ME 321: FLUID MECHANICS-I

Dr. A.B.M. Toufique Hasan
Professor
Department of Mechanical Engineering
Bangladesh University of Engineering and Technology (BUET), Dhaka

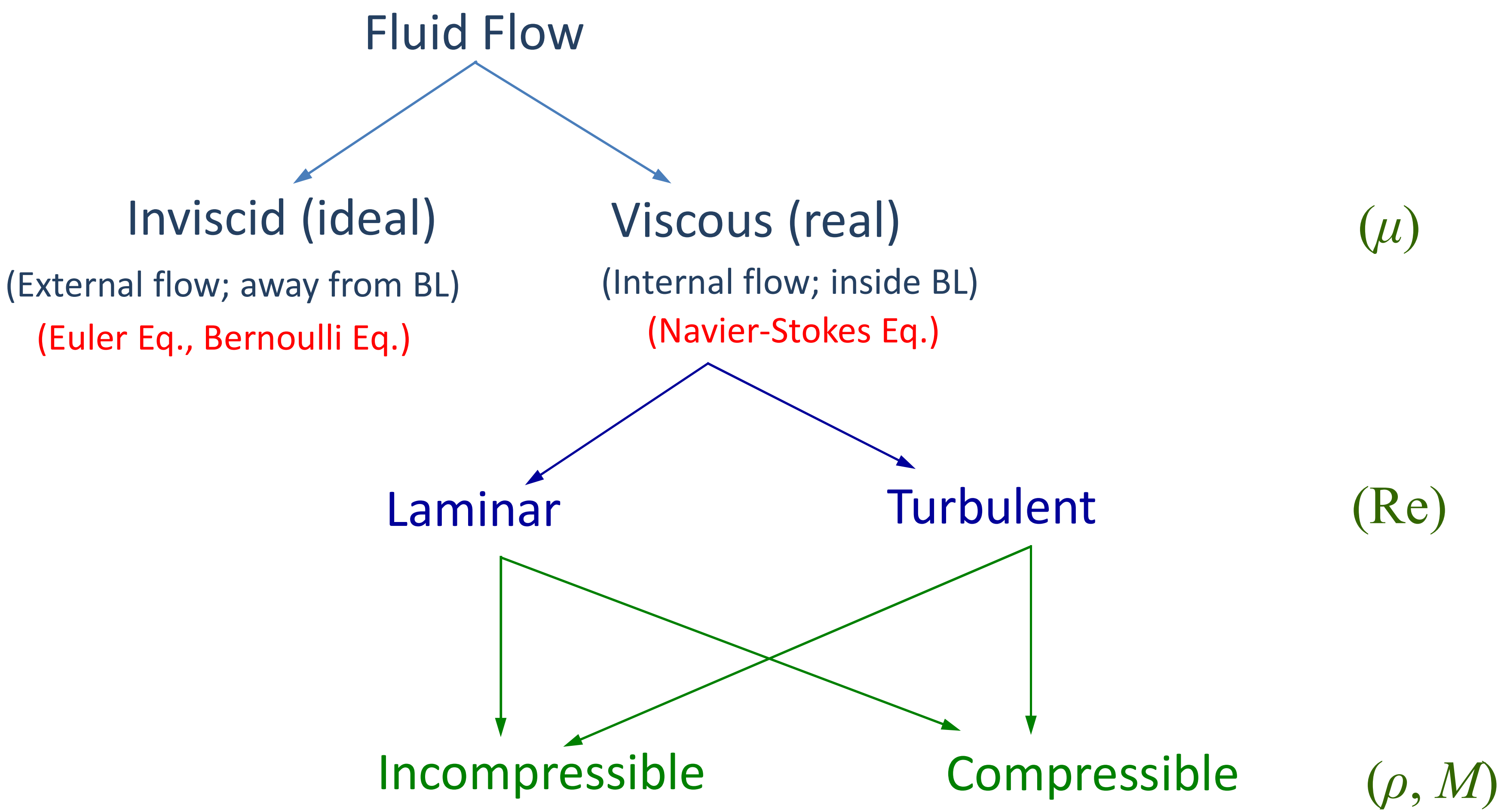
Lecture - 03

06/12/2023

Fluid dynamics

toufiquehasan.buet.ac.bd
toufiquehasan@me.buet.ac.bd

Analysis of flow of fluids can be performed in many ways. A simple example of continuum fluid flow classification is shown below:



