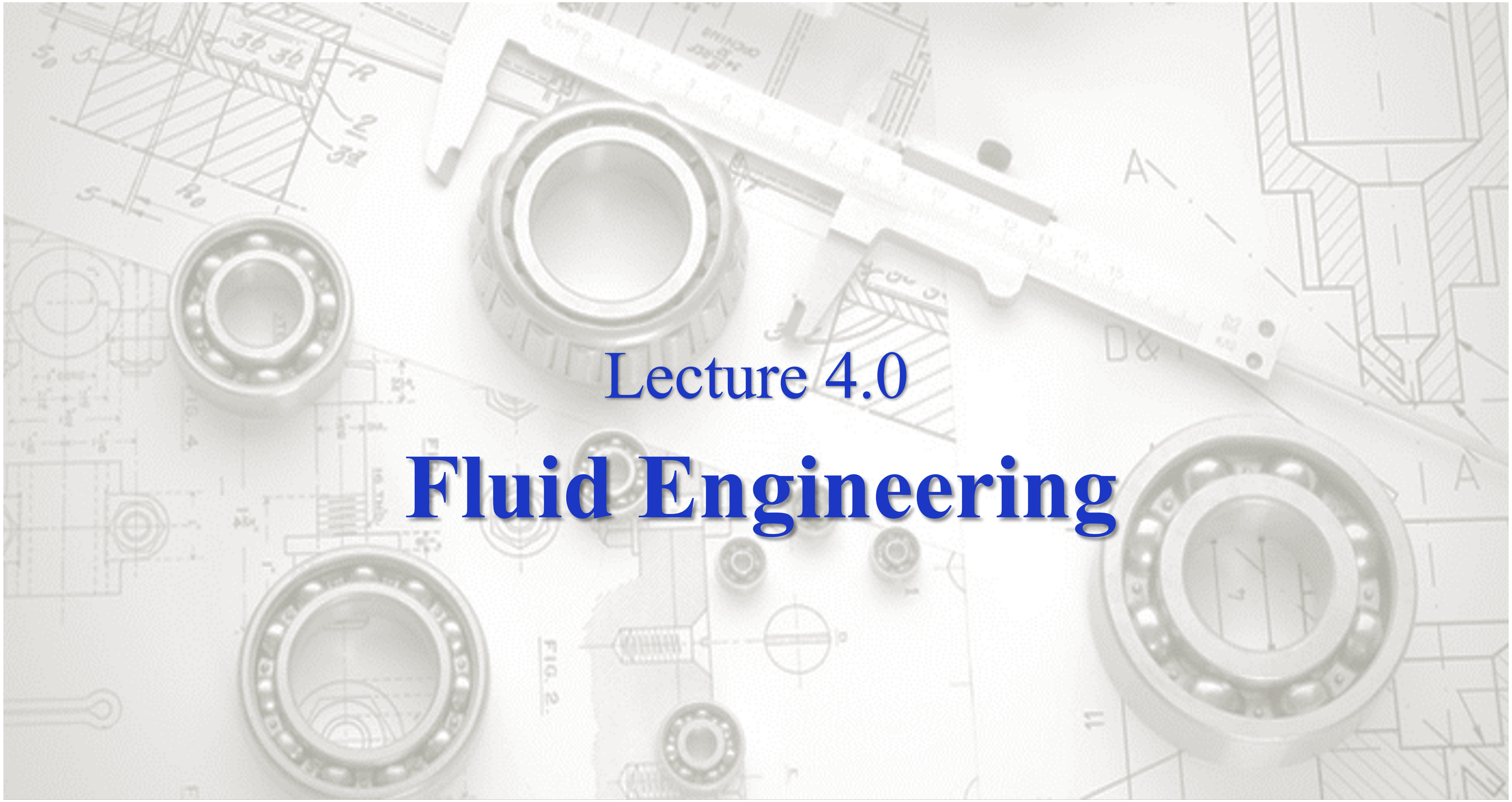

Lecture 4.0

Fluid Engineering

4.0 Fluid Engineering

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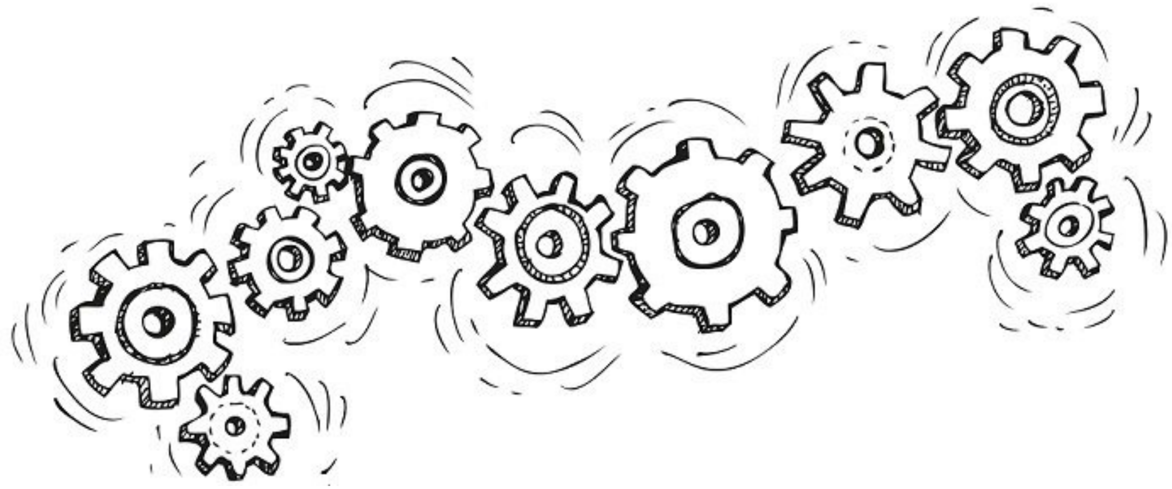

Today's lecture objectives:

- Recognize the application of fluids engineering to such diverse fields as microfluidics, aerodynamics, sports technology, and medicine.
- Explain in technical terms the differences between a solid and a fluid, and the physical meanings of a fluid's density and viscosity properties.
- Understand the characteristics of laminar and turbulent fluid flows.
- Determine the magnitudes of the fluid forces known as buoyancy, drag, and lift in certain applications.
- Analyse the volumetric flow rate and pressure drop of fluids flowing through pipes.

