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MANE 2720 Fluid Mechanics

Week 01 : Introduction and Fundamental Concepts

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Main Topics

1. Course Outline and about my background
2. Introduction to Fluid Mechanics
3. Definition of a Fluid
4. Basic Equations
5. Importance of Dimensions and Units
6. Viscosity, Shear Stress, and Drag Force
7. Timelines, Pathlines, Streaklines, and Streamlines (See the lecture notes as well)
8. Surface Tension and Capillary Effects
9. Analysis of Experimental Error (Read from Textbook)
10. Classification of Fluid Flows

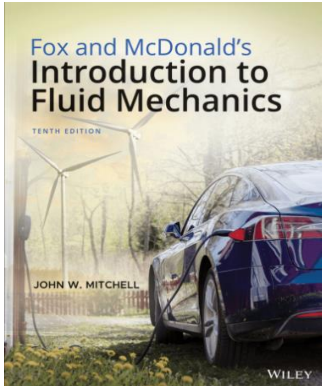
Textbooks and References

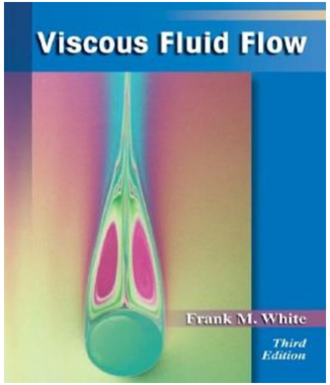
Fox & Macdonald, Introduction to Fluid Mechanics, 10th edition, Wiley (2020)

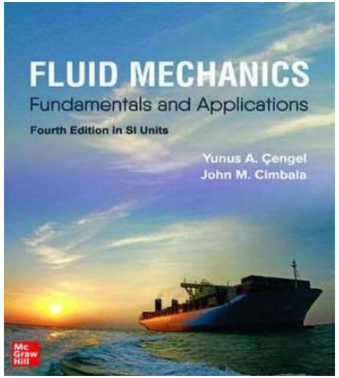
F.M. White, Viscous Fluid Flow, 3rd edition, McGraw-Hill Higher Education, 2006

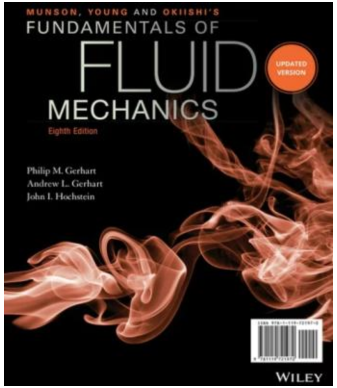
Yunus A. Cengel, John M. Cimbala, Fluid Mechanics: Fundamentals and Applications, 4th edition (SI Unit). Mc Graw Hill. Published July 2, 2019.

Munson's Fluid Mechanics, Global Edition, by P.M. Gerhart et al, Wiley, 2016; OR Munson, Young and Okiishi's Fundamentals of Fluid Mechanics, 8th Edition, by P.M. Gerhart et al, Wiley, 2016









Objectives

- Identify different categories of fluid flow issues observed in real-world applications.
- Formulate engineering challenges and their corresponding solutions.
- Model engineering problems and understand how they are solved.
- Possess practical familiarity with accuracy, precision, and significant figures, and acknowledge the significance of dimensional consistency in engineering computations.

Mechanics: The most ancient branch of physical science that addresses the behavior of both *stationary* and *moving* bodies when subjected to forces.

Statics: A branch of mechanics dedicated to the analysis of bodies in a state of *rest*.

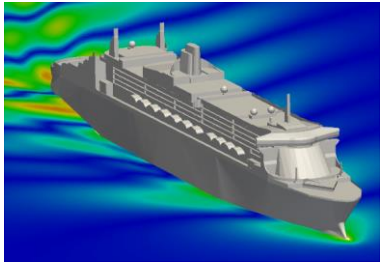
Dynamics: The segment that delves into the study of bodies in *motion*.

Fluid mechanics: The scientific realm focused on elucidating the conduct of fluids, whether **motionless (fluid statics) or in movement (fluid dynamics)**, and exploring how fluids interact with solid surfaces or other fluids at boundaries.

Da Vinci's turbulence painting

Introduction

Hydrodynamics involves the examination of fluid movement in situations where the fluids can be reasonably treated as incompressible, encompassing liquids (especially water) and gases **at lower velocities.**



Gas dynamics, on the other hand, focuses on the behavior of fluids that experience significant alterations in density, as seen in high-speed gas flow through nozzles.

Aerodynamics addresses the patterns of gas flow, particularly air, across objects like aircraft, rockets, and vehicles, whether at high or low speeds.

Meteorology, oceanography, and hydrology, in contrast, tackle the investigation of naturally occurring fluid motions.

