FLUID MECHANICS FOR MECHANICAL ENGINEERING (ME 208F)

Section A:
Fluid Kinematics - I

- Introduce concepts necessary to analyze fluids in motion Fluid Kinematics.
- Identify differences between
  - Steady/unsteady
  - uniform/non-uniform
  - compressible/incompressible flow.
- Demonstrate streamlines and stream tubes.
- Introduce laminar and turbulent flow.
- Introduce the Continuity principle through conservation of mass and control volumes

- Fluid Kinematics is a branch of ‘Fluid mechanics ‘ which deals with the study of velocity and acceleration of fluid particles in motion and their distribution in space without necessarily considering the forces and moments which create the motion.
- Fluid motions manifest themselves in many different ways. Some can be described very easily, while others require a thorough understanding of physical laws.
- In engineering applications, it is important to describe the fluid motions as simply as can be justified. It is the engineer's responsibility to know which simplifying assumptions (e.g., one-dimensional, steady-state, inviscid, incompressible, etc) can be made.

1) Uniform flow; steady flow

If we look at a fluid flowing under normal circumstances - a river for example - the conditions (e.g. velocity, pressure) at one point will vary from those at another point, then we have non-uniform flow. If the conditions at one point vary as time passes, then we have unsteady flow.

- Under some circumstances the flow will not be as changeable as this. The following terms describe the states which are used to classify fluid flow:
- Uniform flow: If the flow velocity is the same magnitude and direction at every point in the flow it is said to be uniform. That is, the flow conditions DO NOT change with position.

$$\longrightarrow \quad \frac{\partial V}{\partial x} = 0$$

- Non-uniform: If at a given instant, the velocity is not the same at every point the flow is non-uniform.

1) Uniform flow; steady flow

- Steady: A steady flow is one in which the conditions (velocity, pressure and cross-section) may differ from point to point but DO NOT change with time.

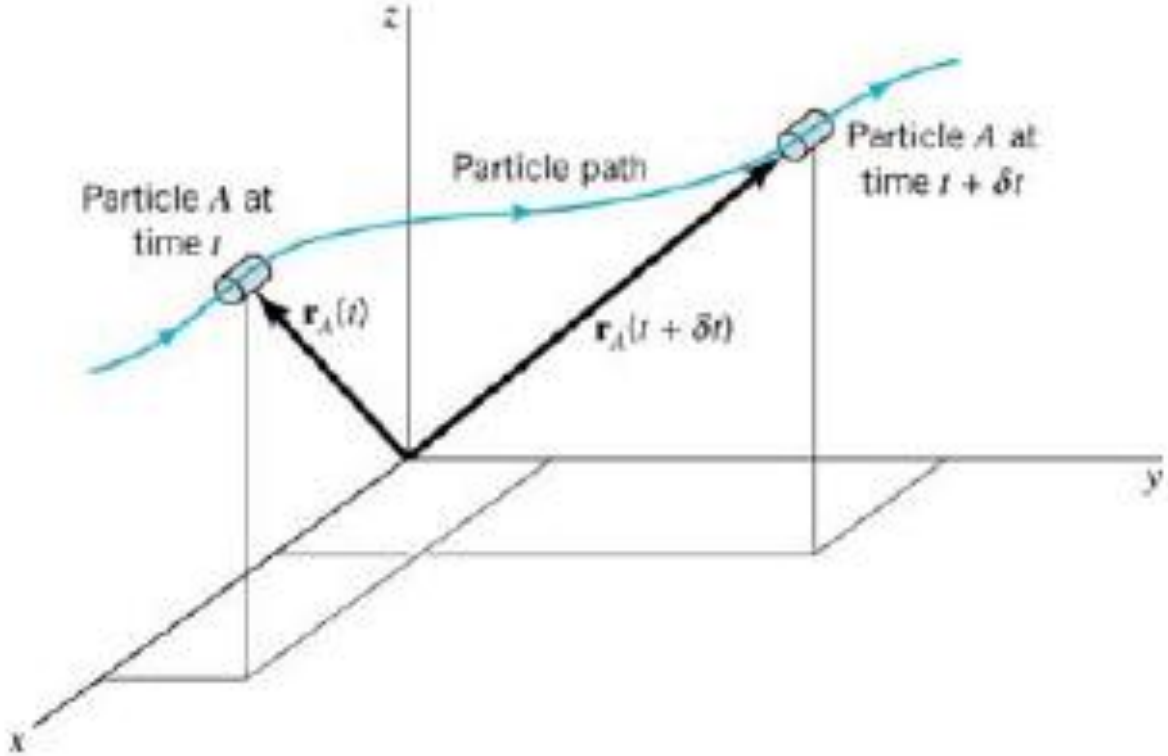
$$\longrightarrow \quad \frac{\partial V}{\partial t} = 0$$