4.1 Overview

1. Fluids engineering and its role in applications as diverse as aerodynamics, biomedical and biological engineering, piping systems, microfluidics and sports engineering.
2. Study of fluids, which are classified as either liquids or gases, is further broken down into the areas of fluid statics and dynamics.
3. Mechanical engineers apply the principles of fluid statics to calculate the pressure and buoyancy force of fluids acting on stationary objects, including ships, tanks, and dams.

4.1 Overview

4. Fluid dynamics refers to the behaviour of liquids or gases when they are moving or when an object is moving through an otherwise stationary fluid.
5. Hydrodynamics and aerodynamics are the specializations focusing on the motions of water and air, which are the most common fluids encountered in engineering - Those fields encompass not only the design of high-speed vehicles but also the motions of oceans and the atmosphere.
6. Some engineers and scientists apply sophisticated computational models to simulate and understand interactions among the atmosphere, oceans, and global climates.

In todays world…

Fluid mechanics also plays a central role in biomedical engineering, a field that was ranked as one of the mechanical engineering profession's top ten achievements. Biomedical applications include the design of devices that deliver medicine by inhaling an aerosol spray and the flow of blood through arteries and veins.

Figure 6.15

The flow of blood in the human circulatory system is similar in many respects to the flow of fluids through pipes in other engineering applications. Images such as this of the human pulmonary system are obtained through magnetic resonance imaging, and they provide physicians and surgeons with the information they need to make accurate diagnoses and devise treatment plans.

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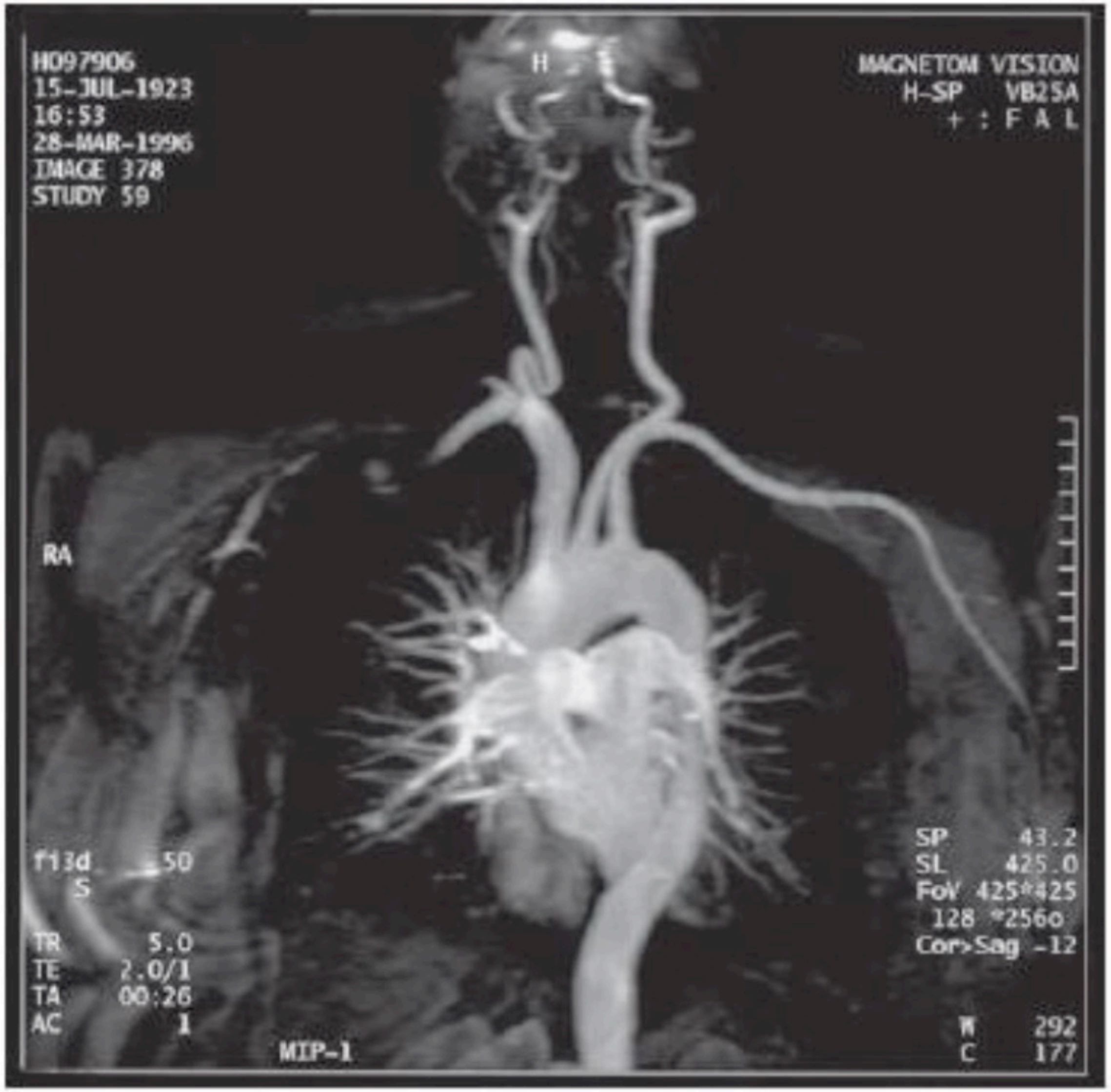


4.2 Fluid Forces

- The forces generated by stationary or moving fluids are important to the hardware designed by mechanical engineers.
- Forces generated by FLUIDS i.e. liquids and gases, are known as buoyancy, drag and lift.
- As shown in **Figure 6.3**, mechanical engineers apply sophisticated computer-aided engineering tools to understand complex airflows around aircraft and automobiles.