Molecular Structure of Three Phases of Mater

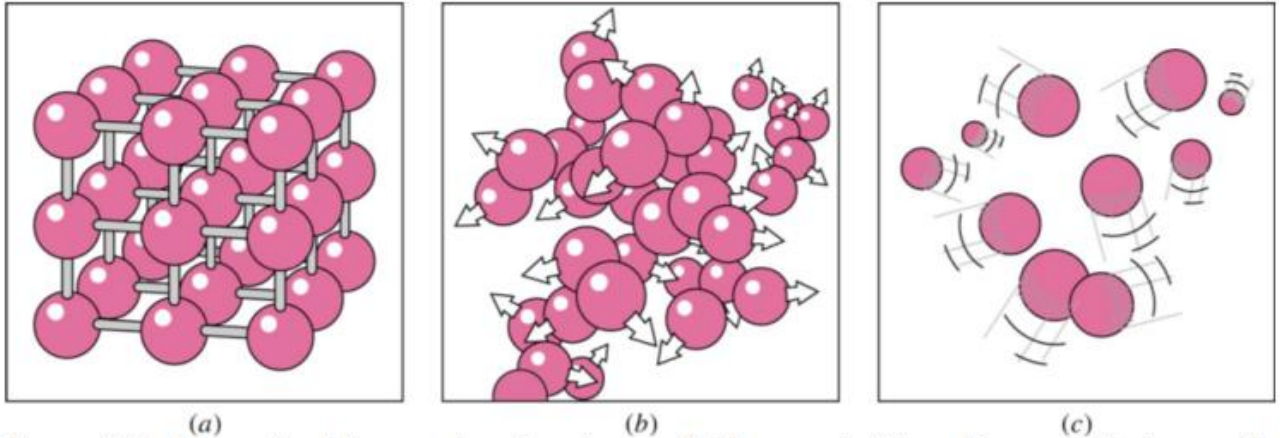


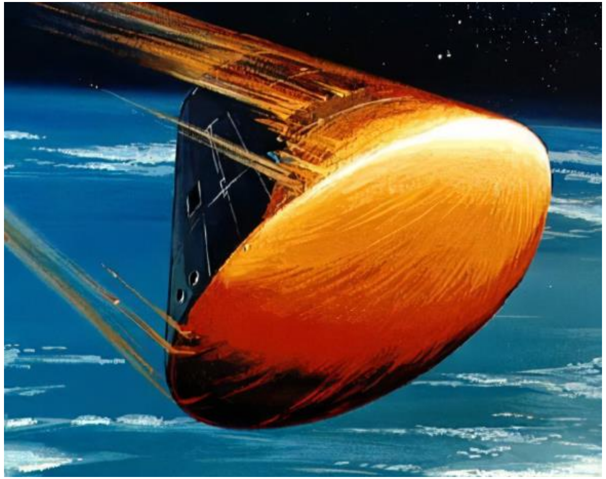
Figure: Figure (a) shows that the molecules in a solid form a lattice. Figure (b) shows that the molecules in a liquid are close together, but they are not structured (organized) as they are in the solid. Crudely, the molecules slip/slide past one another like a collection of buckyballs. This state will be referred to as a liquid lattice. Figure (c) shows that the molecules in a gas are "far apart" and are in random motion.

*Prof. Wayne Hacker's Lecture slides.

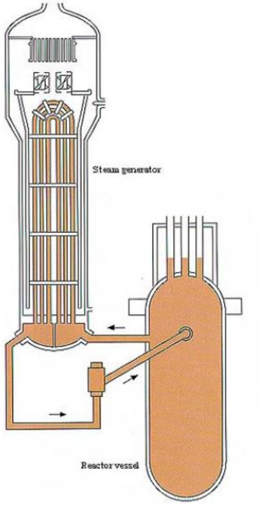
Why is Fluid Mechanics an important field for MANE?

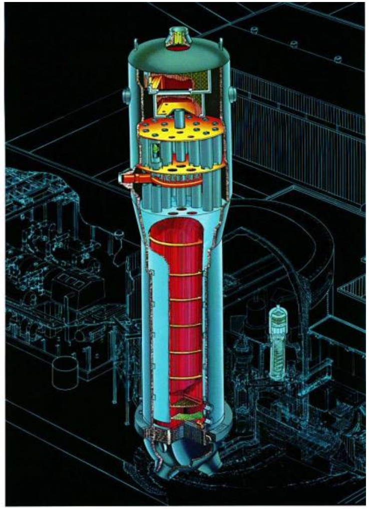
Mechanical Engineering: Car Engine

Aerospace Engineering: Re-entry



Nuclear Engineering: Steam generator





Westinghouse STEAM GENERATOR

Definition of fluid systems, boundaries, and surroundings*:

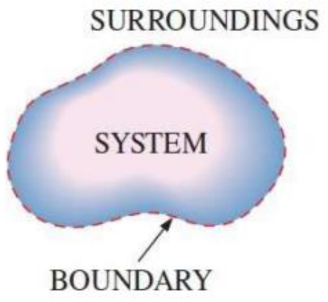
“**Definition**: A **fluid system** is defined as a fixed, identifiable quantity of mass with a clear boundary between the mass and its surroundings (environment).

Definition: The system’s **surroundings** is everything external to the system.

Definition: The area separating the system from its surroundings is the **boundary** of the system (the collection of points that is in contact with both the system and its surroundings). The boundary may be at rest or in motion.

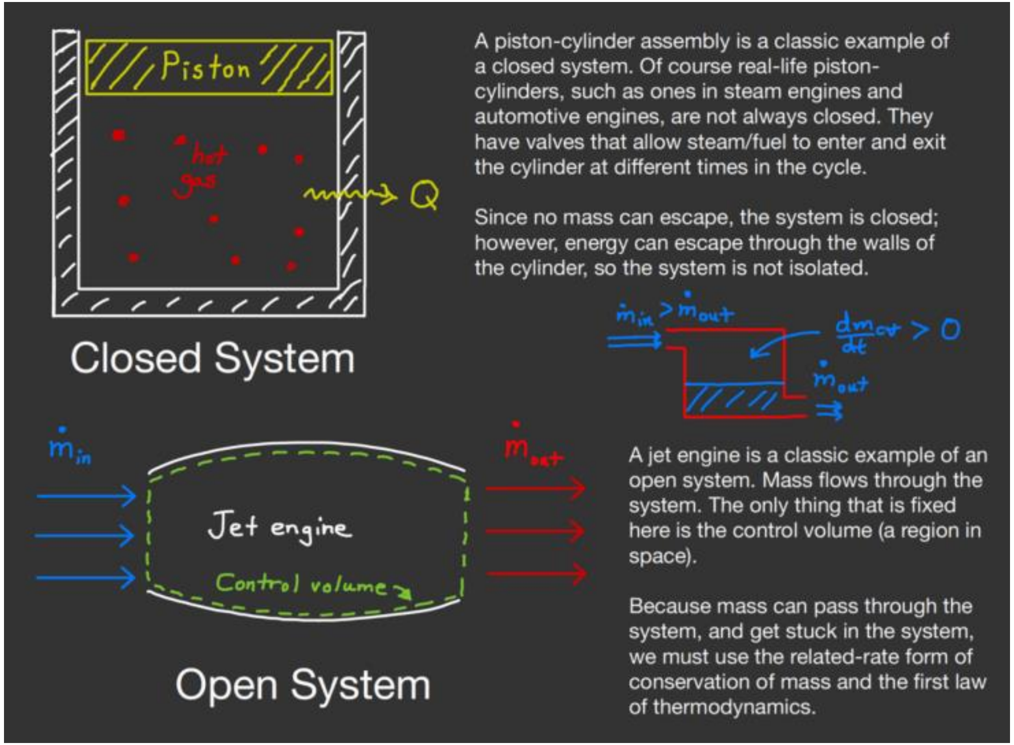
Definition: A **closed system** (or control mass) is a definite quantity of matter contained within some closed surface. An **isolated system** is a closed system from which no energy can escape. Note that an isolated system must also be a closed system.

