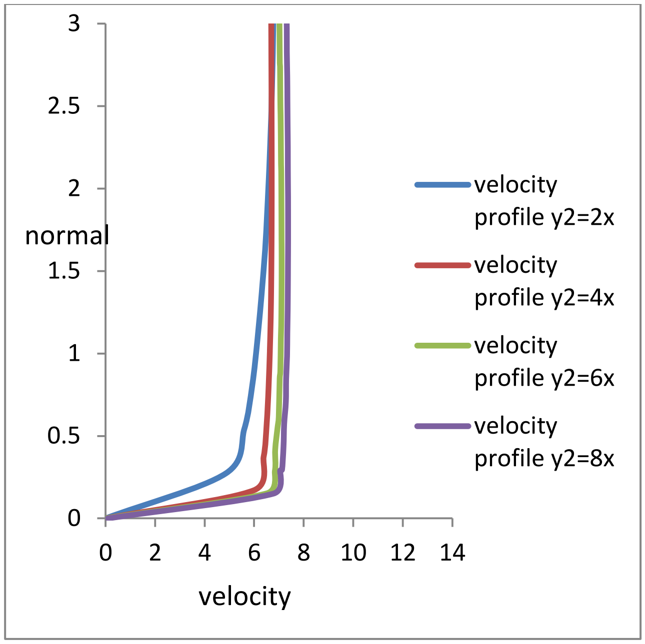


Fig.4.21.