- Unsteady: If at any point in the fluid, the conditions change with time, the flow is described as unsteady.

- Combining the above we can classify any flow in to one of four types:
- **Steady uniform flow**. Conditions do not change with position in the stream or with time. An example is the flow of water in a pipe of constant diameter at constant velocity.
- **Steady non-uniform flow**. Conditions change from point to point in the stream but do not change with time. An example is flow in a tapering pipe with constant velocity at the inlet - velocity will change as you move along the length of the pipe toward the exit.
- **Unsteady uniform flow**. At a given instant in time the conditions at every point are the same, but will change with time. An example is a pipe of constant diameter connected to a pump pumping at a constant rate which is then switched off.
- **Unsteady non-uniform flow**. Every condition of the flow may change from point to point and with time at every point. An example is surface waves in an open channel.
- You may imagine that one class is more complex than another – *steady uniform* flow is by far the most simple of the four.

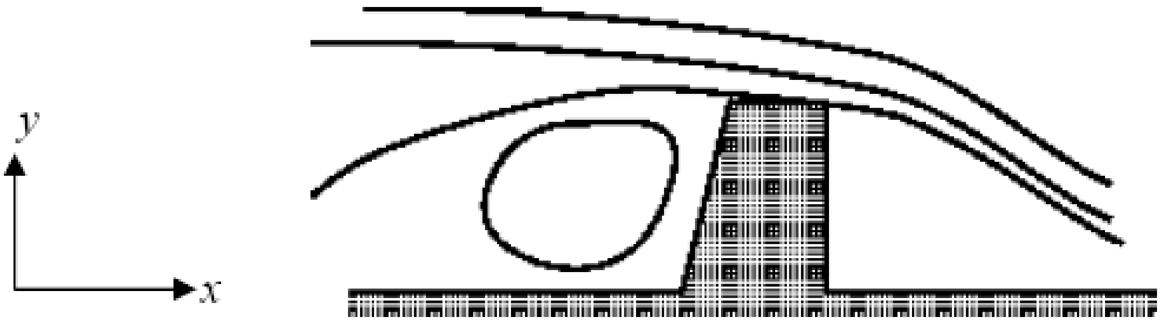
2) One-, two-, and three-dimensional flows

A fluid flow is in general a three-dimensional, spatial and time dependent phenomenon:-



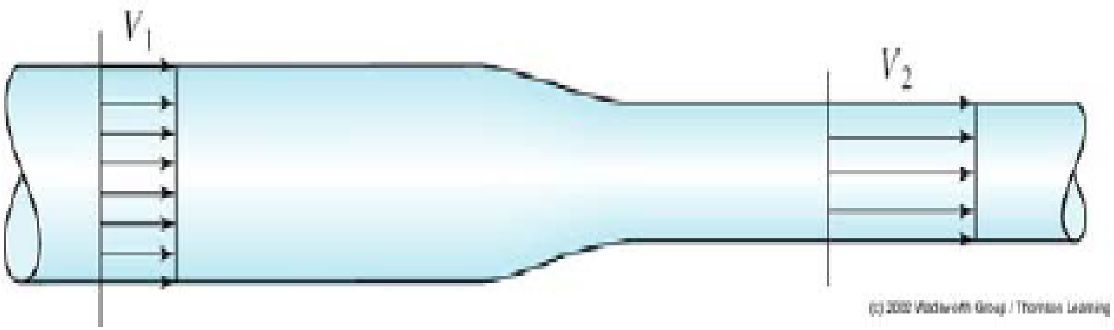
$$V = V(\vec{r}, t) = u(\vec{r}, t)\vec{i} + v(\vec{r}, t)\vec{j} + w(\vec{r}, t)\vec{k}$$