Definition: A **control volume** (a.k.a. open system) is a definite fixed location in space. The system, passing through the control volume, is called open because mass may flow in or out of the control volume.”



*Prof. Wayne Hacker’s (University of Arizona) Lecture slides.

Definition of System and Control Volume*



*Prof. Wayne Hacker's Lecture slides.

Continuum Hypothesis

- The “fluid-point” particle needs to be big enough to contain enough molecules, per randomly selected box, that we can get reliable statistical data to predict a reliable value for all the fluid properties, such as density, at a tiny local region in space; yet small enough that we can discern gradients in the fluid property over characteristic length scales that we are modeling.
- The size of the fluid particle depends on many factors: the substance the fluid is composed of, the temperature, the pressure, etc. These “smallest” particles are sometimes referred to as fluid parcels.

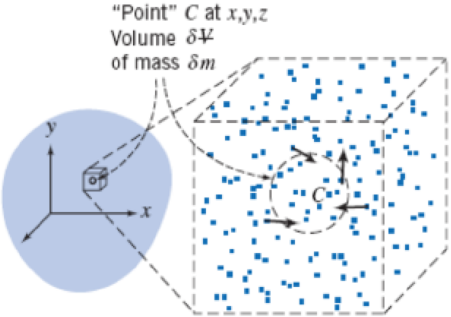
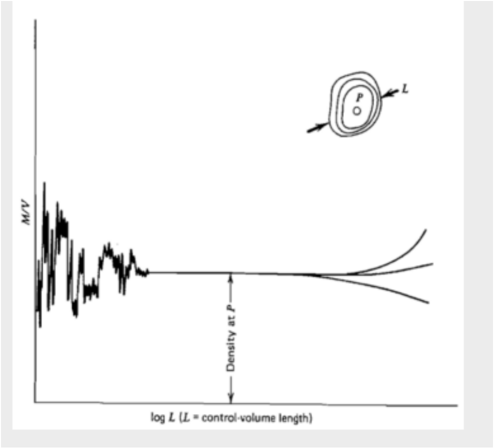


Figure: image depicting how we’d define the density of a fluid particle at a point.



See the lecture notes for the definition of the mean free path and Knudsen number.

Dimensions and Units of Physical Quantities:

Common Unit Systems

Let M, L, T, F, and Θ denote the dimensions of mass, length, time, force, and temperature, respectively. Below we list the fundamental dimensions and units for each of the three common systems of units.

- **SI System:**

  dimensions = $\{M, L, T, \Theta\}$
  units = {kg, m, s, K}

- **British Gravitational System:**

  dimensions = $\{F, L, T, \Theta\}$
  units = {lbf, ft, s, R}

- **(Old) English Engineering System:**

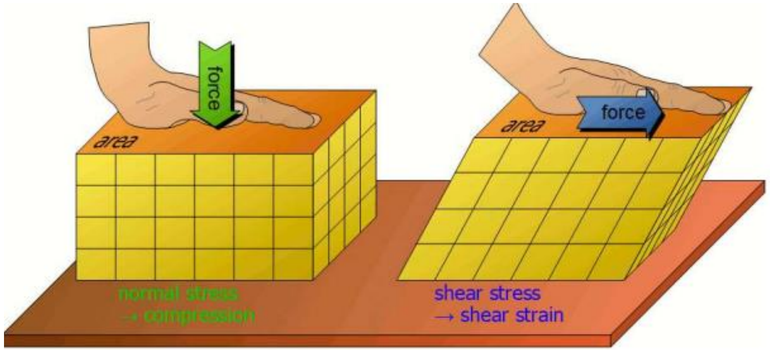
  dimensions = $\{F, M, L, T, \Theta\}$
  units = {lbf, lbm, ft, s, R}

- **(Modern) English Engineering System:**

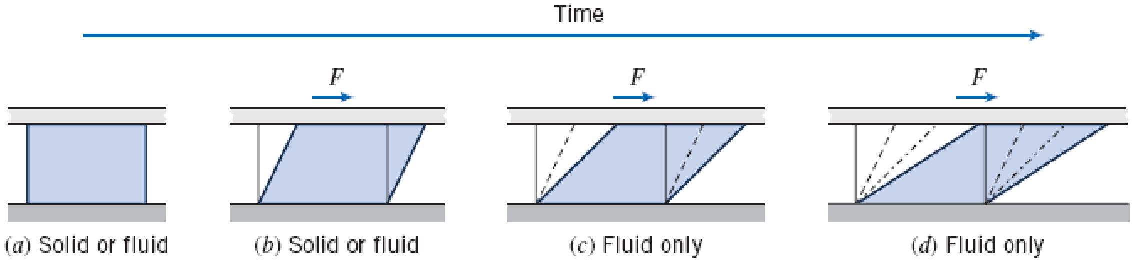
  dimensions = $\{F, M, L, T, \Theta\}$
  units = {lb, slug, ft, s, R} (slug is a derived quanity)

What is a Fluid?

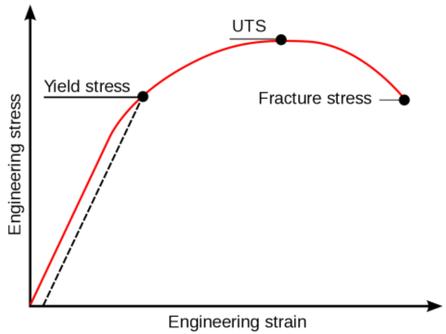
Definition: Shear stress is characterized as a force divided by the area it acts upon, aligned parallel to an extremely small surface element. The principal source of shear stress originates from the interaction between fluid particles, a consequence of fluid viscosity.



