ENE 206 – Fluid Mechanics

WEEK 12

- ## Introduction

➢ Various aspects of the flow over bodies, which are immersed in an unbounded viscous fluid, are discussed. These flows are often referred to as external flows. These flows are viscous near the body surface and nearly inviscid far from the body.

➢ External flows are usually encountered in many branches of engineering. In aerodynamics, external flows that are produced when object such as airplanes or missiles move through the atmosphere are extremely important

- ## Boundary layer concept

➢ Many viscous flows can be analyzed by dividing the flow field into two regions: one close to the solid boundaries, the other covering the rest of the flow field. Only in the thin region adjacent to the solid boundary, which is referred to as **the boundary layer**, the viscous effects are important and the viscous forces are much more significant than the inertial forces.

➢ The velocity of the fluid at the wall relative to the solid boundary is zero and increases towards the main stream. Shear stresses in this zone are very high owing to the existence of extremely high velocity gradients at and near the solid boundaries and the governing equations of motion are the Navier-Stokes equations.

➢ In the region outside the boundary layer, the influence of viscosity is negligible, so that the inertial forces dominate the viscous ones. Therefore, the flow in this region can be considered inviscid and the potential flow theory can be used for analyzing the flow. The governing equations of motion in this zone are the Euler's equations.

- ## Development of the flow in the pipe

As soon as the fluid comes in contact with the leading edge of the plate, its velocity reduces to zero and the fluid particles adhere to the plate boundary to satisfy the no-slip condition. The velocity of the fluid increases rapidly from zero at the plate boundary to the free stream velocity within a very short distance, causing extremely high velocity gradient to develop in the boundary layer. Therefore, even if the viscosity of the fluid is very small, as in the case of air and water, extremely high velocity gradients generate excessively high shear stresses. As the fluid passes over the flat plate, the action of the shear forces retards more and more fluid in the lateral direction. Therefore, the thickness of the boundary layer increases in downstream direction.

The turbulent flow within the boundary layer is characterized by strong mixing of fluid particles in a direction normal to the solid boundary, which results in momentum exchange between the fluid particles. The presence of turbulence within the boundary layer not only modifies the velocity distribution, but also increases the rapidity with which the boundary layer expands in the vertical direction.

- **The boundary layer thickness:** is usually defined as the distance from the solid boundary where the velocity in the *x*-direction differ by 1 percent from the main stream velocity, *U*, as shown in Figure 9.1. It is a region where the flow develops. At the end of the entrance region the flow is no longer function of the flow direction and the radius of the pipe determines the velocity profile. Its length also affected by the nature of the flow. At the entrance region the fluid accelerates or decelerates.

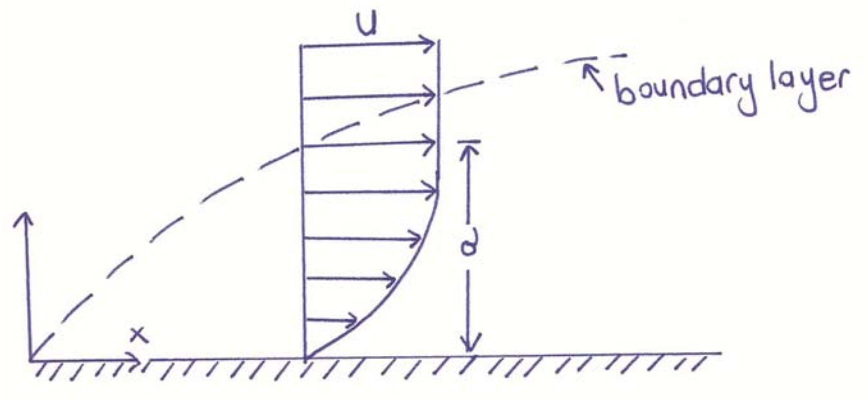

Figure 9.1. The boundary layer thickness

- **The boundary layer displacement thickness:** It can be defined as the distance by which the solid boundary layer would have to be displaced to maintain the same mass flow rate in an imaginary frictionless flow (see Figure 9.2).