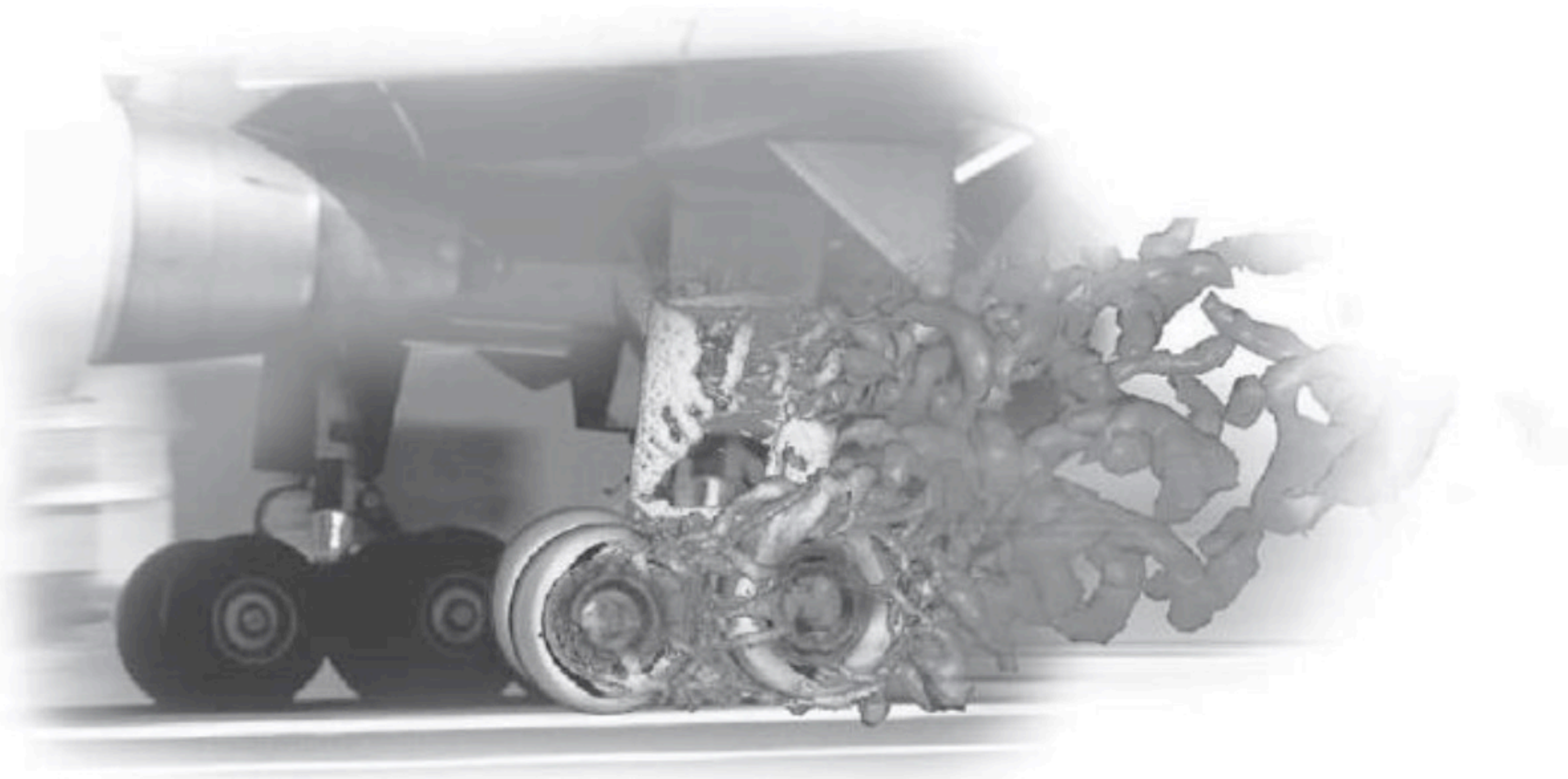


Figure 6.3 Mechanical engineers apply computer simulations of three-dimensional airflow including these vortex structures generated by aircraft landing gear.

Courtesy of ANSYS, Inc.

Fluid Properties

From an engineering standpoint, what exactly is a FLUID ?

- Scientists categorize compositions of matter in different ways.
- Mechanical engineers often categorize substances as being either solids or fluids.
- The technical distinction between the two centres on how they behave when forces are applied to them.

A fluid is a substance that is unable to resist a shear force without continuously moving. No matter how small, any amount of shear stress applied to a fluid will cause it to move and it will continue to flow until the force is removed.

Fluid substances are further categorized as being either liquids or gases, and the distinction here depends on whether the fluid easily can be *compressed* **(Figure 6.4).**

Figure 6.4

(a) For most practical purposes in engineering, liquids are incompressible and retain their original volume when forces act on them. (b) The gas within the cylinder is compressed by the piston and force F.