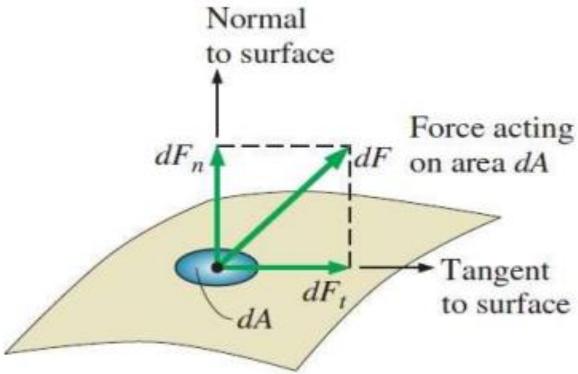
Upon the application of a consistent shear force, a solid ultimately ceases its deformation at a particular strain angle, whereas a fluid perpetually undergoes deformation and converges toward a steady rate of strain.



For solids



Shear Stress:



Normal stress: $\sigma = \dfrac{dF_n}{dA}$

Shear stress: $\tau = \dfrac{dF_t}{dA}$

Stress: The force applied per unit area.

Normal stress: The component of force that acts perpendicular to a surface, divided by the area. It originates from pressure.

Shear stress: The component of force that acts tangent to a surface, divided by the area. It arises from viscous friction.

Zero shear stress: A **motionless fluid** is in a condition of no shear stress.

Stress Field*

Why the stress tensor is not a vector: Crudely, stress must be represented by a two-tensor, as opposed to a vector, because it describes things happening in two directions simultaneously. Below we breakdown the role of each component in describing stress.

- Separate the force on a tiny, but finite, surface from the orientation of that surface.
- Start by breaking the area vector into components:

$$\delta\vec{A} = \delta A_x\,\hat{\imath} + \delta A_y\,\hat{\jmath} + \delta A_z\,\hat{k}\,.$$

- To each component we associate a small surface that is perpendicular to the component axis.
- To each of these “component surfaces” we can imagine the force $\delta\vec{F}$ acting on that surface.
- We can then break the force on each subsurface into components:

$$\delta\vec{F} = \delta F_x\,\hat{\imath} + \delta F_y\,\hat{\jmath} + \delta F_z\,\hat{k}\,.$$

- This decomposition of area vector and force requires nine components to describe (keep track of) the stresses that form on a surface with an arbitrary orientation at the point P_0. Clearly, the stress tensor is *not* a vector!
- See Cauchy stress tensor on wikipedia.

Stress Field*

A typical stress component takes the form:

$$\tau_{xy} \equiv \lim_{\delta A_x \to \delta A'_x} \frac{\delta F_y}{\delta A_x} ,$$

where the force component, δF_y, is in the y-direction and the orientation of the normal component (normal vector) of the local area vector, δA_x, is in the x-direction. The area $\delta A'_x \neq 0$!

Sign convention for stress components: A stress component is positive when the direction of the force component causing the stress and the plane on which it acts are both positive or both negative.

Example 13

$\tau_{yx} = 3$ Pa represents a shear stress on a *positive* y-plane in the *positive* x-direction, or a *negative* y-plane in the *negative* x-direction.

Stress Tensor*

The **general stress tensor** (matrix) τ_{ij} at a point:

$$\tau_{ij} = \begin{bmatrix} \sigma_{xx} & \tau_{xy} & \tau_{xz} \\ \tau_{yx} & \sigma_{yy} & \tau_{yz} \\ \tau_{zx} & \tau_{zy} & \sigma_{zz} \end{bmatrix}$$

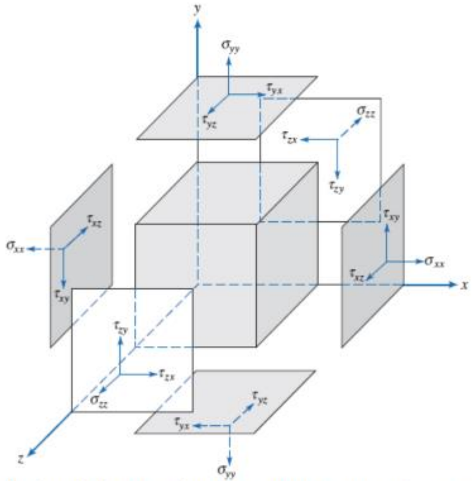
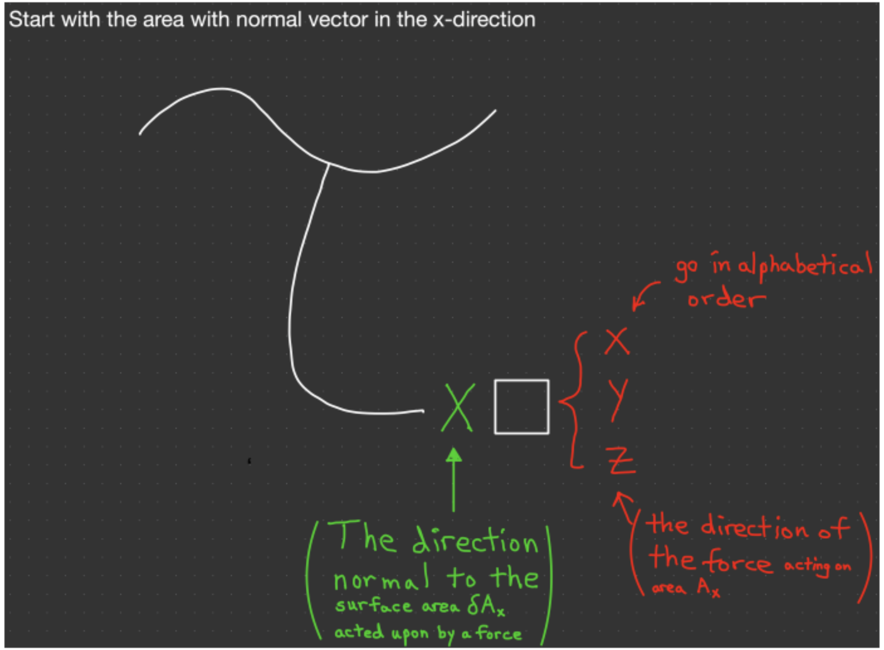


Figure: A visual picture of stress components along each side of a cube. Each stress component is drawn in the positive direction according to the standard sign convention.

