5.1 BOUNDARY LAYER

When fluids flow over surfaces, the molecules near the surface are brought to rest due to the viscosity of the fluid. The adjacent layers are also slow down, but to a lower and lower extent. This slowing down is found limited to a thin layer near the surface. The fluid beyond this layer is not affected by the presence of the surface. The fluid layer near the surface in which there is a general slowing down is defined as boundary layer. The velocity of flow in this layer increases from zero at the surface to free stream velocity at the edge of the boundary layer.

When a real fluid flow past a solid body or a solid wall, the fluid particles adhere to the boundary and condition of no slip occurs. This means that the velocity of fluid close to the boundary will be same as that of the boundary. If the boundary is stationary, the velocity of fluid at the boundary will be zero. The theory dealing with boundary layer flows is called boundary layer theory.

According to the B.L. theory, the flow of fluid in the neighbourhood of the solid boundary may be divided into two regions as shown below

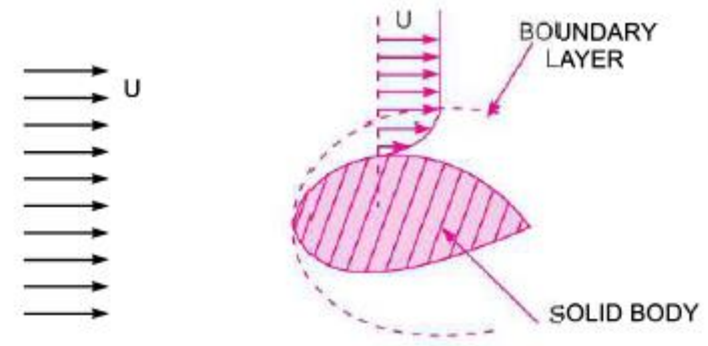


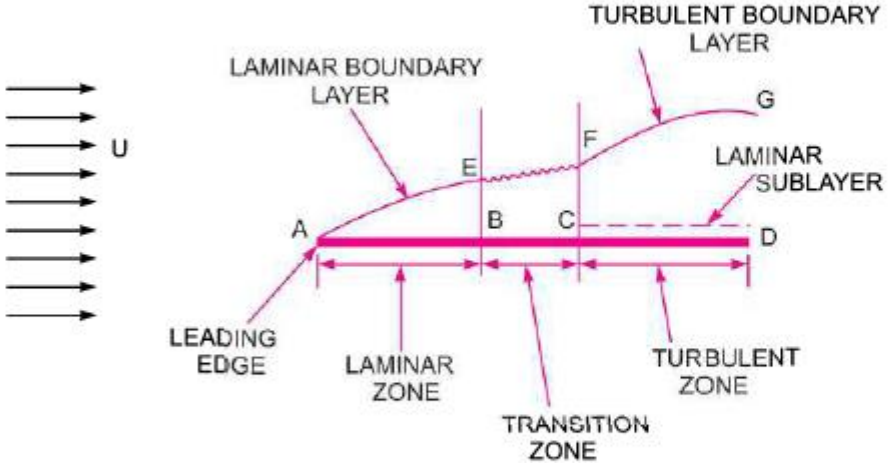
Figure 5.1.1 Description of the Boundary Layer

[Source: "Fluid Mechanics and Hydraulics Machines" by Dr.R.K.Bansal, Page: 611]

The simplest boundary layer to study is that formed in the flow along one side of a thin, smooth, flat plate parallel to the direction of the oncoming fluid. No other solid surface is near, and the pressure of the fluid is uniform. If the fluid were inviscid no velocity gradient would, in this instance, arise. The velocity gradients in a real fluid are therefore entirely due to viscous action near the surface.

The fluid, originally having velocity U_∞ in the direction of plate, is retarded in the neighborhood of the surface, and the boundary layer begins at the leading edge of the plate. As more and more of the fluid is slowed down, the thickness of the layer increases. The fluid in contact with the plate surface has zero velocity, 'no slip' and a velocity gradient exists between the fluid in the free stream and the plate surface.

The flow in the first part of the boundary layer (close to the leading edge of the plate) is entirely laminar. With increasing thickness, however, the laminar layer becomes unstable, and the motion within it becomes disturbed. The irregularities of the flow develop into turbulence, and the thickness of the layer increases more rapidly. The changes from laminar to turbulent flow take place over a short length known as the transition region.



Graph of velocity u against distance y from surface at point X

Reynolds' Number Concept

If the Reynolds number locally were based on the distance from the leading edge of the plate, then it will be appreciated that, initially, the value is low, so that the fluid flow close to the wall may be categorized as laminar. However, as the distance from the leading edge increases, so does the Reynolds number until a point is reached where the flow regime becomes turbulent.

For smooth, polished plates the transition may be delayed until Re equals 500000. However, for rough plates or for turbulent approach flows transition may occur at much lower values. Again, the transition does not occur in practice at one well-defined point but, rather, a transition zone is established between the two flow regimes.

The figure above also depicts the distribution of shear stress along the plate in the flow direction. At the leading edge, the velocity gradient is large, resulting in a high shear stress. However, as the laminar region progresses, so the velocity gradient and shear stress decrease with thickening of the boundary layer. Following transition the velocity gradient again increases and the shear stress rises.

Theoretically, for an infinite plate, the boundary layer goes on thickening indefinitely. However, in practice, the growth is curtailed by other surfaces in the vicinity.

Factors affecting transition from Laminar to Turbulent flow Regimes

As mentioned earlier, the transition from laminar to turbulent boundary layer condition may be considered as Reynolds number dependent,

$Re_x = \rho U_s x / \mu = \frac{\mu x}{\nu}$ and a figure of 5 x 10^5 is often quoted.

However, this figure may be considerably reduced if the surface is rough. For Re<105, the laminar layer is stable; however, at Re near 2 x 105 it is difficult to prevent transition.