BUOYANCY AND FLOATATION - STABILITY OF FLOATING BODIES.

SEPARATION OF BOUNDARY LAYER

When a solid body is immersed in a flowing fluid, a thin layer of fluid called the boundary layer is formed adjacent to the solid body. In this thin layer of fluid, the velocity varies from zero to free stream velocity in the direction normal to the solid body.

Along the length of the solid body, the thickness of the boundary layer increases. The fluid layer adjacent to the solid surface has to do work against surface friction at the expense of its kinetic energy. This loss of the kinetic energy is recovered from the immediate fluid layer in contact with the layer adjacent to solid surface through momentum exchange process.

Thus the velocity of the layer goes on decreasing. Along the length of the solid body, at a certain point a stage may come when the boundary layer may not be able to keep sticking to the solid body if it cannot provide kinetic energy to overcome the resistance offered by the solid body. In other words, the boundary layer will be separated from the surface. This phenomenon is called the boundary layer separation. The point on the body at which the boundary layer is on the verge of separation from the surface is called point of separation.

Effect of Pressure Gradient on Boundary Layer Separation

The effect of pressure gradient $\left(\dfrac{dp}{dx}\right)$ on boundary layer separation can be explained by considering the flow over a curved surface ABCSD as shown in the figure below. In the region ABC of the curved surface, the area of flow decreases and hence velocity increases. This means that flow get accelerated in this region. Due to the increase of the velocity, the pressure decreases in the direction of the flow and hence pressure gradient $\dfrac{dp}{dx}$ is negative in this region. As long as $\dfrac{dp}{dx} < 0$, the entire boundary layer moves forward as shown.

Region CSD of the curved: the pressure is minimum at the points C. Along the region CSD of the curved surface, the area of flow increases and hence velocity of flow along the direction of fluid decreases. Due to decrease of velocity, the pressure increases in the direction of flow and hence pressure gradient $\dfrac{dp}{dx}$ is positive or $\dfrac{dp}{dx} > 0$. Thus is the region CSD, the pressure gradient is positive and velocity of fluid layers along the direction of flow decreases. As earlier mentioned, the velocity of the layer adjacent to the solid surface along the length of the solid surface goes on decreasing as the kinetic energy of the layer is used to overcome the frictional resistance of the surface. Thus the

energy of the layer is used to overcome the frictional resistance of the surface. Thus the combine effect positive pressure gradient and surface resistance reduces the momentum of the fluid. A stage comes, when the momentum of the fluid is unable to overcome the surface resistance and the boundary layer starts separating from the surface at the point S. Downstream the point S, the flow is taking place in reverse direction and the velocity gradient becomes negative.
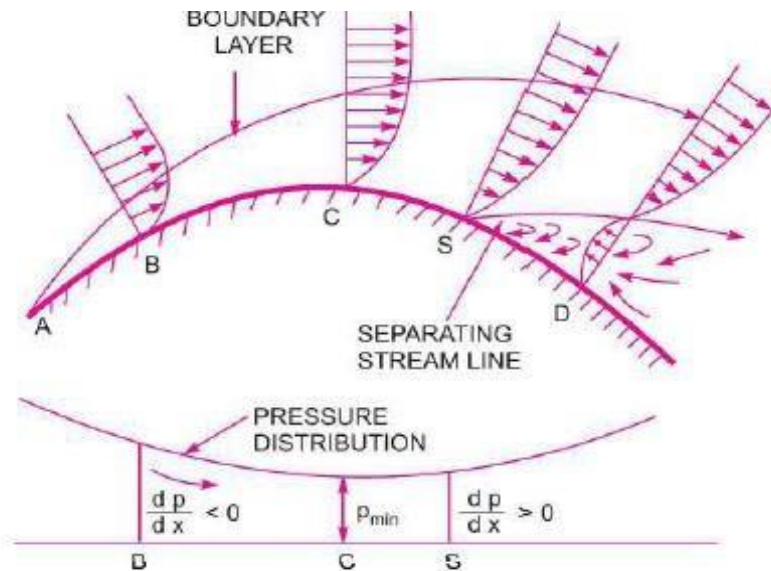

Figure 5.6.1 Effect of pressure gradient on boundary layer separation

[Source: "Fluid Mechanics and Hydraulics Machines" by Dr.R.K.Bansal, Page: 649]

