ME 321: FLUID MECHANICS-I

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Lecture-01

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Introduction: Fluid dynamics

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Fluid Dynamics

Fluid dynamics is the science dealing with the motion of fluids. **Fluids**, unlike solids, cannot assume a fixed shape under load and **will immediately deform** (liquid and gas).

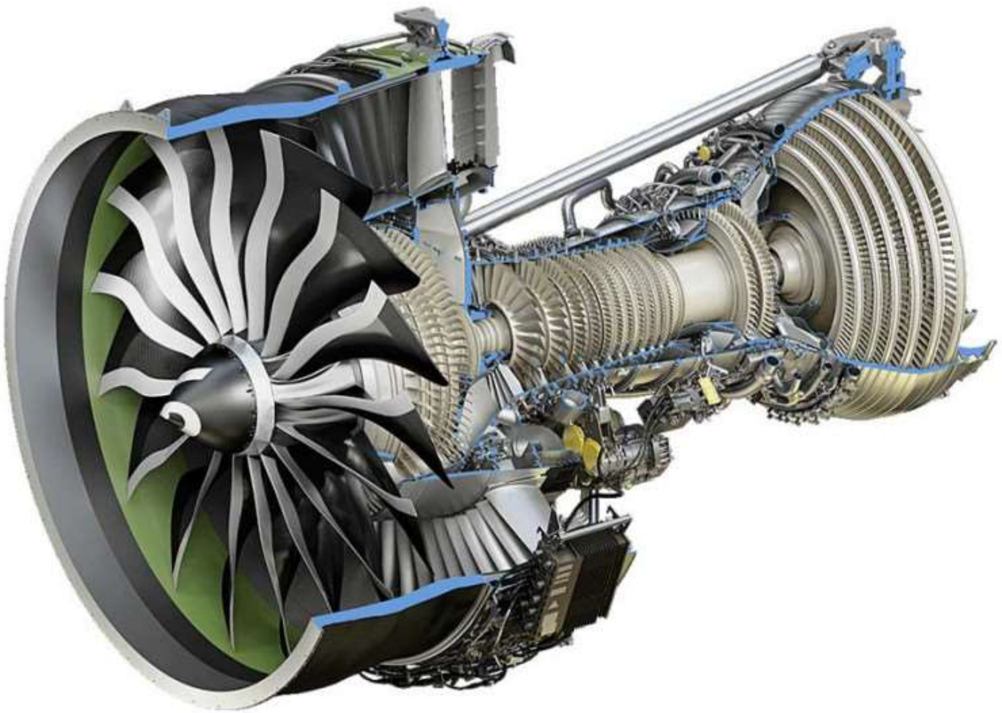
Fluid dynamics can be studied by *focusing on a particle* or *focusing at a point in fluid* to understand the nature of flow. It covers a vast array of phenomena that occur in nature, modern engineering inventions, biology, life sciences, and so on.

Hurricane
(2023: Midhili, Hamoon)