- Accordingly, a fluid flow is called three-dimensional if all three velocity components are equally important. Intrinsically, a three-dimensional flow problem will have the most **complex characters** and is the most **difficult to solve**.
- Fortunately, in many engineering applications, the flow can be considered as **two-dimensional**. In such a situation, one of the velocity components (say, w) is either identically zero or much smaller than the other two components
- Examples of two-dimensional flow typically involve flow past a long structure (with the axis of structure being perpendicular to the flow):



Two-dimensional flow over a long weir.

- Typical examples are fully-developed flows in long uniform pipes and open-channels. One-dimensional flow problems will require only elementary analysis, and can be solved analytically in most cases.

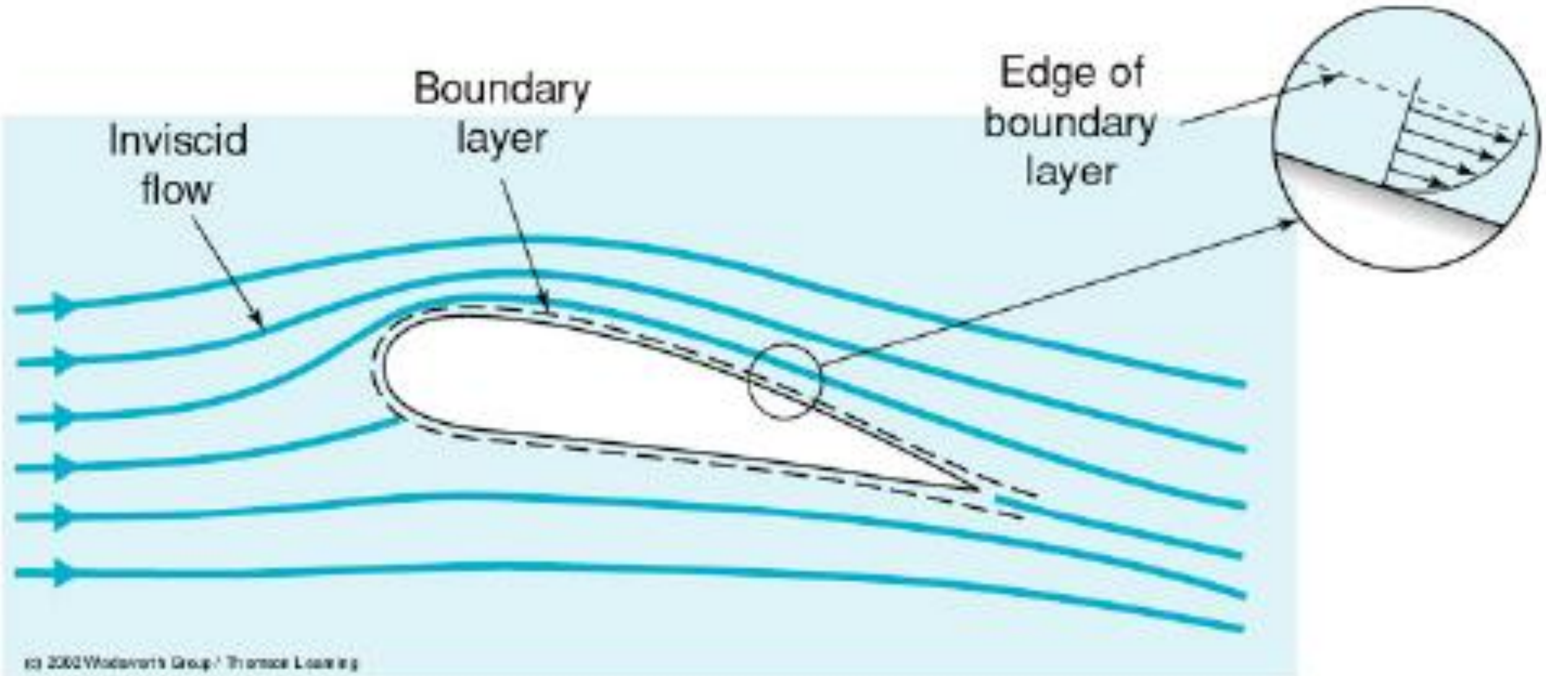