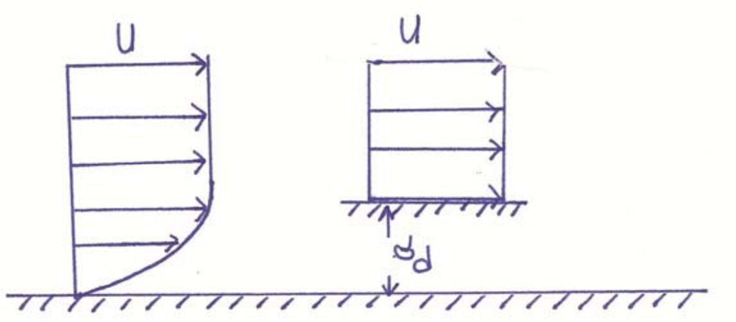

Figure 9.2. Boundary layer displacement thickness

- **The boundary layer momentum thickness:** It can be defined as the distance by which the solid boundary would have to be displaced to maintain the same momentum transport rate at the actual mass flow rate in an imaginary frictionless flow. The momentum thickness concept is illustrated in Figure 9.3.

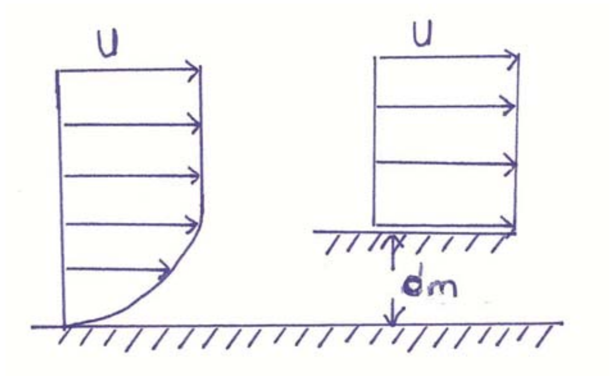

Figure 9.3. Boundary layer momentum thickness

- **The boundary layer energy thickness:** It can be defined as the distance by which the solid boundary would have to be displaced to maintain the same energy transport rate at the actual mass flow rate in an imaginary frictionless flow. The energy thickness concept is illustrated in Figure 9.3.

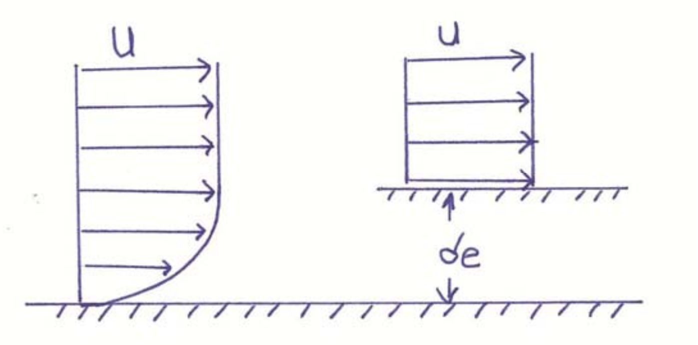

Figure 9.4. Boundary layer energy thickness

- ## Drag and lift forces

- **Drag force**: When an arbitrary shaped body is immersed in a fluid stream, it will experience forces and moments from the flow about the mutually perpendicular axes. The force exerted on the body along the axis parallel to the flow is called the drag force, while the moment about the axis is known as the rolling moment. The non-dimensional drag force can be interpreted in terms of the drag coefficient as follows:

$$C_D = \frac{D}{0.5\rho U^2{}_\alpha A} \quad (9.1)$$

where D is the drag force, ρ is the fluid density, $U\alpha$ is the free stream velocity, A is the projected area of the object.

- **Lift force**: Another important force is the lift force which is perpendicular to the drag force. The moment about the axis in the direction of lift force is known as the yawing moment. The non-dimensional lift force can be interpreted in terms of the lift coefficient as follows:

$$C_L = \frac{L}{0.5\rho U^2{}_{\alpha} A} \tag{9.2}$$

- **Side force**: The third component of the force is the side force and it is neither a loss nor a gain. The moment about this axis is the pitching moment.

- ## References

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