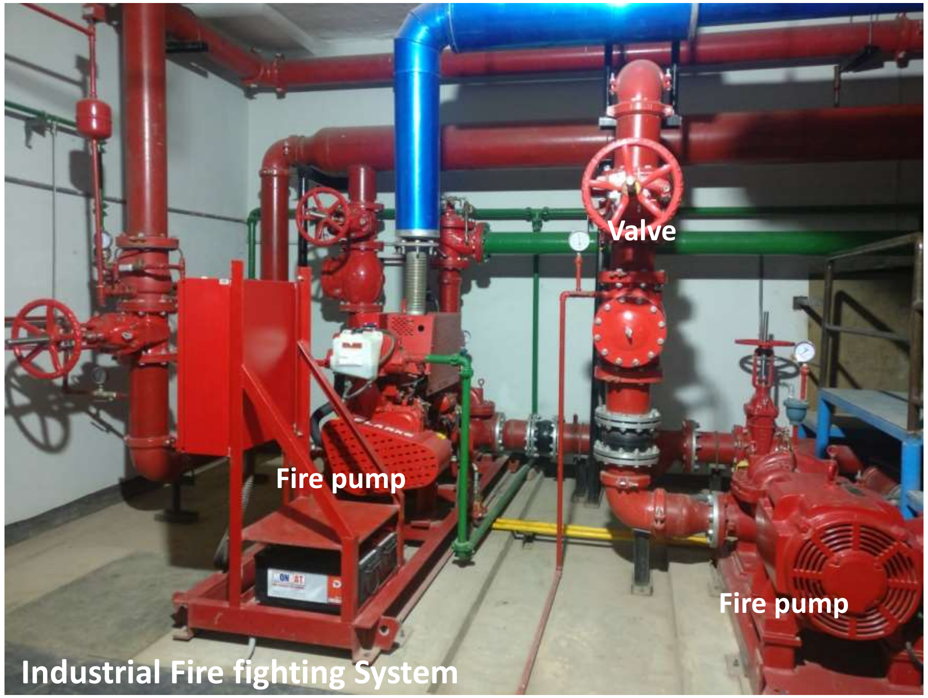
Tornado

Geophysical (atmospheric) fluid dynamics

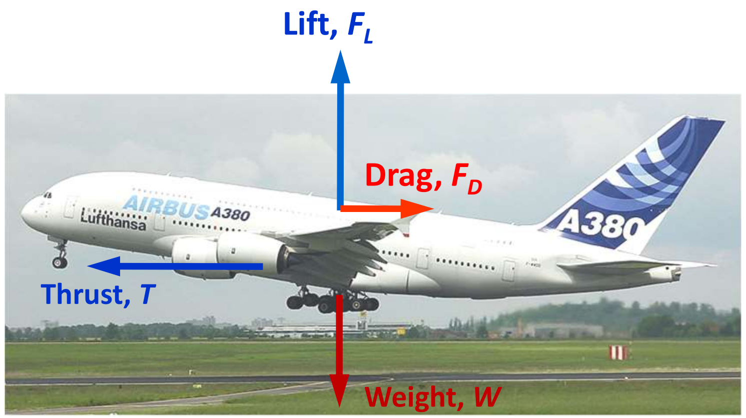
Fluid Dynamics



GE 9X commercial aircraft engine



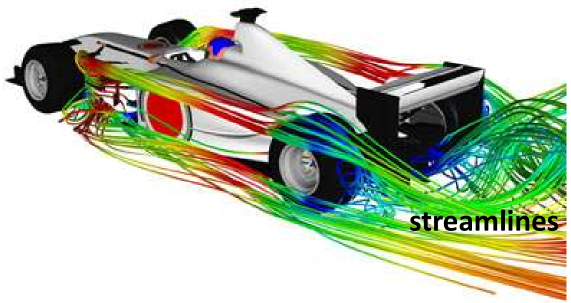
Fluid Dynamics



Airplane aerodynamics

F-16 Fighter plane

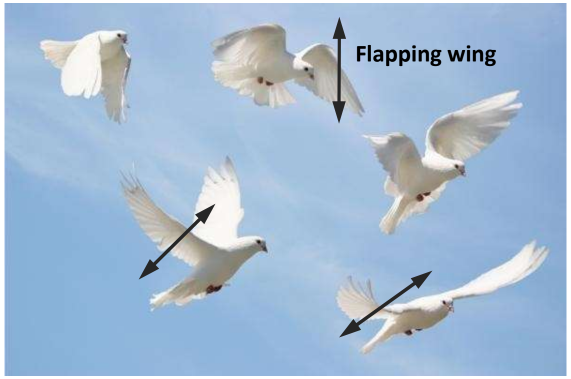
Rocket launching
(SpaceX Falcon 9)



Racing car aerodynamics

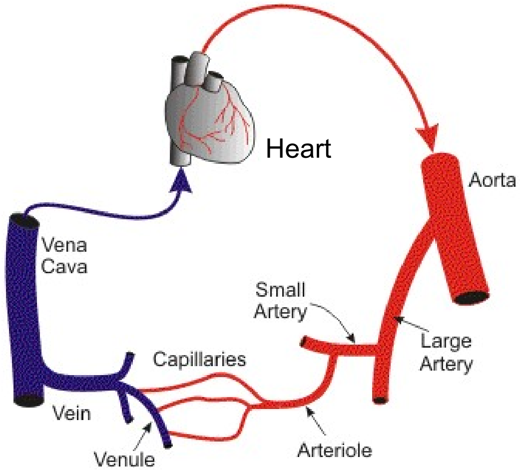
High speed train (320 km/hr)