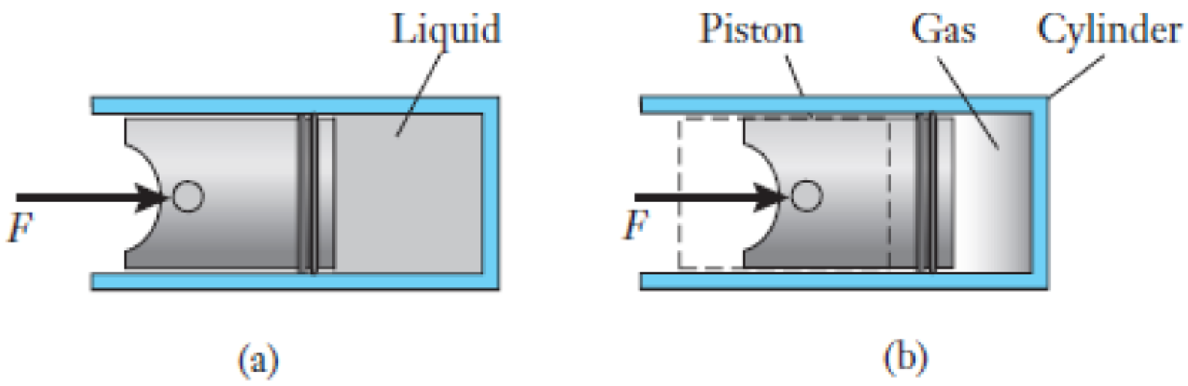
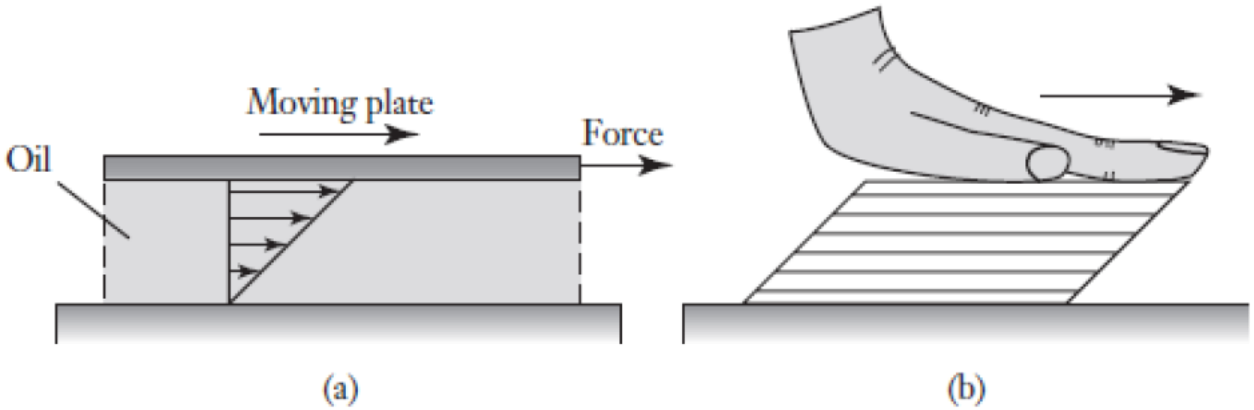


Figure 6.5

(a) A layer of oil is sheared between a moving plate and a stationary surface. (b) The shearing motion of the fluid is conceptually similar to a deck of cards that is pressed and slid between one's hand and a tabletop.



Gases, the second category of fluids, have molecules that separate from one another widely in order to expand and fill an enclosure. A gas can be easily compressed, and, when it is compressed, its density and pressure increase accordingly.

The primary difference between a solid and a fluid is the manner in which each behaves when subjected to a shear force.

As we look across the thickness of the oil film, each layer of fluid moves at a different speed, with the velocity of the oil changing gradually across its thickness.

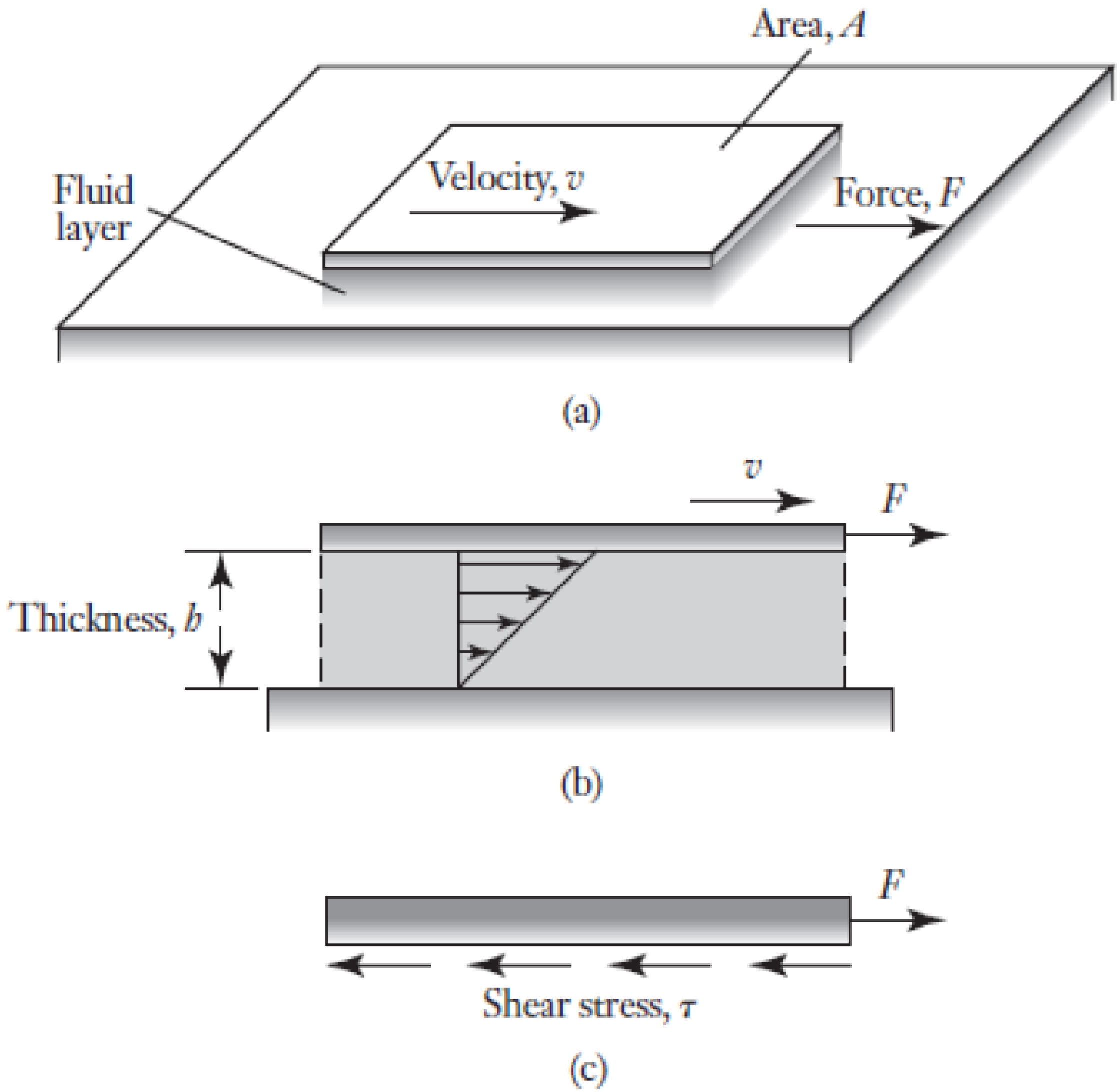
When the upper plate in **Figure 6.7** slides over the fluid layer at constant speed, it is in equilibrium in the context of **Newton's second law of motion.**

