Chapter 2 - Fundamental Concepts

Lecture 11
Section 2.6

Introduction to Fluid Mechanics

Mechanical Engineering and Materials Science
University of Pittsburgh

Learning Objectives

2.6 Description and Classification of Fluid Motion

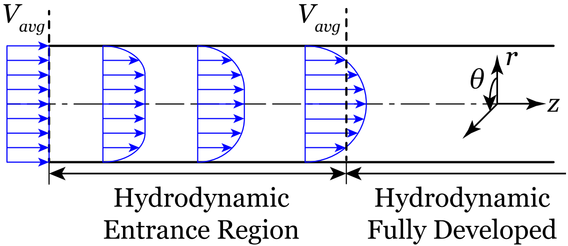
Student Learning Objectives

Students should be able to:

- Formulate an expression for the Reynolds number and understand it's relevance in relation to laminar and turbulent flows
- Understand how the Reynolds number provides insight into the average velocity profile

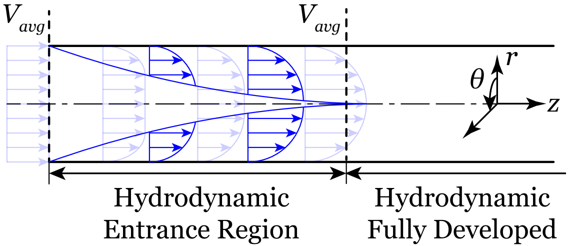
No-Slip Boundary Condition

- The no-slip boundary condition is responsible for the development of a velocity profile for both internal and external flows.
- The flow region directly adjacent to the solid wall in which the viscous effects dominate the flow is referred to as the ***boundary layer***.



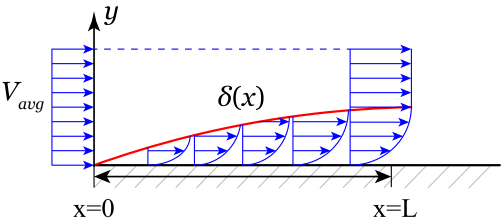
Internal Flow Boundary Layer

- As the fluid enters the pipe, the fluid in contact with the wall stops, and the fluid layer adjacent slows down, changing the velocity profile as the flow moves down the pipe:



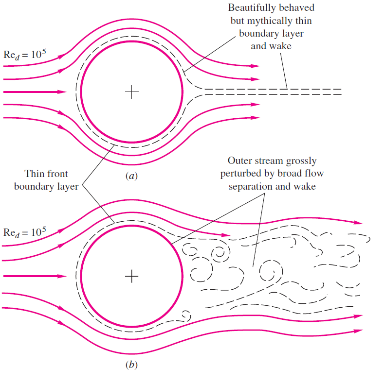
External Flow Boundary Layer

- As a fluid with a free-stream velocity U approaches an external surface, the fluid in contact with said surface stops, and fluid layer adjacent slows down, changing the velocity profile as the flow moves over the surface:



External Flow Boundary Layer

- Depending upon the viscosity and velocity of the fluid, a phenomena of flow separation can happen for external flows.
- Flow separation is when the boundary layer is no longer attached to the surface.

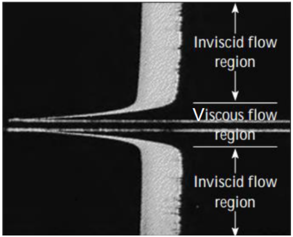


Viscous Flow

- Viscous flow takes into account the viscosity of a fluid, i.e. where the frictional effects are significant.
- Viscosity dictates the behavior of the fluid and the response of the object immersed within the fluid, i.e. how a golf ball spins or how an airfoil generates lift.

Inviscid Flow

- Inviscid flow does not take into account the viscosity of the fluid (μ=0), i.e. when analyzing regions far from a surface.
- The viscous forces in inviscid flow are assumed negligible or small in comparison the inertial forces.



Laminar vs. Turbulent Flow

- There are three classifications of flow based upon motion

1. <u>Laminar flow</u> - fluid particles move in smooth layers, *laminas*

Laminar vs. Turbulent Flow

2. Transitional flow - a flow in between laminar and turbulent

Laminar vs. Turbulent Flow

3. Turbulent flow - fluid particles move chaotically due to fluctuations

Flow Visualization

- Flow can be visualized through experiment, using lasers to illuminate particles suspended in the field, using colored smoke or computation

Reynolds Number

- To quantify if a flow is laminar or turbulent, we use the Reynolds number, Re:

$$Re = \frac{\rho V D_h}{\mu} = \frac{\rho U_\infty x}{\mu}$$

- V and U_∞ are the velocities for internal and external flow, respectively, [m/s].
- ρ is the density of the fluid, [kg/m^3]
- x is the characteristic length along a plate, [m]
- μ is the dynamic viscosity, [Pa-s]=[kg/m-s]
- D_h is the hydraulic diameter of the pipe/duct, [m]:

$$D_h = \frac{4A}{P}$$

Reynolds Number - Internal Flows

- For internal flows, we have three classifications of flow scenarios and they can be classified based upon Re:

$$\begin{aligned} Re \leq 2,300 & \quad \text{Laminar} \\ 2,300 < Re < 4,000 & \quad \text{Transition} \\ Re > 4,000 & \quad \text{Turbulent} \end{aligned}$$

- For external flows over a flat plate, we have only one point of demarcation for Re:

$$Re_x > 5 \cdot 10^5 \quad \text{Turbulent}$$

Reynolds Number - Viscous vs. Inviscid

- Re characterizes the flow (laminar or turbulent), but also gives an impression on the how the viscosity and density contribute to flow conditions:
- $Re \gg 1$, viscous effects often times can be ignored
- If Re is very large, we can often assume the flow is inviscid, i.e. μ=0
- $Re \ll 1$, viscous effects dictate flow behavior