Chapter 1 - Introduction and Basic Concepts

Lecture 1

Sections 1.2, 1.3, 1.5 and 2.1

MEMS 0071 - Introduction to Fluid Mechanics

Mechanical Engineering and Materials Science
University of Pittsburgh

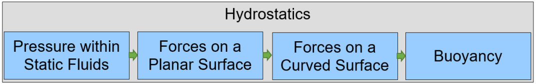
Student Learning Objectives

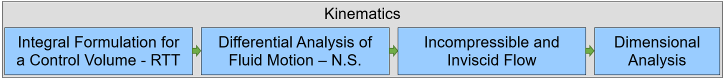
Students should be able to determine:

- What constitutes a fluid
- No-slip boundary condition
- The Continuum Assumption
- Application of control surfaces and control volumes (open and closed)

Introduction

- **Fluid mechanics** is the study of fluids at rest (fluid statics) or in motion (fluid mechanics), often referred to as fluid dynamics.
- This course will be broken down into 3 distinct sections
  1. Hydrostatics
  2. Kinematics expressed by RTT
  3. Kinematics expressed by N-S





What is a Fluid?

- A fluid is a substance that exists as a gas or liquid.
- A fluid does not resist the application of a shear stress, unlike a solid.
- A fluid deforms continuously when a shear stress is applied, no matter how small

How do Fluids Move?

- The stress generated within the fluid is proportional to the strain rate - the change in deformation of a material with respect to time.
- The top layer of fluid in contact with the plate will move with the plate velocity - **no slip boundary condition**.
- The layer of fluid directly below the layer in contact with the top plate will move with a little less velocity due to the presence of friction.
- The bottom layer of fluid in contact with the plate will have zero velocity - **no slip boundary condition**.

No-Slip Boundary Condition

- The no-slip boundary condition has important implications - fluid in contact with a solid surface has zero velocity, that is, the fluid comes into contact and adheres to the surface due to viscous effects.
- The **viscosity** of a fluid, μ, is the quantification of magnitude of internal friction, or resistance to flow - this is quantified as a rheological property
- Viscosity has units of Pa·s.

The Continuum Assumption

- Fluids are made up of individual molecules, where the mass is not continuously distributed in space.
- How would we define the density of a fluid, ρ?
- Would we need to know the position of each fluid molecule in space?
- What is the minimum volume $\delta\forall'$ we need to have such that fluid behaves as a continuous media and not a group of individual molecules, i.e. a *macroscopic* view?

The Continuum Assumption

- Say we define density as:

$$\rho = \frac{\delta m}{\delta \forall}$$

- Then we can say:

$$\rho \equiv \lim_{\delta \forall \to \delta \forall'} \frac{\delta m}{\delta \forall}$$

- $\delta \forall'$ is based upon the mean free path of the fluid of interest - average distance a particle travels before colliding with another particle or the walls of the system.
- That is, every property is *continuous* at any point we select such that:

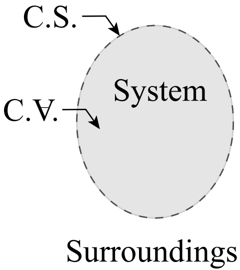
$$\rho = \rho(x, y, z, t)$$

The Continuum Assumption

- The **continuum assumption** allows us to treat the average properties of a fluid as something that is continuous through the whole fluid.
- Note, the continuum assumption fails when the mean free path is the same order of magnitude of the characteristic length.
- This assumption fails in things such as heat transfer in thin-films, upper-atmosphere flight, high-pressure gases, micro-fluid applications.

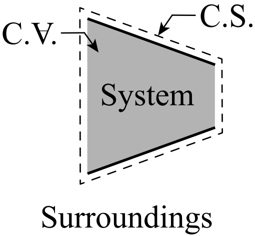
Control Volume Formulation

- A **control surface** (C.S.) is a boundary that surrounds our system of interest - a system is quantity of matter or region of space chosen for study.
- All matter inside the C.S. is part of the system of interest, i.e. the **control volume** (C.$\forall$.) - everything outside the C.S. is considered the surroundings.



Control Volume Formulation

- The C.∀. can either be *closed* or *open*. Consider a nozzle:



- An open C.∀. allows mass to cross the C.S.
- A closed C.∀., also known as a **control mass** (C.M), does not allow mass to cross the C.S.
- If not work or heat crosses the C.S. of a C.M., it is referred to as an *isolated system*.

Student Learning Objectives - Completed

Students should have determined:

- What constitutes a fluid
  - a gas or liquid that does not resist shear
- No-slip boundary condition
  - a fluid in contact with a wall has the velocity of said wall
- The Continuum Assumption
  - the fluid is homogeneous at any point
- Application of control surfaces and control volumes (open and closed)