(BL = Boundary layer (ME 323))

Laminar and Turbulent Flows

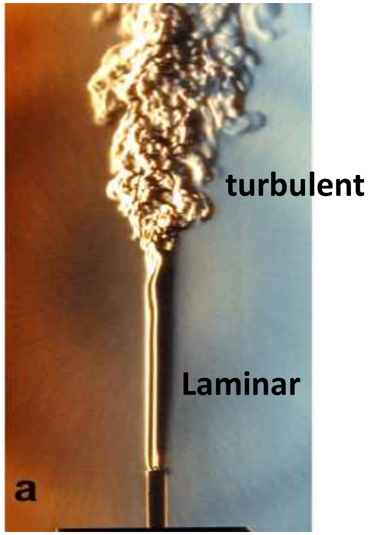
Laminar flow occurs when a fluid flows in parallel layers and slide past one another. This flow is very regular, well-behaved and smooth. There will be no lateral mixing and interaction between the layers. In classical scale, laminar flow occurs at low speed.

Turbulent flow is a fluid motion with particle trajectories varying randomly in time, in which irregular fluctuations of various flow properties arise.

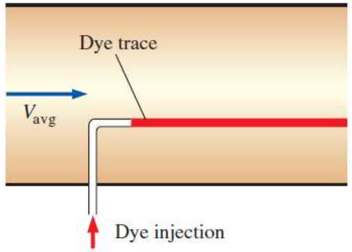
Due to conditions imposed by the geometry and flow field, such as

- surface topography
- surface roughness
- pressure gradient
- surface mass injection (or suction)
- surface temperature and so on,

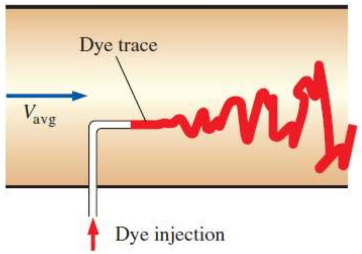
the interaction of the fluid particles increases and takes place at the macroscopic level; the **streamlines of the flow field are no longer well-behaved rather chaotic**. This type of flow is known as **turbulent flow**.



Candle plume

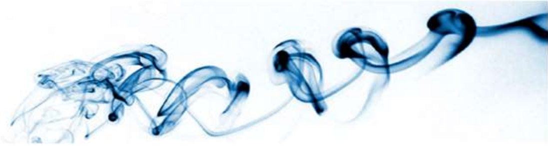


(a) Laminar flow



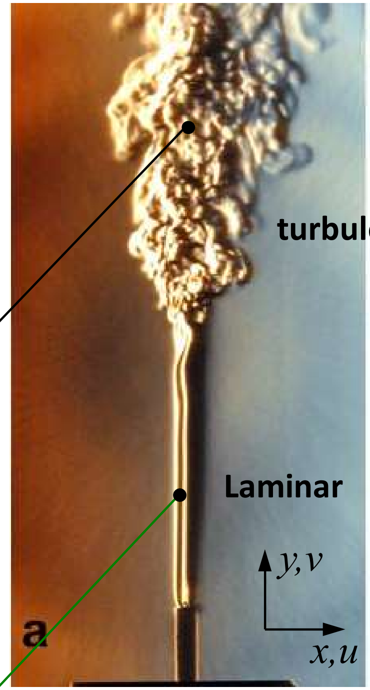
(b) Turbulent flow

Laminar and Turbulent Flows



The fundamental difference between laminar and **turbulent flow** lies in the **chaotic, random behavior of the various flow properties**. Such variations might occur in the three components of velocity (u, v, w), the pressure, the shear stress, the temperature, and any other variable that has a field description (such as density).