Offshore wind turbines



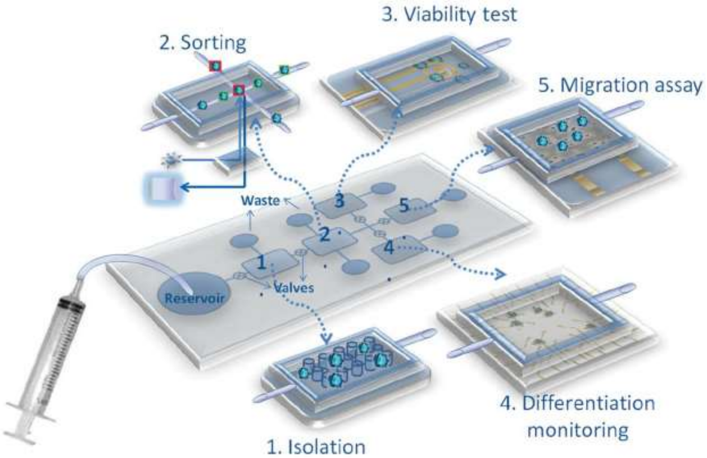
Flying of birds

(Biomimetics)



Blood flow through vascular network

Micro Unmanned Air Vehicle (μUAV)



Lab-on-a-chip (LoC) microfluidic device

Reynolds number, Re

Inertial / inertia force, F_I of a fluid element that has a **length scale L** (characteristic dimension) can be determined as:

$$F_I = ma \propto \left(\rho L^3\right)\left(\frac{L}{T^2}\right) = \left(\rho L^2\right)\left(\frac{L}{T}\right)^2 = \rho L^2 V^2$$

Viscous force, F_V can be determined as:

$$F_V = \mu \frac{dV}{dy} A \propto \mu\left(\frac{V}{L}\right)\left(L^2\right) = \mu V L$$

Reynolds number, Re is a measure of the ratio of inertial to the viscous force on a fluid element having a velocity scale V, length scale L, and fluid properties ρ and μ

$$\mathrm{Re} = \frac{\text{inertial force}}{\text{viscous force}} = \frac{F_I}{F_V} = \frac{\rho V^2 L^2}{\mu V L}$$

$$\Rightarrow \quad \mathrm{Re} = \frac{\rho V L}{\mu}$$

Re is important for almost all types of flow.

Gives the basic idea on the nature of flow: laminar or turbulent

Mach number, M / Ma

Elastic force, F_E on a fluid element that has a **length scale L** with **bulk modulus of elasticity B** is given by

$$F_E = BA \;\propto\; BL^2$$

Mach number, M is a measure of the ratio of inertial to the elastic force on a fluid element having a velocity scale V, length scale L and bulk modulus of elasticity B.

$$\mathrm{M}^2 = \frac{\text{inertial force}}{\text{elastic force}} = \frac{F_I}{F_E} = \frac{\rho V^2 L^2}{BL^2}$$

$$\Rightarrow \quad \mathrm{M}^2 = \frac{\rho V^2}{B} = \frac{V^2}{\left(\dfrac{B}{\rho}\right)} = \frac{V^2}{c^2} \quad ;\ c = \text{speed of sound at that medium}$$

$$\Rightarrow \quad \mathrm{M} = \frac{V}{c}$$

M is important for high speed flows where compressibility effects can't be neglected.

Fluid Flow at Microscale

At the **microscale**, the interaction between the fluid and solid wall is different than that at the **macroscale**. Fundamental studies have shown that the **continuum hypothesis** may not be valid at microscale and some specific effects may be present that can alter the fluid flow and heat transfer characteristics significantly.