The applied force *F* is balanced by the cumulative effect of the **shear stress.**

The property of a fluid that enables it to resist a shear force by developing steady motion is called **viscosity.**

Figure 6.7

(a) A fluid layer is sheared between a stationary surface and a moving plate. (b) The velocity of the fluid changes across its thickness. (c) The applied force is balanced by the shear stress exerted on the plate by the fluid.



Pressure & Buoyancy Forces

- The forces known as buoyancy, drag, and lift arise when fluids interact with a solid structure or vehicle. Drag and lift forces arise when there is relative motion between a fluid and a solid object.
- A vehicle can either move through the fluid (as an aircraft moves through air, for instance) or the fluid can flow around the structure (such as a gust of wind impinging on a skyscraper).
- Forces between fluids and solid objects can arise even if there is no relative motion. The force that develops when an object is simply immersed in a fluid is called ***buoyancy***, and it is related to the weight of the fluid displaced.

- The weight of a quantity of fluid is determined by its density ρ (the lowercase Greek character rho) and volume. **Table 6.1** lists the density values of several gases and liquids in the SI and USCS.

Table 6.1

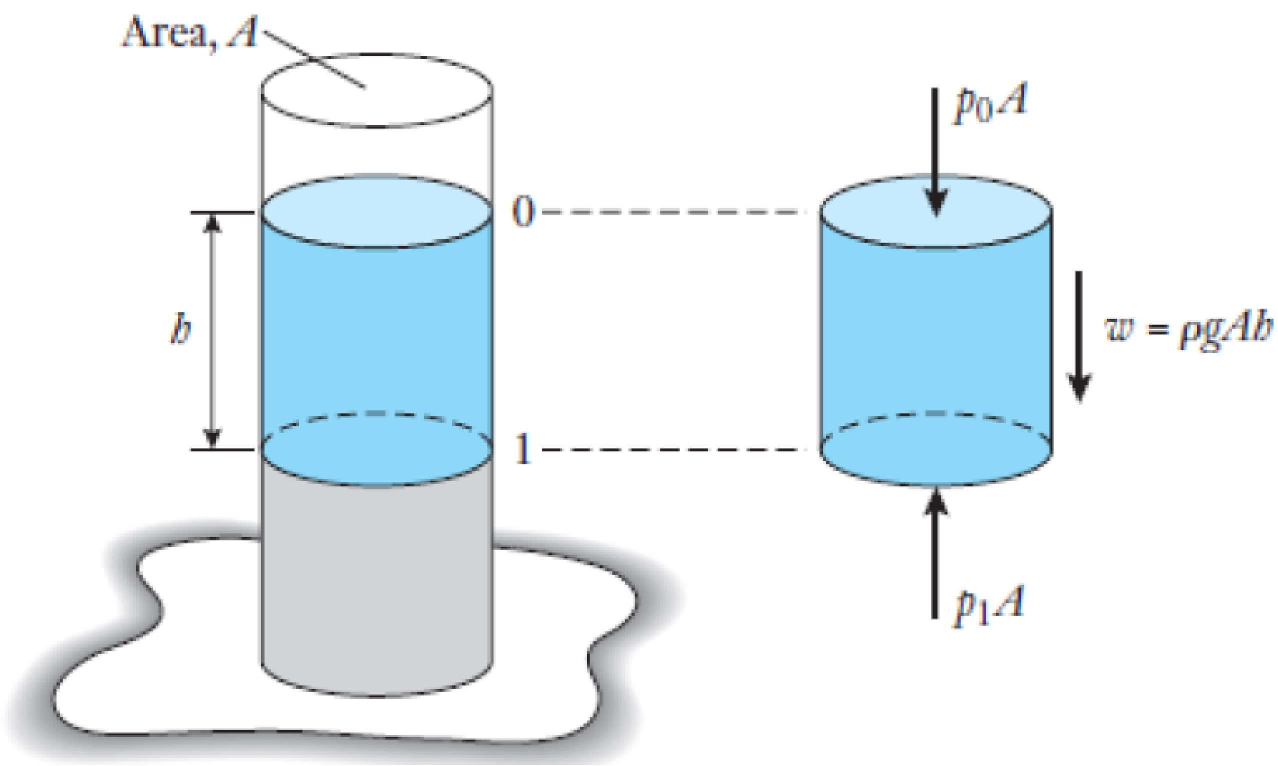
Density and Viscosity Values for Several Gases and Liquids at Room Temperature and Pressure