Variation in velocity profiles at section x=6cm ,at velocity 8m/s

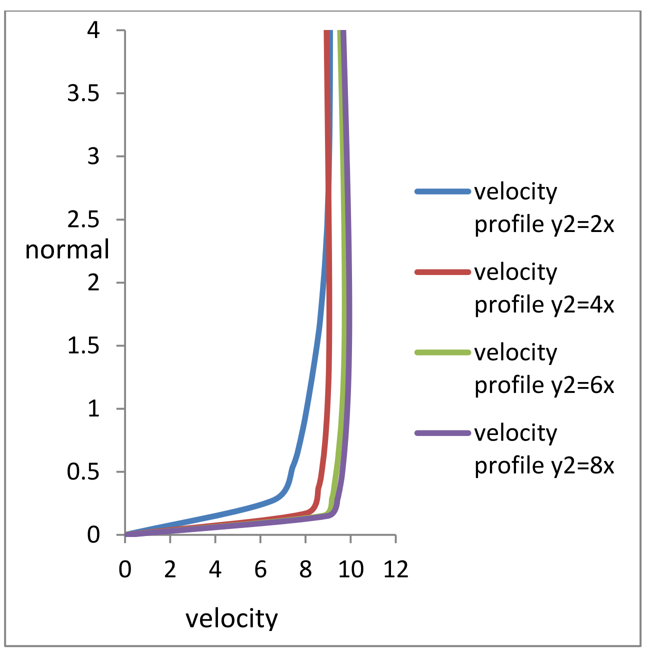


Fig.4.22

Variation in velocity profiles at section x=6cm ,at velocity 10m/s

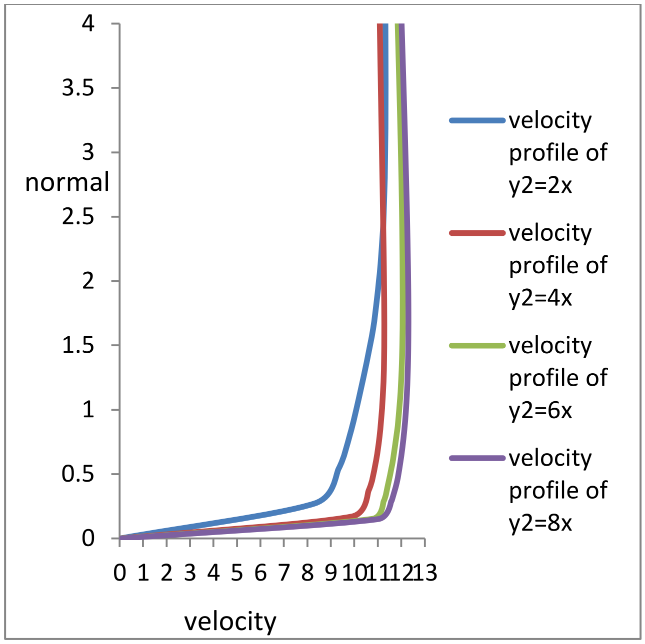


Fig.4.23

Variation in velocity profiles at section x=6cm ,at velocity 12m/s

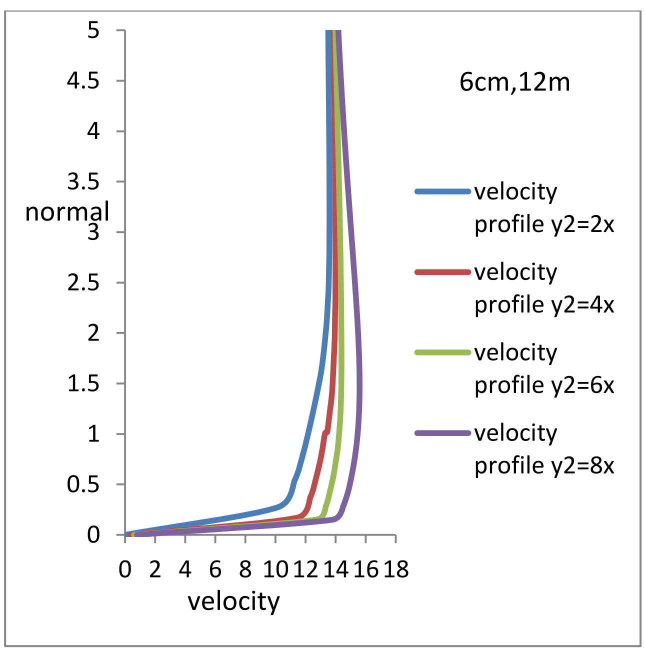


Fig.4.24

Variation in velocity profiles at section x=9cm, at velocity 6m/s

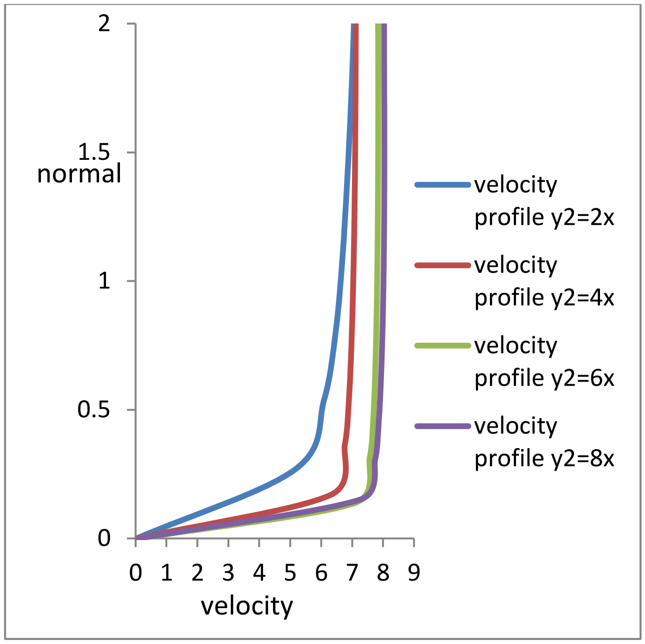


Fig.4.25

Variation in velocity profiles at section x=9cm ,at velocity 8m/s

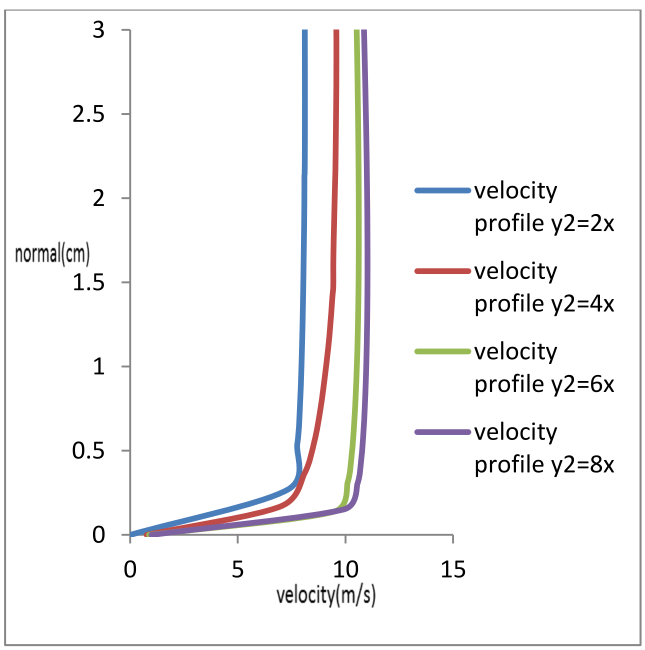


Fig.4.26

Variation in velocity profiles at section x=9cm ,at velocity 10m/s

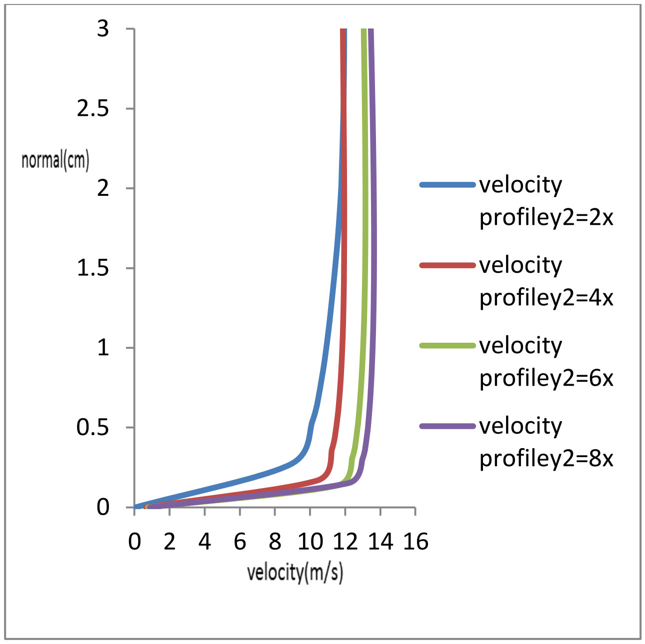


Fig.4.27

Variation in velocity profiles at section x=9cm, at velocity 12m/s

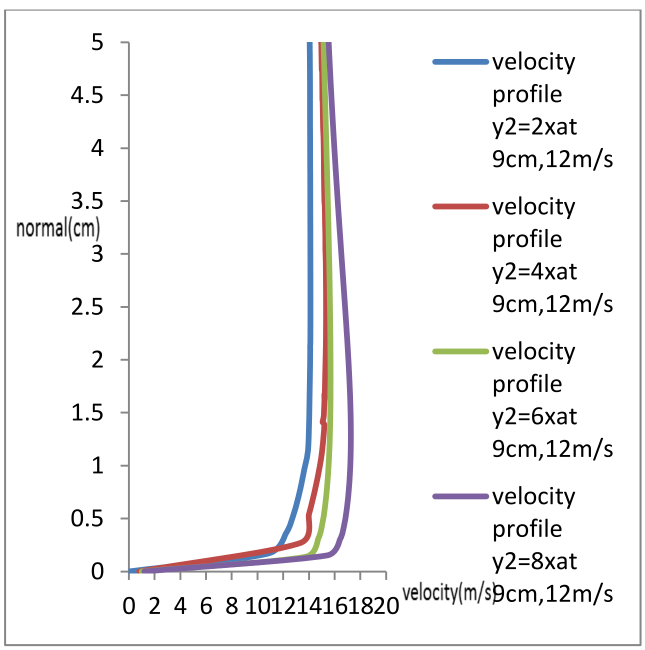


Fig.4.28

Variation in velocity profiles at section x=12cm, at velocity 6m/s

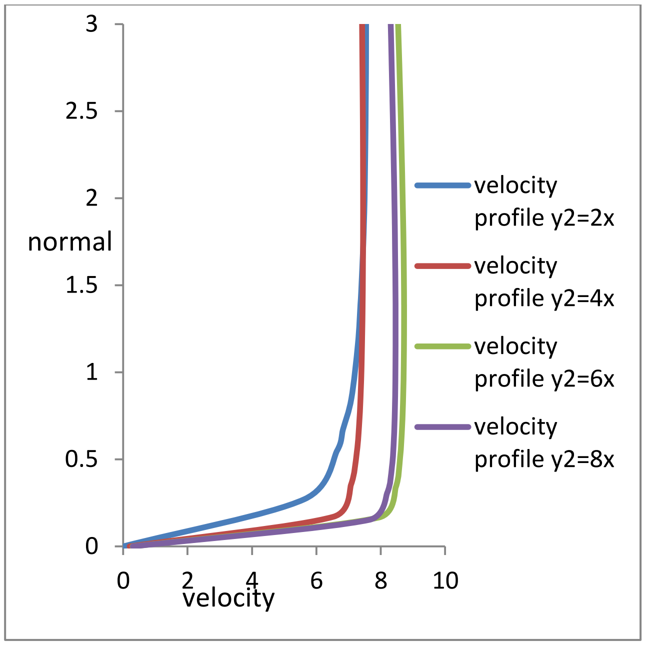


Fig.4.29

Variation in velocity profiles at section x=12cm, at velocity 8m/s

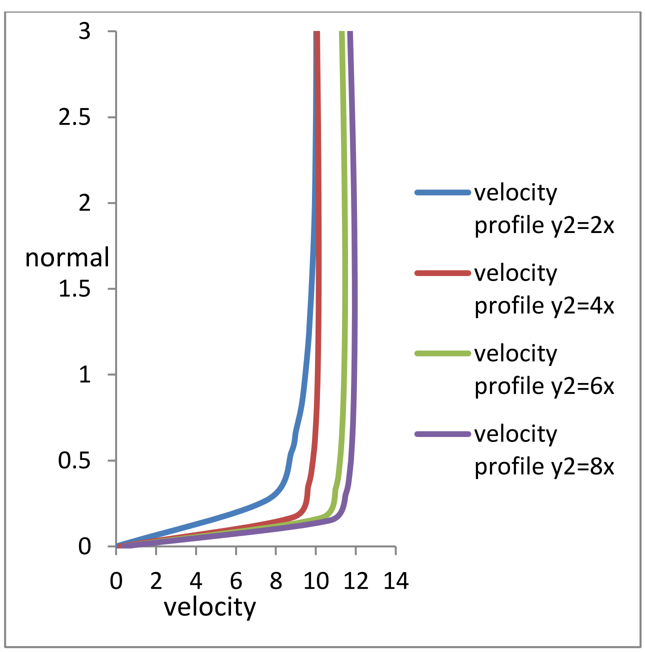


Fig.4.30

Variation in velocity profiles at section x=12cm, at velocity 10m/s

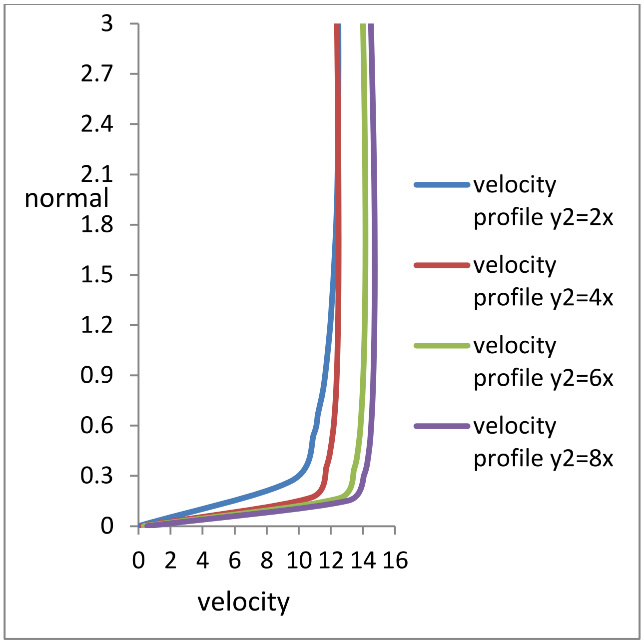


Fig.4.31

Variation in velocity profiles at section x=12cm ,at velocity 12m/s

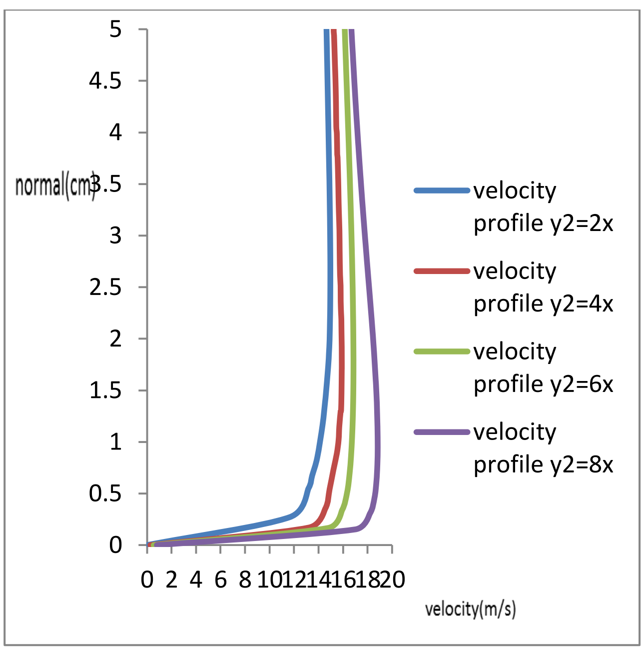


Fig.4.32