At the **microscale**, **surface area to volume ratio is much larger**, which results in

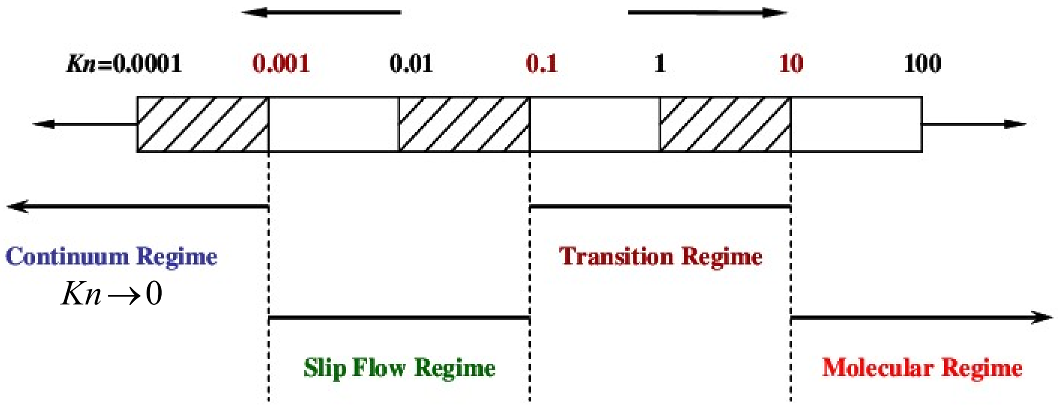
- increased surface forces, which may produce **large pressure drops**,
- **Increased viscous dissipation** (small length scale, large velocity gradient);
- **decreased inertial forces**, which allows diffusion and conduction processes to become relatively more significant;
- **increased heat transfer**, which may lead to variable fluid properties and
- **thermal creep** (The thermal creep is defined as the macroscopic movement of rarefied gas molecules induced by a temperature gradient from lower to higher temperature zone).

Therefore, these effects need to be considered to predict the fluid flow and heat transfer characteristics.

Flow classification based on molecular action

Table: Flow classification

Regime	*kn*
Continuum flow	$kn < 0.001$
Slip flow	$0.001 < kn < 0.1$
Transitional flow	$0.1 < kn < 10$
Free molecular flow	$kn > 10$



$$\text{Knudsen number}, Kn = \frac{\lambda}{L}$$

$$Kn = \frac{\text{mean free path of gas}}{\text{characteristic dimension}}$$

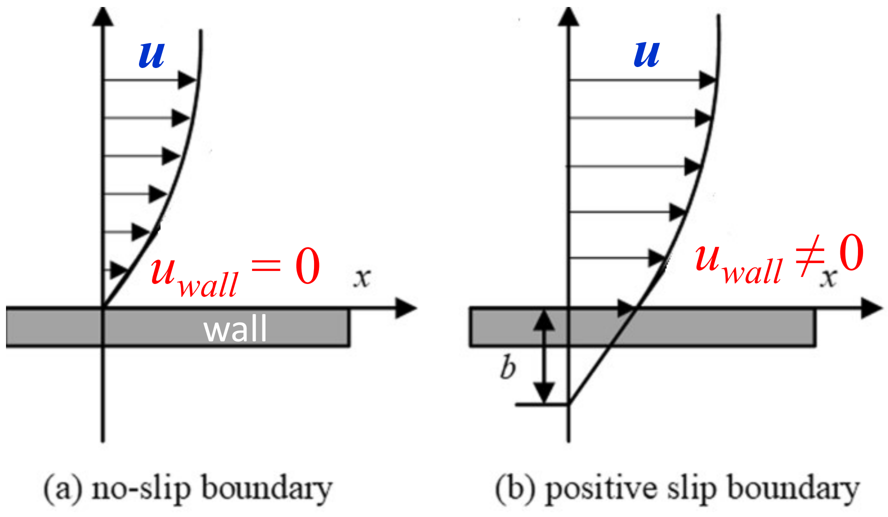
(**Continuum approach:** individual molecule is not important rather averaged behavior is considered in bulk; continuous flow) (Undergraduate level)