	Density, ρ		Viscosity, μ	
Fluid	**kg/m³**	**slug/ft³**	**kg/(m · s)**	**slug/(ft · s)**
Air	1.20	2.33×10^{-3}	1.8×10^{-5}	3.8×10^{-7}
Helium	0.182	3.53×10^{-4}	1.9×10^{-5}	4.1×10^{-7}
Freshwater	1000	1.94	1.0×10^{-3}	2.1×10^{-5}
Seawater	1026	1.99	1.2×10^{-3}	2.5×10^{-5}
Gasoline	680	1.32	2.9×10^{-4}	6.1×10^{-6}
SAE 30 oil	917	1.78	0.26	5.4×10^{-3}

- As you swim to the bottom of a pool or travel in the mountains, the pressure changes in the water or air that surrounds you, and your ears "pop" as they adjust to the rising or falling pressure. Our experience is that the pressure in a liquid or gas increases with depth. Referring to the beaker of liquid shown in **Figure 6.10**, the difference in pressure p between levels 0 and 1 arises because of the intervening liquid's weight. With the two levels separated by depth h, the weight of the liquid column is $\boldsymbol{\omega = \rho g A h}$, where Ah is the enclosed volume. By using the free body diagram of **Figure 6.10**, the equilibrium-force balance of the liquid column shows that the pressure at depth **1 Pascal (N/m^2)**

Figure 6.10

Equilibrium of a beaker filled with liquid. Pressure increases with depth because of the weight of the fluid above.



4.3 Fluid Flows

- If you’ve ever travelled on an airplane, you might recall the pilot instructing you to fasten your seat belt because of the turbulence associated with severe weather patterns or airflow over mountain ranges. You may also have had other first hand experiences with laminar and turbulent fluid flows.
- When fluid flows smoothly around an object, as in the sketch of airflow around a sphere in **Figure 6.14(a)**, the fluid is said to move in a laminar manner.
- ***Laminar*** flow occurs when fluid is moving relatively slowly (the exact definition of “relative” being given shortly).

- As fluid moves faster past the sphere, the flow's pattern begins to break up and become random, particularly on the sphere's trailing edge. The irregular flow pattern shown in Figure 6.14(b) is said to be *turbulent*.

- Small **eddies and whirlpools** develop behind the sphere, and the fluid downstream of the sphere has been severely disrupted by its presence.

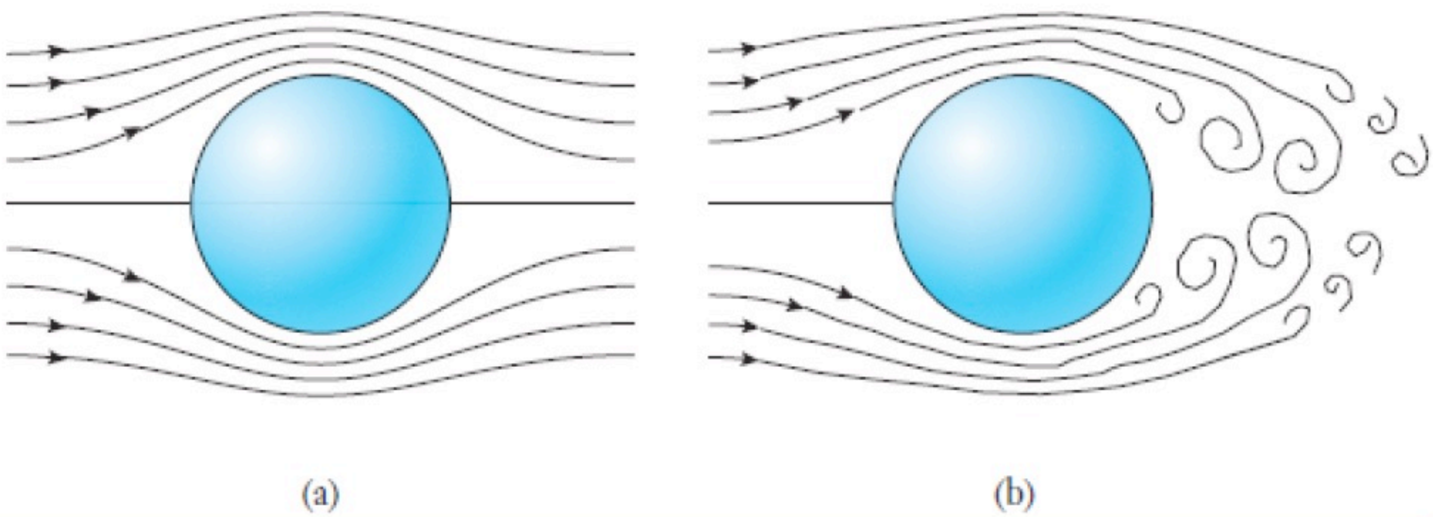


Figure 6.14 (a) Laminar and (b) turbulent flow of a fluid around a sphere.

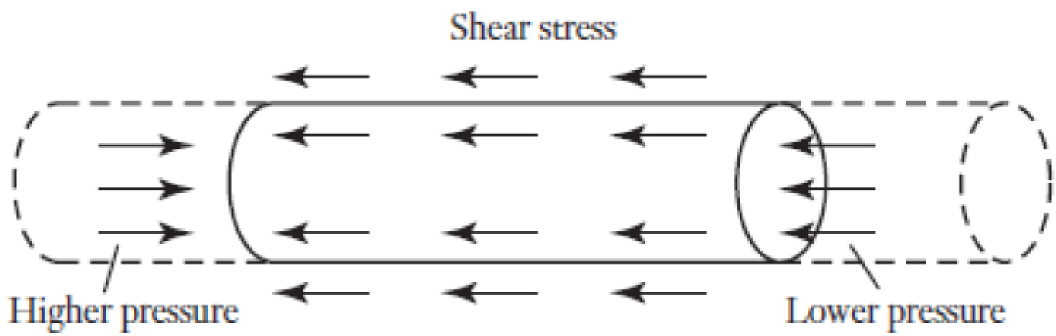


Figure 6.16

Free body diagram of a volume of fluid within a pipe. The pressure difference between two locations balances the viscous shear stresses between the fluid and the pipe's inner surface. The fluid is in equilibrium, and it moves with a constant speed.