*Prof. Wayne Hacker's Lecture slides.

Stress Tensor*



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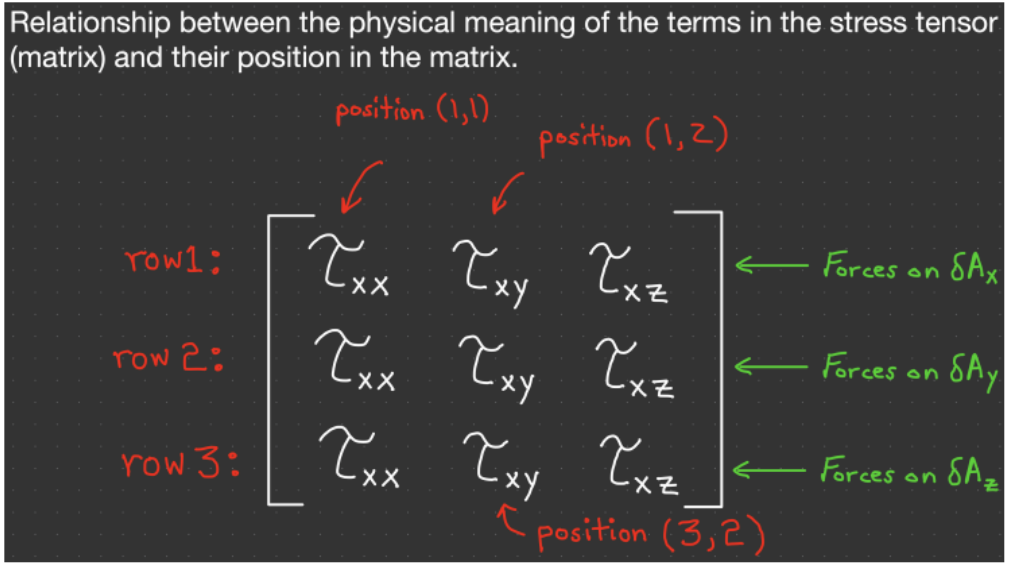
Stress Tensor*



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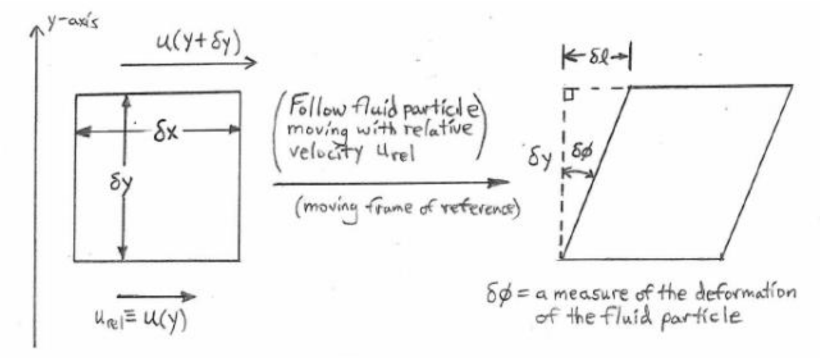
Shear Stress*:



Using distance = rate × time, we have that $\delta\ell = \delta u\,\delta t$, where

$$\delta u = u(y+\delta y) - u(y) \approx \left(u(y) + \frac{\partial u}{\partial y}\delta y\right) - u(y) = \frac{\partial u}{\partial y}\delta y\,. \qquad (*)$$

is the relative speed between the top of the fluid particle and the bottom (see class notes for details). For short times $\delta t > 0$, we expect the deformation angle $\delta\phi$ to be small. From the figure we see that

$$\delta\phi \approx \tan\delta\phi = \frac{\delta\ell}{\delta y} = \frac{\delta u\,\delta t}{\delta y}$$

$$\xrightarrow{\div\delta t} \quad \text{rate of deformation} \equiv \frac{\delta\phi}{\delta t} = \frac{\delta u}{\delta y}\,. \qquad (**)$$

This is an amazing result! We've just related the rate of change of the angle $\delta\phi$ to the velocity profile. This idea can be visualized by translating and shearing a deck of cards in your hands with the edge of the cards representing the velocity profile. (See picture below)

For solids: Deformation is quantified using **shear strain** ($\emptyset$), either in terms of angle or distance.

For fluids: Deformation is gauged by the **rate of shear strain** ($\emptyset/t$), expressed as angle per unit time or length per unit time.

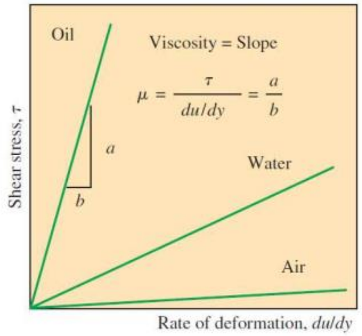
*Prof. Wayne Hacker's Lecture slides.

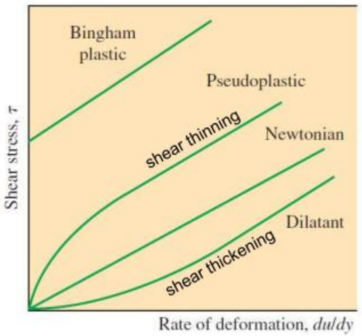
Viscosity:

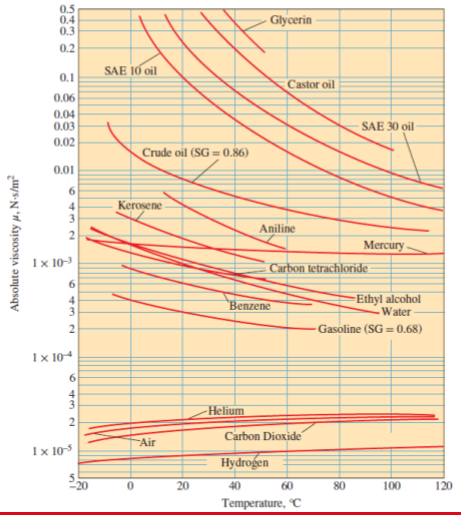
Newton's Law of Viscosity (for a **Newtonian fluid**) is given by the linear shear-stress-to-strain-rate relationship (See the lecture notes for the derivations of units):

$$\tau_{yx} = \mu \frac{du}{dy} \qquad [\tau_{yx}] = [\mu]\frac{[du]}{[dy]} = [\mu]\frac{[u]}{[y]} \Rightarrow \frac{F}{L^2} = [\mu]\frac{1}{T} \Rightarrow [\mu] = \frac{TF}{L^2} = \frac{M}{LT}.$$

The viscosity has SI units of kg/(m·s). Notice that viscosity has fundamental units of mass, length, and time.