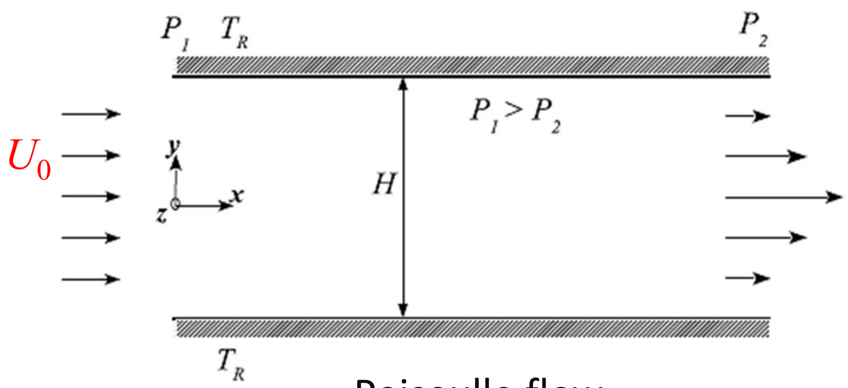
Classical fluid mechanics

(**Molecular approach:** individual molecule is important and should be modeled; gas kinetic theory, statistical approach, etc.) (Advanced graduate level)

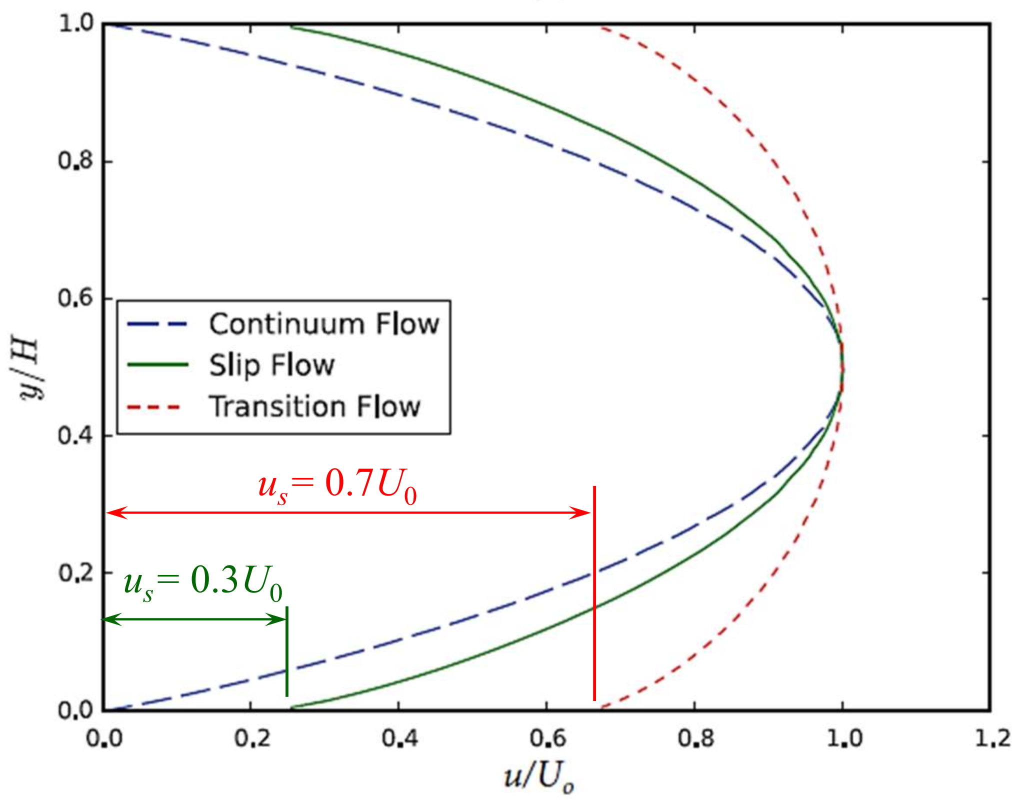
Micro/nano scale fluid mechanics, rarefied gas dynamics, space applications, etc.