Fluid Flow in Pipes

- A practical application for the concepts of pressure, viscosity and the Reynolds number is the flow of fluids through pipes, hoses, and ducts.

- Fluids tend to flow from a location of high pressure to one of lower pressure.

- As the fluid moves in response, it develops viscous shear stresses that balance the pressure differential and produce steady flow.

- The change in pressure along the length of a pipe, hose, or duct is called the ***pressure drop***, denoted by **Δp.** The more viscous a fluid is, the greater the pressure differential that is necessary to produce motion.

- **Figure 6.16** depicts a free body diagram of a volume of fluid that has been conceptually removed from a pipe. Since the pressure drop is related to the shear stress, we expect that **Δp** will increase with the fluid's viscosity and speed.

SUMMARY

- In this chapter, we introduced the physical properties of fluids, the distinction between laminar and turbulent flows and the forces that are known as buoyancy, drag and lift.
- Mechanical engineers categorize substances as being either solids or fluids and the distinction between the two centres around how they respond to a shear stress.

- Mechanical engineers apply the principles of fluids engineering to applications such as aerodynamics, biomedical engineering, microfluidics and sports engineering.
- The flow of fluids through pipes, hoses and ducts is an example of this diversity. In addition to the distribution of water, gasoline, natural gas and air through piping systems, the principles behind fluid flow in pipes can be applied in studies of the human circulatory and respiratory systems.

Table 6.5

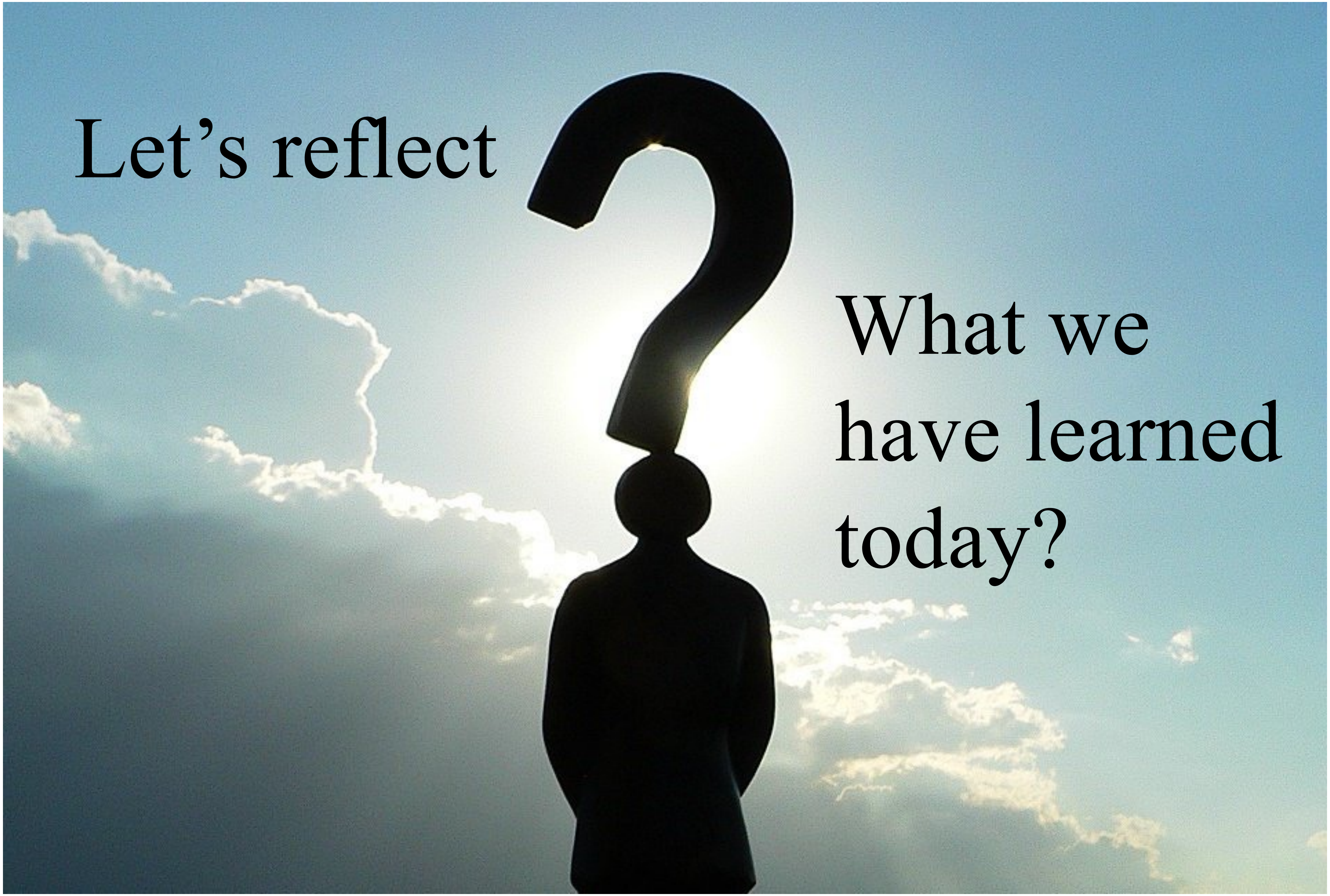
Quantities, Symbols, and Units that Arise in Fluids Engineering