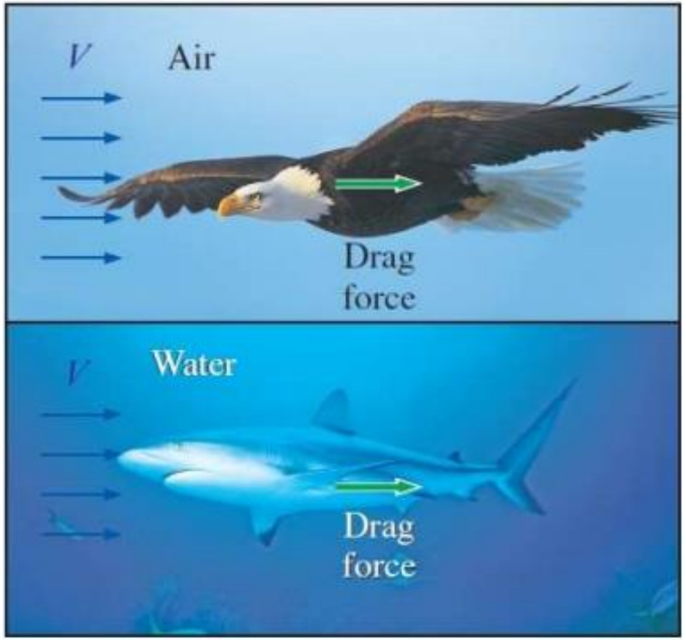






In the case of gases, viscosity tends to rise with higher temperatures, whereas the trend is opposite for liquids.
Also, for a Newtonian fluid, the shear stress changes linearly with the rate of deformation.

Viscous Flows*



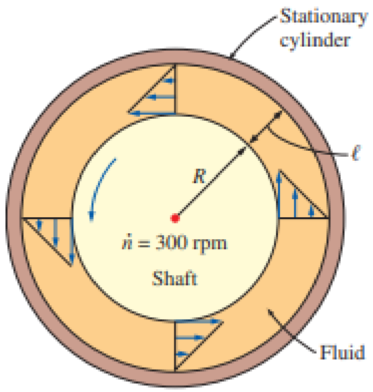
Viscosity is a characteristic that represents the internal resistance of a fluid to movement, often referred to as its *fluidity*. The resistance of a fluid to deformation is quantified by its viscosity. Viscosity arises from internal frictional strength that emerges between distinct layers of fluids when they are forced to **move.**

Drag force pertains to the energy a fluid in motion applies to an object in the direction of the flow. The extent of this force is influenced, *to some extent*, by viscosity. When a fluid moves with respect to a body, it generates a drag force upon the body, primarily attributed to the friction introduced by viscosity.

*Yunus A. Cengel, John M. Cimbala, Fluid Mechanics: Fundamentals and Applications, 4th edition (SI Unit). Mc Graw Hill. Published July 2, 2019.

Example

The viscosity of a fluid is to be measured by a viscometer constructed of two 40-cm-long concentric cylinders.The outer diameter of the inner cylinder is 12 cm, and the gap between the two cylinders is 0.15 cm. The inner cylinder is rotated at 300 rpm, and the torque is measured to be 1.8 Nm. Determine the viscosity of the fluid.



(See the Examples Folder in LMS for the solution)

Timelines*

Definition: A *timeline* is a line of adjacent fluid particles that have been marked at a particular time. Typically the line of particles is taken to be perpendicular to the direction of flow.

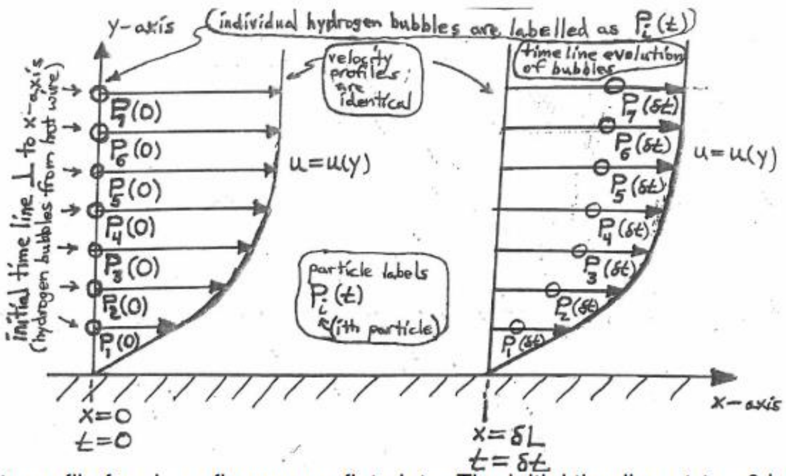


Figure: Velocity profile for shear flow over a flat plate. The initial timeline at $t = 0$ is shown in the figure. There are seven marked fluid particles that we follow from $t = 0$ to a short time later $t = \delta t$.

*Prof. Wayne Hacker (*University of Arizona*)'s Lecture slides.

Timelines*

Example 9 (Timeline Evolution)

For the steady, one-dimensional, one-directional flow field between two parallel plates of the form: $\vec{V} = u(y)\,\hat{\imath}$ shown in figure below demonstrate your knowledge of the definition of a *timeline* by drawing a sketch of the initial timeline a short time later at $t = \delta t$. Label each of the seven hydrogen bubbles, which are labelled $P_i(t = 0)$ for the i^{th} bubble, on the figure at the right. Notice that the initial timeline of the seven hydrogen bubbles are initialized on the positive y-axis at $t = 0$ on the left-hand figure in the drawing. Justify your answer.

*Prof. Wayne Hacker (*University of Arizona*)'s Lecture slides.