The flow separation depends upon factors such as

(i) The curvature of the surface

(ii) The Reynolds number of flow

(iii) The roughness of the surface

The velocity gradient for a given velocity profile, exhibits the following characteristics for the flow to remain attached, get detached or be on the verge of separation:

$$1 \left(\frac{du}{dy} \right)_{y=0} \text{ is } +ve \text{ ------ attached flow (the flow will not separate)}$$

$$2 \left(\frac{du}{dy} \right)_{y=0} \text{ is zero ------ The flow is on the verge of separation}$$

$$3 \left(\frac{du}{dy} \right)_{y=0} \text{ is } -ve \text{ ------ Separated flow}$$

Methods of preventing the Separation of Boundary Layer

The following are some of the methods generally adopted to retard or arrest the flow separation:

1. Streamlining the body shape

2. Tripping the boundary layer from laminar to turbulent by provision of surface

roughness

3. Sucking the retarded flow

4. Injecting high velocity fluid in the boundary layer

5. Providing slots near the leading edge

6. Guidance of flow in a confined passage

7. Providing a rotating cylinder near the leading edge

8. Energizing the flow by introducing optimum amount of swirl in the in coming flow

PROBLEM 1: For the following velocity profiles, determine whether the flow is attached or detached or on the verge of separation:

i. $\quad \dfrac{u}{U} = 2\left(\dfrac{y}{\sigma}\right) - \left(\dfrac{y}{\sigma}\right)^2$
   ii. $\quad \dfrac{u}{U} = 2\left(\dfrac{y}{\sigma}\right)^2 + \left(\dfrac{y}{\sigma}\right)^3 + 2\left(\dfrac{y}{\sigma}\right)^4$

iii. $\quad \dfrac{u}{U} = 2\left(\dfrac{y}{\sigma}\right) - \left(\dfrac{y}{\sigma}\right)^3 + 2\left(\dfrac{y}{\sigma}\right)^4$

Solution

i. $\quad \dfrac{u}{U} = 2\left(\dfrac{y}{\sigma}\right) - \left(\dfrac{y}{\sigma}\right)^2$ or $U = 2U\left(\dfrac{y}{\sigma}\right) - U\left(\dfrac{y}{\sigma}\right)^2$

Differentiating w.r.t.y the above equation, we get

$$\dfrac{du}{dy} = 2U\left(\dfrac{1}{\sigma}\right) - 2U\left(\dfrac{y}{\sigma}\right) \times \dfrac{1}{\sigma}$$

$$At \quad y = 0, \left(\dfrac{du}{dy}\right)_{y=0} = \dfrac{2U}{\sigma}$$

$$As \left(\dfrac{du}{dy}\right)_{y=0} \; is + ve, \; the \; given \; flow \; is \; attached$$

ii. $\dfrac{u}{U} = 2\left(\dfrac{y}{\sigma}\right) + \left(\dfrac{y}{\sigma}\right)^3 + 2\left(\dfrac{y}{\sigma}\right)^4$

or $u = -2U\left(\dfrac{y}{\sigma}\right) + \left(\dfrac{y}{\sigma}\right)^3 + U\left(\dfrac{y}{\sigma}\right)^3 + 2U\left(\dfrac{y}{\sigma}\right)^4$

$\dfrac{du}{dy} = 2U\left(\dfrac{1}{\sigma}\right) - 3U\left(\dfrac{y}{\sigma}\right)^2 \times \dfrac{1}{\sigma} + 8U\left(\dfrac{y}{\sigma}\right)^3 \times \dfrac{1}{\sigma}$

At $y = 0,\ \left(\dfrac{du}{dy}\right)_{y=0} - \dfrac{2U}{\sigma}$

As $\left(\dfrac{du}{dy}\right)_{y=0}$ is $-ve$, the given flow is detached (i.e. the flow has separated)

iii. $\dfrac{u}{U} = \left(\dfrac{y}{\sigma}\right)^2 + \left(\dfrac{y}{\sigma}\right)^3 + 2\left(\dfrac{y}{\sigma}\right)^4$

Or $u = -2U\left(\dfrac{y}{\sigma}\right)^2 + \left(\dfrac{y}{\sigma}\right)^3 - 2U\left(\dfrac{y}{\sigma}\right)^4$

$\therefore \dfrac{du}{dy} = 4U\left(\dfrac{y}{\sigma}\right) \times \dfrac{1}{y} + 3U\left(\dfrac{y}{\sigma}\right) \times \dfrac{1}{\sigma} - 8U\left(\dfrac{y}{\sigma}\right)^3 \times \dfrac{1}{\sigma}$

At $y = 0,\ \left(\dfrac{du}{dy}\right)_{y=0} = 0$

As $\left(\dfrac{du}{dy}\right)_{y=0} = 0$, the given flow is on the verge of separation