One-dimensional **ideal** flow along a pipe, where the velocity is uniform across the pipe section.

3) Viscous and inviscid flows

- An **inviscid flow** is one in which viscous effects do not significantly influence the flow and are thus neglected. In a **viscous flow** the effects of viscosity are important and cannot be ignored.
- It is more difficult to create an inviscid flow experimentally, because all fluids of interest (such as water and air) have viscosity.
- The question then becomes: are there flows of interest in which the viscous effects are negligibly small?
- The answer is "yes, if the shear stresses in the flow are small and act over such small areas that they do not significantly affect the flow field." .
- Inviscid flows are of primary importance in flows around streamlined bodies,

3) Viscous and inviscid flows



External flow around an airfoil.

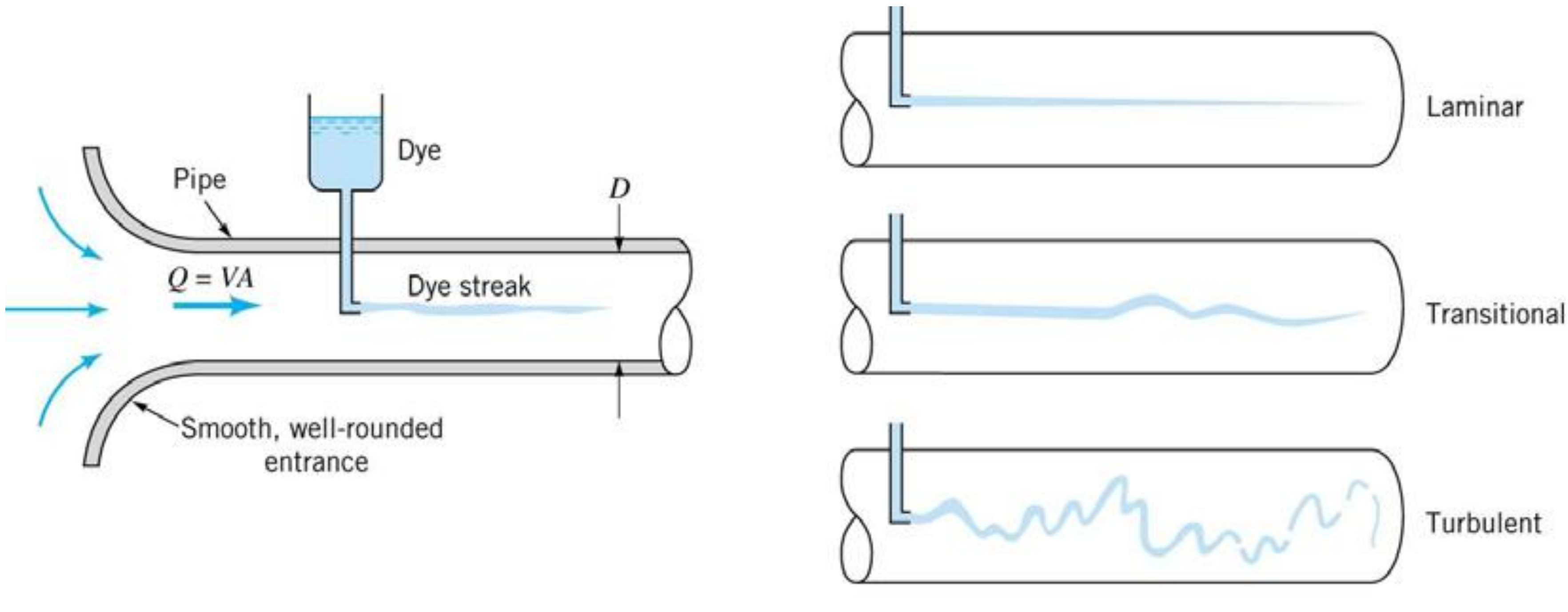
4) Incompressible and compressible flows