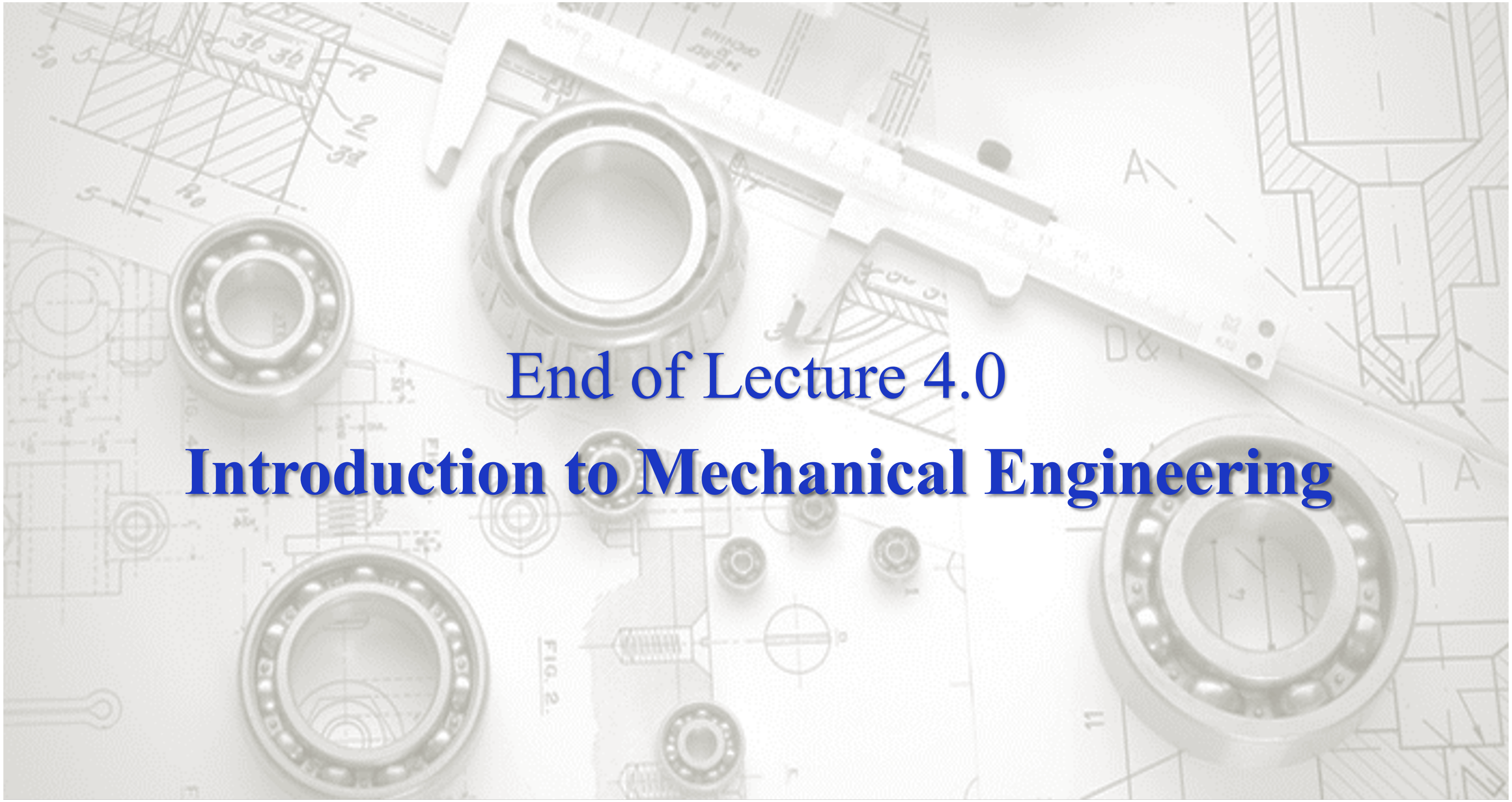
Quantity	Conventional Symbols	Conventional Units	
		USCS	SI
Area	A	ft^2	m^2
Coefficient of drag	C_D	—	—
Coefficient of lift	C_L	—	—
Density	ρ	$slug/ft^3$	kg/m^3
Force			
Buoyancy	F_B	lb	N
Drag	F_D	lb	N
Lift	F_L	lb	N
Weight	w	lb	N
Length			
Characteristic length	l	ft	m
Pipe length	L	ft	m
Mach number	Ma	—	—
Pressure	p	psi, psf	Pa
Reynolds number	Re	—	—
Shear stress	τ	psi	Pa
Time interval	Δt	s	s
Velocity	v, v_{avg}, v_{max}	ft/s	m/s
Viscosity	μ	slug/(ft · s)	kg/(m · s)
Volume	$V, \Delta V$	gal, ft^3	L, m^3
Volumetric flow rate	q	gal/s, ft^3/s	L/s, m^3/s

Table 6.6

Key Equations that Arise in Fluids Engineering

Bernoulli's equation	$\frac{p}{\rho} + \frac{v^2}{2} + gh = \text{constant}$
Buoyancy force	$F_B = \rho_{\text{fluid}} g V_{\text{object}}$
Drag force	
General	$F_D = \frac{1}{2} \rho A v^2 C_D$
Special case: Sphere with $Re < 1$	$C_D = \frac{24}{Re}$
Lift force	$F_L = \frac{1}{2} \rho A v^2 C_L$
Pipe flow velocity	$v_{\max} = \frac{d^2 \Delta p}{16 \mu L}$ $v_{\text{avg}} = \frac{1}{2} v_{\max}$ $v = v_{\max}\left(1 - \left(\frac{r}{R}\right)^2\right)$
Pressure	$p_1 = p_0 + \rho g h$
Reynolds number	$Re = \frac{\rho v l}{\mu}$
Shear stress	$\tau = \mu \frac{v}{h}$
Volumetric flow rate	$q = \frac{\Delta V}{\Delta t}$ $q = A v_{\text{avg}}$ $q = \frac{\pi d^4 \Delta p}{128 \mu L}$ $A_1 v_1 = A_2 v_2$
Weight	$w = \rho g V$


Let’s reflect
What we have learned today?


End of Lecture 4.0
Introduction to Mechanical Engineering