A typical time trace of the axial component of velocity (v) measured at a location in the flow is shown in the figure. **Its irregular, random nature is the distinguishing feature of turbulent flow.**



Candle plume

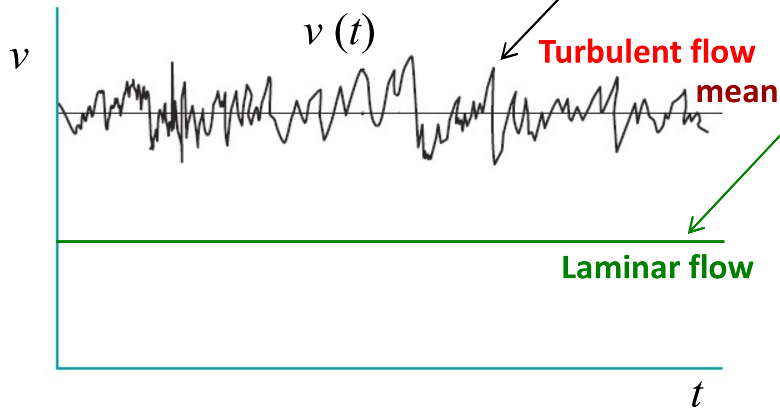


Fig. time trace of *v*-velocity component, *v* = *v*(*t*) in flow

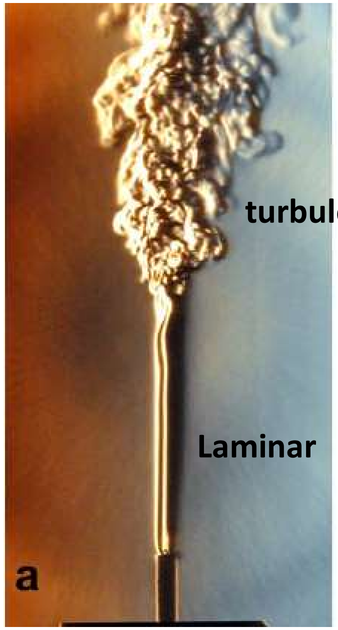
Laminar and Turbulent Flows

Shear stress in fluid flow (for **1-D flow**):

$$\text{Laminar}: \quad \tau_{\text{lam}} = \mu \frac{\partial u}{\partial y} \qquad ; \frac{\partial u}{\partial y} = \text{velocity gradient (1-D)}$$

$$\text{Turbulent}: \quad \tau_{\text{tur}} = (\mu + \mu_t) \frac{\partial u}{\partial y}$$

where μ is the **molecular viscosity of fluid** and μ_t is the turbulent (eddy) **viscosity of flow**.



Candle plume

The nature of the flow (laminar/turbulent) can be characterized based of one dimensionless number called the "**Reynolds number, Re**".

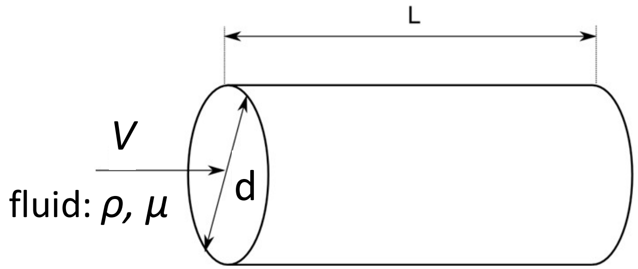
As general criteria:

For flow through smooth pipe in ideal uniform conditions:

$Re_d < 2300$; flow is laminar

$Re_d > 4000$; flow is turbulent

; Re_d = Reynolds number based on pipe diameter $\quad Re_d = \dfrac{\rho V d}{\mu}$