Timelines*

Example 9 (**Timeline Evolution [cont.]**)

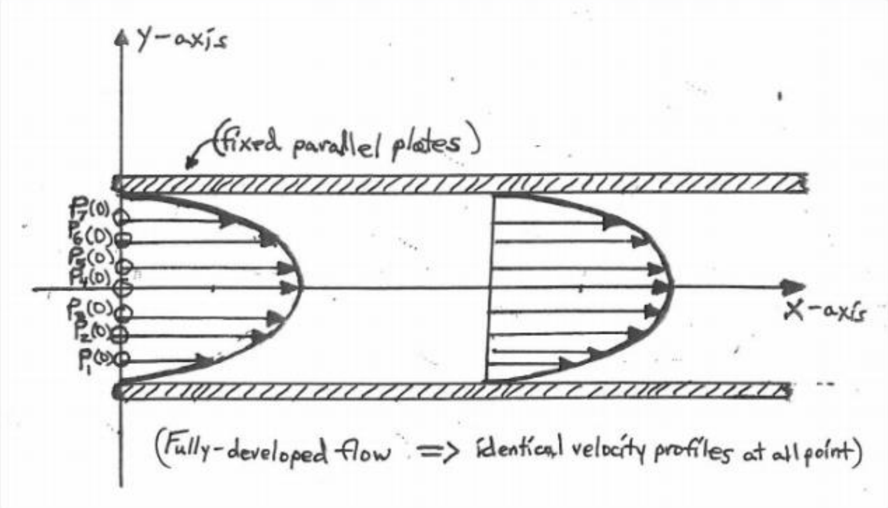


Figure: Velocity profile for flow between two infinite parallel plates. The initial timeline at $t = 0$ is shown in the figure. There are seven marked fluid particles.

Timelines*

Example 9 (**Timeline Evolution [cont.]**)

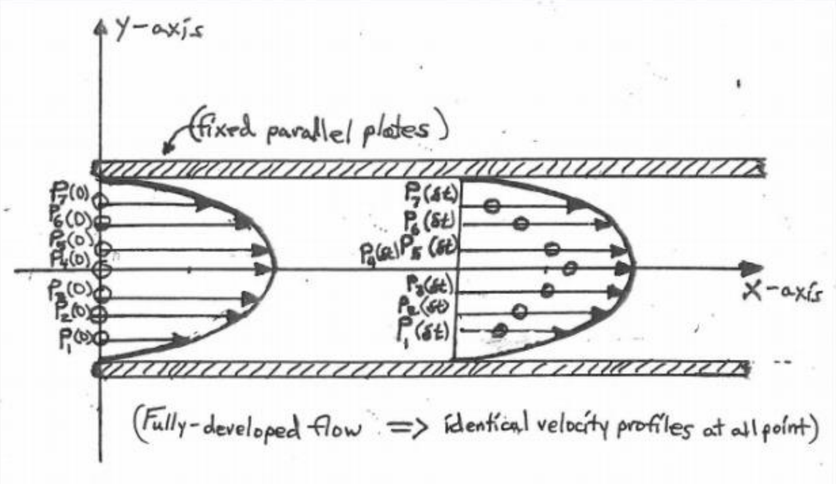


Figure: Velocity profile for flow between two infinite parallel plates. The initial timeline at $t = 0$ is shown in the figure as well as a possible later position for the seven initial fluid particles.

*Prof. Wayne Hacker (*University of Arizona*)'s Lecture slides.

Streaklines*

Definition: A *streakline* is a line joining all of the fluid particles that have passed through a particular fixed point in the flow field.

Figure: Cartoon of a continuous stream of dye emanating from a fixed point (x_0, y_0) in a flow field. As each particle marches forward from the fixed point, the dye particles form a continuous chain of particles that trace out a path through the flow field. This path is known as a streakline.

Pathlines*

Definition: A *pathline* is the path, or trajectory, traced out by a moving parcel (particle) of fluid. It's the fluid analogy to tracking a particle trajectory in mechanics, such as following the parabolic trajectory of a ball as it is fired out of a cannon.

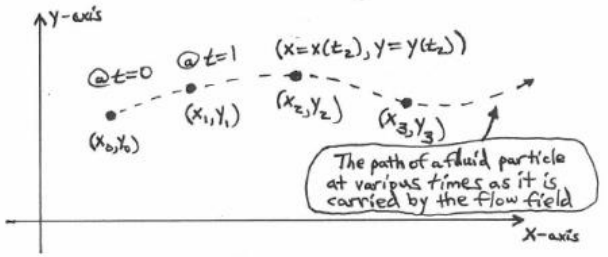


Figure: Cartoon of the pathline of a particle released into the flow at time $t = 0$ at position (x_0, y_0). The particle's position as a function of time is given by the expression $(x_p(t), y_p(t))$, where in order to distinguish the particular particle we're tracking, a subscript p is placed on the function representing the particle's position. The figure shows the particle's position at four different times along its path. The subscript p is dropped in the figure and replaced by observation time.

*Prof. Wayne Hacker (*University of Arizona*)'s Lecture slides.

Pathlines*

How we compute pathlines:

The equations describing the particle's motion are

$$\frac{dx_p}{dt} = u(x_p(t), y_p(t)),$$
$$\frac{dy_p}{dt} = v(x_p(t), y_p(t)),$$

with initial conditions for the x- and y-components:

$$x_p(0) = x_0 \quad \text{and} \quad \frac{dx_p}{dt}(0) = u(x_0, y_0),$$

$$y_p(0) = y_0 \quad \text{and} \quad \frac{dy_p}{dt}(0) = v(x_0, y_0).$$

Key point: These equations are based on the subtle assumption that fluid particle is moving with the flow field. See class notes for details.