Velocity slip





Poiseulle flow



*Agrawal et al. Microscale Flow and Heat Transfer Mathematical Modelling and Flow Physics (2020)

Course Contents

- Fundamental concept of fluid as a continuum; Fluid Properties. (MMR)
- Fluid Statics: basic hydrostatic equation, pressure variation in static incompressible and compressible fluids; Manometers; Forces on submerged plane and curved surfaces; Buoyant force; Stability of floating and submerged bodies; Pressure distribution of a fluid in rotating and accelerating systems. (MA)
- ***Fluid dynamics: Concepts of system and control volume: Continuity, momentum and energy equations and their applications; Introduction to Navier-Stokes equations. (MTH)***
- ***Pressure, Velocity and Flow measurement devices. (MTH)***
- **Introduction to inviscid incompressible flow. (*MMR*)**

Text books:

- F. M. White, Fluid Mechanics, 7th Edition, 2011, ISBN: 978-007-131121-2.
- M.C. Potter, D.C. Wiggert, Mechanics of Fluids, 3rd Edition, 2010, ISBN: 978-0-495-43857-1.
- Class lectures will be available at **http://toufiquehasan.buet.ac.bd**

Reference books: (for further reading)

i. Munson, Okiishi, Huebsch, Rothmayer, Fundamentals of Fluid Mechanics, 7th Edition, 2013, ISBN: 978-1-118-18676.

ii. Fox and McDonald, Introduction to Fluid Mechanics, 9th Edition, 2015, ISBN: 978-1118912652.

iii. J. F. Douglas, J. M. Gasiorek, J. A. Swaffield, L. B. Jack, Fluid Mechanics, 5th Edition, 2005, ISBN- 978-0-13-129293-2.

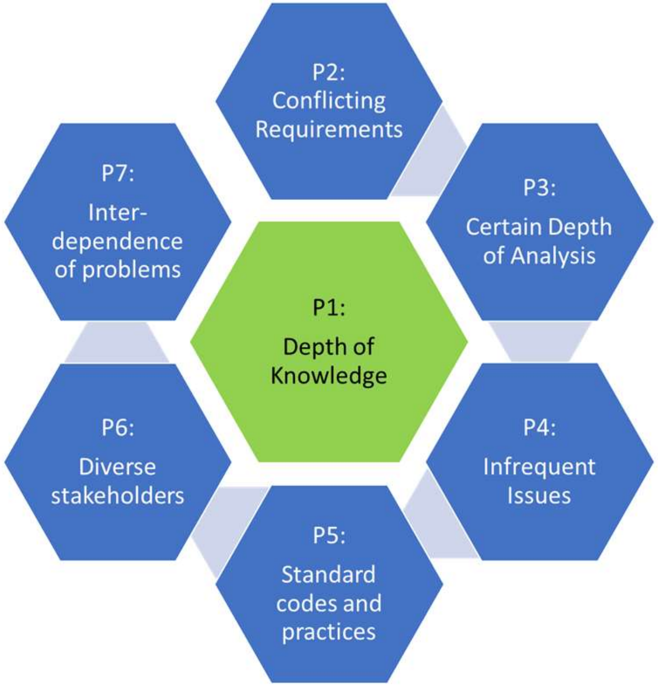
Outcome Based Education (OBE)

- **What is OBE?**
  - a concept/framework for educational programs that focuses on **what the student should be able to do** at the end of a course/program **rather than what he/she is taught**
- **OBE** has been adopted by most well-recognized Accreditation bodies to improve higher educational programs continuously
- **OBE** is being adopted in many of the present day textbooks as well

Complex Engineering Problems

Engineers	ability to solve Complex engineering problems*
Technologists	ability to solve Broadly defined problems**
Technicians	ability to solve Well-defined problems***

According to *Washington Accord, **Sydney Accord and ***Dublin Accord



Course Outcome (CO) of ME 321

CO No.	CO Statement
CO 1	**Explain** the properties of fluids such as viscosity, vapor pressure, surface tension, and compressibility.
CO 2	**Determine** the pressure in a fluid system using the concept of manometry.
CO 3	**Calculate** the hydrostatic pressure force on a plane and curved submerged surface.
CO 4	**Apply** the continuity, momentum and energy equations to solve fluid dynamic problems.
CO 5	**Analyse** the flow measurement devices.
CO 6	**Apply** the concepts of stream function and velocity potential in simple inviscid incompressible flows.