(II). Displacements thickness:

Because of the viscosity, the velocity on the vicinity of the plate is smaller than in the free flow region.

The reduction in total flow rate caused by the action is

$$\int_0^\infty (U-u)\,dy$$

If this integral is equated to a quantity $U\delta_1$; δ_1 may be considered as the amount by which the potential flow has been displaced from the plate. Thus for displacement thickness, we have, the definition,

$$U\delta_1 = \int_0^\infty (U-u)\,dy$$

i.e. $$\delta_1 = \int_{y=0}^\infty \left(1-\frac{u}{U}\right)dy$$

Here, δ_1 is known as the displacement thickness.

(III) Momentum thickness:

The loss of momentum in the boundary layer as compared to the potential flow is given by

$$\int_0^\infty \rho u U\,dy - \int_0^\infty \rho u^2\,dy = \rho\int_0^\infty u(U-u)\,dy$$

If $\rho U^2\delta_2$ denotes the loss of momentum, then δ_2 is known as the momentum thickness. Thus for the momentum thickness δ_2, we have the definition

$$\rho U^2\delta_2 = \rho\int_{y=0}^\infty u(U-u)\,dy$$

$$\Rightarrow \delta_2 = \int_0^\infty \frac{u}{U}\left(1-\frac{u}{U}\right)dy$$

(IV). Energy Equation thickness:

There is always a loss in energy because of the viscosity of the fluid. Now, the loss of kinetic energy in the boundary layer at a distance y from the plate is

$\frac{1}{2}\rho(U^2-u^2)$ and consequently the total rate at which the kinetic energy is being lost is

$$\frac{1}{2}\rho\int_{y=0}^{\infty}(U^2-u^2)u\,dy.$$

If this integral is equated to a quantity $\frac{1}{2}\rho U^3\delta_3$ may be considered as thickness of a layer which has the same K.E. flux as the rate at which the K.E is being lost in the boundary region. Thus for the energy thickness δ_3, we have the difition

$$\frac{1}{2}\rho U^3\delta_3 = \frac{1}{2}\rho\int_{y=0}^{\infty}(U^2-u^2)u\,dy$$

i.e. $$\delta_3 = \int_{y=0}^{\infty}\frac{u}{U}\left(1-\frac{u^2}{U^2}\right)dy.$$

(V). Drag and Lift:

If ~~the~~ a fluid flow in presence of a solid body then the body will experience two types of forces. The force component exerted on the body from a moving fluid in the direction of free strain of the fluid far from the body is defined as <u>drag</u> and the force component on the body normal to the force stream of the fluid far from the body is defined as Lift.

Since the measurement of drag and Lift depends on the transition in boundary layer, separation of the boundary layer and so on, it is very difficult to measure them. We therefore employ experimental data and define them as follows:

$$\text{Drag} = \frac{1}{2}\rho U^2 A C_D$$

$$\text{Lift} = \frac{1}{2}\rho U^2 A C_L$$

where C_D is the coefficient of drag

C_L is the " of Lift

A is the projected area in the direction of flow

U is the free stream velocity

This two forces are provided by tangential and normal stress. The drag due to tangential or shearing stress is called skin friction or viscous drag. The drag due to normal stress is called pressure drag.