From fig.4.1 (a), fig.4.1 (b), fig4.1(c) and fig4.1 (d) it is clear velocity increases in rare direction of parabola. It is due to reduction in flow area. Theoretically if we apply continuity equation for incompressible fluid flow, reduction in flow area is the cause of increment in velocity. Characteristics of parabola are also responsible to affect the velocity. As we know increasing the characteristic in parabola curve becomes steeper which restrict the flow area. We can compare change in velocity due to change in characteristics in fig4.17, fig4.18, fig4.19, fig4.20, fig4.21, fig4.22 (b), fig 4.23, fig4.24, fig4.25, fig4.26, fig4.27, fig4.28, fig4.29, fig4.30 and fig4.31. At a particular section in all experimental parabolas. We can see velocity is increasing in normal direction, at the surface due to viscosity of fluid velocity is low but in outward normal direction velocity is continuously increasing up to the free stream velocity than it becomes constant. Its increment in normal direction is high for high characteristic of parabola (See fig.4.17).

In fig.4.1(a) to fig4.16(d). We can see at low free stream velocity, velocity increment near the nose of parabola is low while it is high in the rare end of parabola. And we can see clearly for high free stream velocity, velocity increment near the nose of parabola is higher than low free stream velocity.

From fig 4.2(a),4.2(b),4.2(c) and 4.2(d) it is clear maximum velocity point has tendency to approach the surface of parabola and at long distance all velocity points of the profile superimposes the surface of parabola. This phenomenon will occur at lower distance from the nose of parabola for rough surface while things are other way around for smooth surface parabola. When air passes around the nose of parabola it exerts high pressure then after some distance it becomes align along the surface of parabola. So aircraft or any other parabolic design will consume more fuel to overcome the pressure exerted by air. And parabola which has high characteristics, this distance is high. It increases with increment in characteristics of parabola.

From fig.4.17 to fig4.31, we can see magnitude of velocity gradient near the nose of any parabola at a particular section has high value while moving in backward direction this value reduces. It is due to viscosity of air and characteristics of parabola. And velocity gradient is directly dependent on free stream velocity. If free stream velocity is high than velocity gradient becomes low. No slip condition is responsible for this behavior.

Conclusions:

1. For a particular parabolic surface and particular location, velocity increases with increase in free stream velocity.
2. Velocity increases with increasing the characteristics of parabola (a in $y^2=aX$).
3. In normal direction velocity is increasing on increment of upstream velocity and it increases rapidly for parabola which has bigger characteristics.
4. For low upstream velocity, increase in velocity near the nose of parabola is low while it is high from the nose to the rare end of parabola.
5. For high upstream velocity, velocity increment near the nose of parabola is higher than low upstream velocity.
6. In all parabolas, maximum velocity point over surfaces has tendency to approach the surface as we move towards rare end.
7. Up to few distances, from the nose of parabola air streams exerts more pressure on the parabolic surface then it started to become align with the surface.
8. For a particular velocity this distance is high for high characteristics parabola it increases with increment in the characteristic of parabola.
9. For high up stream velocity this distance is more compare to low up stream velocity for all parabolas.
10. Magnitude of velocity gradient near the nose of any parabola at a particular section has high value while moving in backward direction this value reduces.(inside boundary layer zone)
11. For high stream velocity this gradient is relatively low at any section compare to low up stream velocity.

12. Magnitude of velocity gradient for an upstream velocity is higher for low characteristics parabola and it reduces when we increases the characteristic of parabola.
13. Magnitude of velocity gradient reduces when upstream velocity increases.
14. On increment in the characteristics of parabola, velocity gradient changes rapidly in the beginning then it changes slowly.

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