Laminar and Turbulent Flows

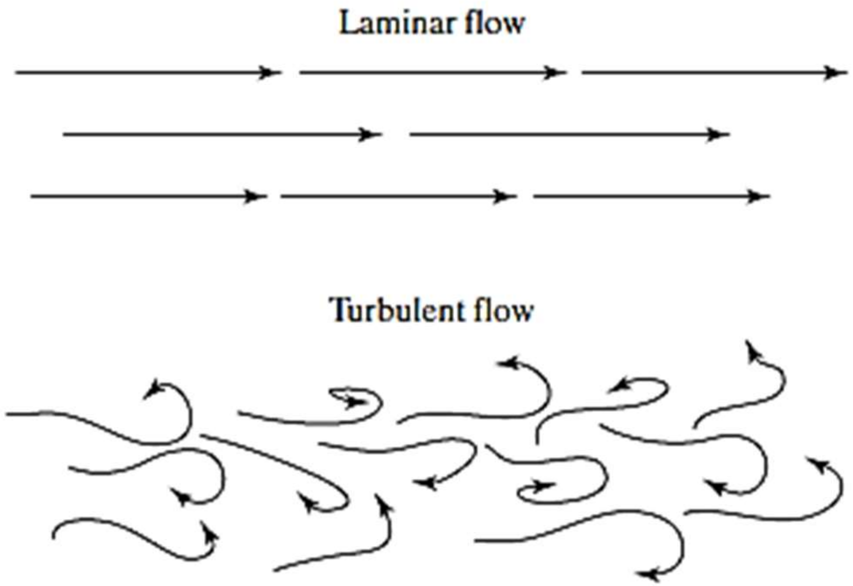


Figure 1.1. Schematic description of laminar and turbulent flows having the same average velocity.

Attached & separated flows

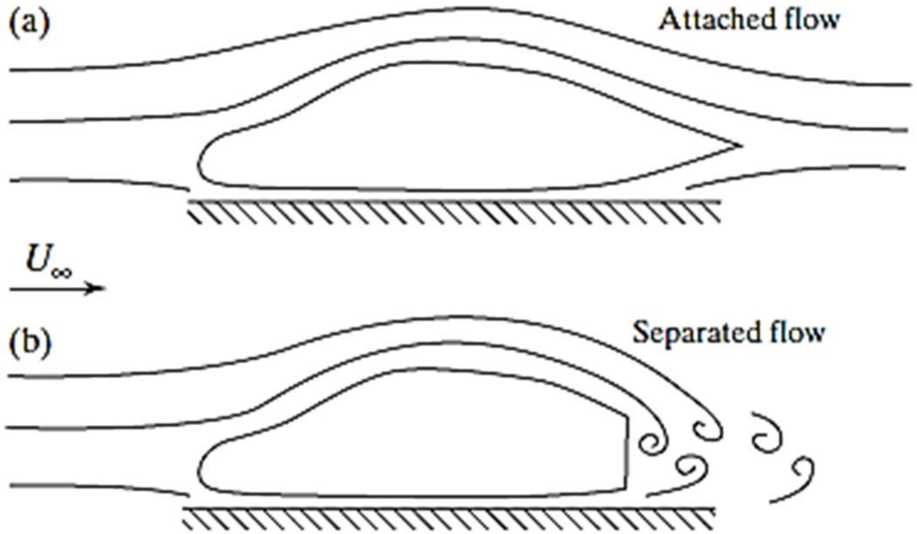
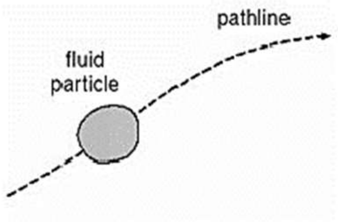


Figure 1.2. (a) Attached flow over a streamlined car and (b) the locally separated flow behind a more realistic automobile shape.

Eulerian and Lagrangian flow description

Lagrangian (follow the particle)

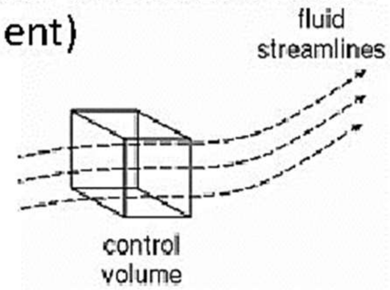
- A flow field can be thought of as being comprised of many "fluid particles". Mathematical laws can be derived for each fluid particle