- All fluids are compressible - even water - their density will change as pressure changes. Under steady conditions, and provided that the changes in pressure are small, it is usually possible to simplify analysis of the flow by assuming it is incompressible and has constant density.
- *incompressible flow* is defined as one in which the density of each fluid particle remains relatively constant as it moves through the flow field.
- The Mach number is defined as:

$$M = \frac{V}{c}$$

- where V is the gas speed and c is the speed of sound.
- If $M < 0.3$, density variations are at most 3% and the flow is assumed to be incompressible; for standard air this corresponds to a velocity below about 100 m/s.
- If $M > 0.3$, the density variations influence the flow and compressibility effects should be accounted for.

5) Laminar and turbulent flows



(a) (b)

5) Laminar and turbulent flows

- Viscous or Laminar: in which the fluid particles appear to move in definite smooth parallel path with no mixing, and the velocity only in the direction of flow.

Example. (*i*) *Flow through a capillary tube.*
(*ii*) *Flow of blood in veins and arteries.*
(*iii*) *Ground water flow.*

- Transitional: in which some unsteadiness becomes apparent (the wavy filament).
- Turbulent: in which the flow incorporates an eddying or mixing action. The motion of a fluid particle within a turbulent flow is complex and irregular, involving fluctuations in velocity and directions. mixing is very significant in turbulent flow, in which fluid particles move haphazardly in all directions

Example. *High velocity flow in a conduit of large size. Nearly all fluid flow problems encountered in engineering practice have a turbulent character.*

5) Laminar and turbulent flows

Whether the flow is laminar or not depends on the Reynolds number,

$$\mathrm{Re} \equiv \frac{\rho \bar{V} d}{\mu} \quad \rho = density,\ \ \mu = \text{viscosity},\ \ \bar{V} = \text{section-mean velocity},\ \ d = \text{diameter of pipe}$$

and it has been demonstrated experimentally that

$$\mathrm{Re}\begin{cases} < 2,000 & \text{laminar flow} \\ \text{between } 2{,}000 \text{ and } 4{,}000 & \text{transitional flow} \\ > 4,000 & \text{turbulent flow} \end{cases}$$

- ***It can be interpreted that:***
- When the inertial forces dominate over the viscous forces (when the fluid is flowing faster and Re is larger) then theflow is turbulent.
- When the viscous forces are dominant (slow flow, low Re) they are sufficient enough to keep all the fluid particles in line, then the flow is laminar

5) Laminar and turbulent flows

EXAMPLE:

Oil of viscosity 0.05 kg/m.s and density 860 kg/m3 flows in a 0.1 m diameter pipe with a velocity of 0.6 m/s. Determine the type of flows.

- Solution:

$$\mathrm{Re} = \frac{\rho V D}{\mu} = \frac{860 \times 0.6 \times 0.1}{0.05} = 1032$$

$$\mathrm{Re} = 1032 < 2000 \quad \therefore \quad \text{laminar flow}$$

2) Streakline

- A streakline is an instantaneous line whose points are occupied by particles which have earlier passed through a prescribed point in space. A streakline is hence an integrated pattern.
- A streakline can be formed by injecting dye continuously into the fluid at a fixed point in space. As time marches on, the streakline gets longer and longer, and represents an integrated history of the dye streak.