Particle description

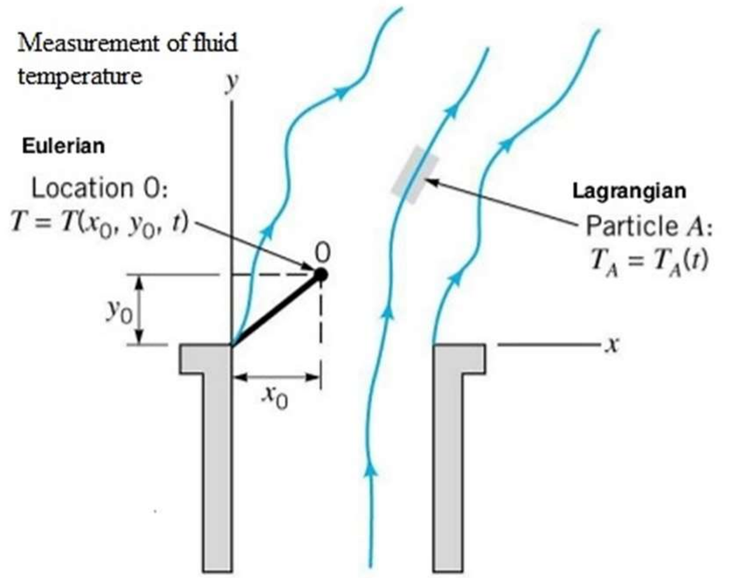
Eulerian (fixed location)

- A flow field can be thought of in terms of how flow properties change at a fixed point in space and time (i.e. in a control volume or fluid element)



Field description

(velocity field, pressure field, etc.)



Eulerian approach is more convenient for analysis in elementary fluid dynamics.

One-, Two-, and Three-Dimensional Flows

Generally, a fluid flow is a rather complex three-dimensional, time dependent phenomena-

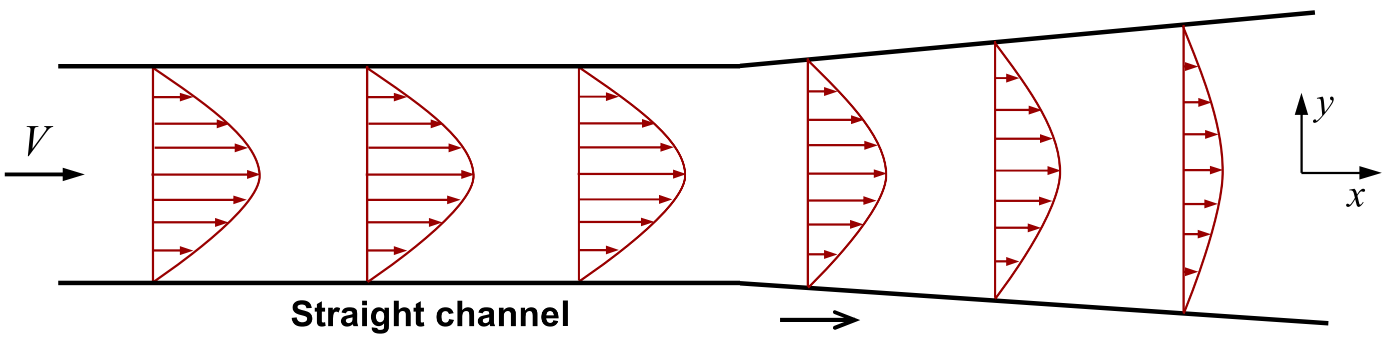
$$\vec{\mathbf{V}} = V(x, y, z, t)$$

In many situations, however, it is possible to make simplifying assumptions that allow a much easier understanding/analysis of the problem.

1-D flow: $\boldsymbol{V} = V(x)$

2-D flow: $\boldsymbol{V} = V(x, y)$

3-D flow: $\boldsymbol{V} = V(x, y, z)$

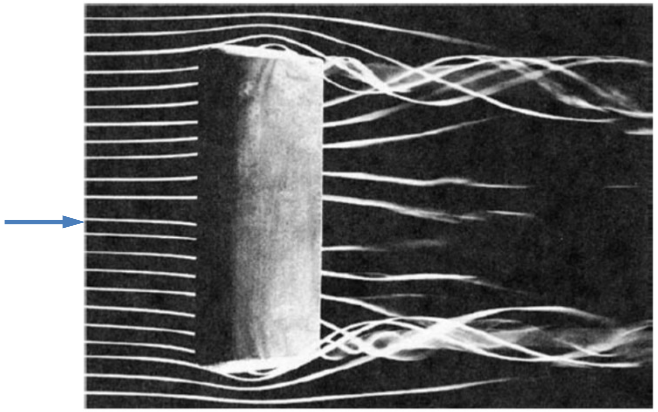


Straight channel

$$V = V(y)$$
$$V \neq V(x)$$

Diverging channel

$$V = V(x, y)$$



Complex 3-D flow over a model wing