Streamlines*

Definition: A *streamline* is a curve in a vector field with the following special property: to each spatial point on the streamline, at each moment in time, the tangent line to the curve at that point is parallel to the corresponding velocity vector (from the field) at that point. This can be expressed mathematically as

$$\left.\frac{dy}{dx}\right|_{\text{streamline}} = \frac{v(x,y)}{u(x,y)} \qquad \text{(by similar triangles)}\,.$$

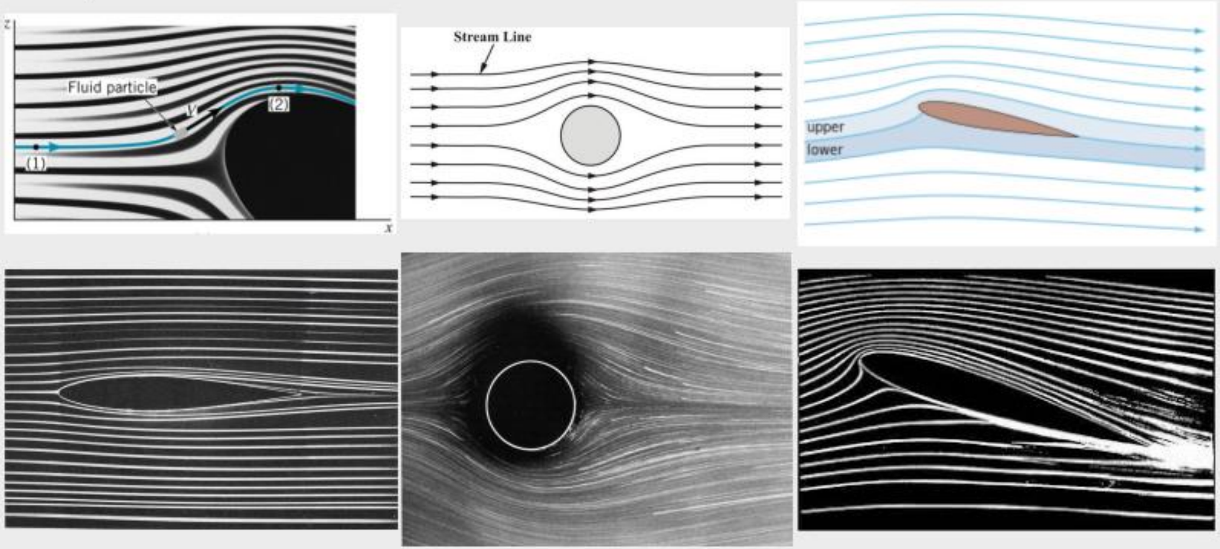
Comments:

- Recall that by the definition of velocity field as a vector-valued function over a region of space $\mathcal{D}$, to each point in space-time, $(x_0, y_0, z_0, t_0) \in \mathcal{D}$ there is a velocity vector associated with it $\vec{V}(x_0, y_0, z_0, t_0)$.
- A streamline is a mathematical construct. For a steady two-dimensional flow, at every point (x_0, y_0) in the flow field, the velocity vector is parallel to the slope of the tangent line to the streamline at (x_0, y_0). This is where the formula for computing the streamlines comes from.

Streamlines*

Example 10

Examples of streamlines for both real and cartoon flow field situations.



*Prof. Wayne Hacker (*University of Arizona*)'s Lecture slides.

Streamlines*

Connection between the geometry and the physics of streamlines

Using the fundamental principle slope $= \frac{\text{rise}}{\text{run}}$, observe from the figure to the right that the slope, $\tan\theta$, of the tangent line and the velocity vector at (x_0, y_0) are, respectively,

$$\tan\theta = \frac{dy}{dx} \qquad \text{(slope of streamline)}\ ,$$

$$\tan\theta = \frac{v(x,y)}{u(x,y)} \qquad \text{(slope of velocity vector)}\ .$$

By similar triangles, we can equate these two slopes to get the equation for computing the streamlines:

$$\left.\frac{dy}{dx}\right|_{\text{streamline}} = \tan\theta = \frac{v(x,y)}{u(x,y)}\ .$$

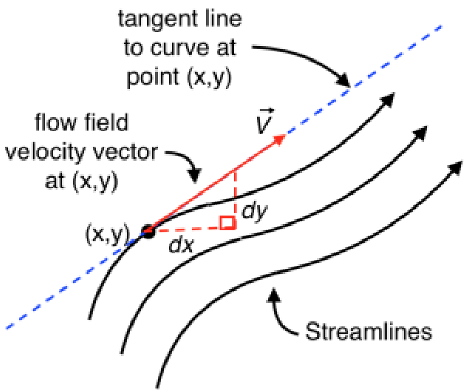


Figure: By similar triangles, the slope of the vector $\vec{V} = \langle u, v\rangle$ equals the slope of the tangent line to the streamline, dy/dx, at (x, y). This relationship is used to define the streamline.

Streamlines*

Comments:

- For steady flow streamlines, pathlines, and streaklines are the same thing. Timelines are typically never aligned with streamlines, since if they were, then they would be useless for illustrating the velocity profile.
- When it comes to dealing with streamlines, pathlines, and streaklines in this course we'll restrict our study to steady flows.

The figure to the right shows flow visualization of streamlines passing over a car.

Attention: At this point you should watch the video *Flow Visualization*. This video will give you an understanding of timelines, streamlines, pathlines, and streaklines that cannot be matched by words and pictures.

*Prof. Wayne Hacker (*University of Arizona*)'s Lecture slides.

Surface Tension and Capillary Effect*

The origins of surface tension

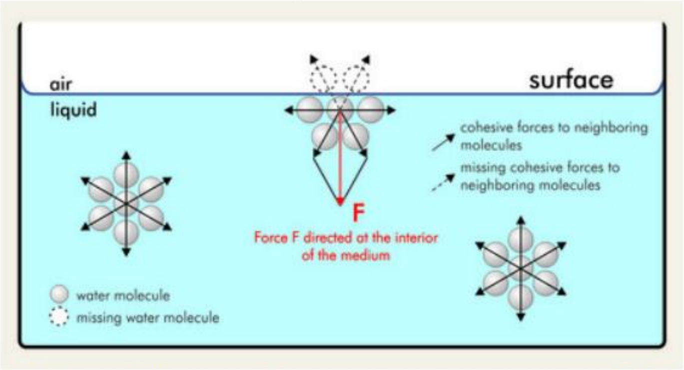


Figure: Cartoon of the source of surface tension in a liquid at the molecular level.

Definition: Capillary action is the ability of a liquid to flow in narrow spaces without the assistance of, or even in opposition to, external forces like gravity.

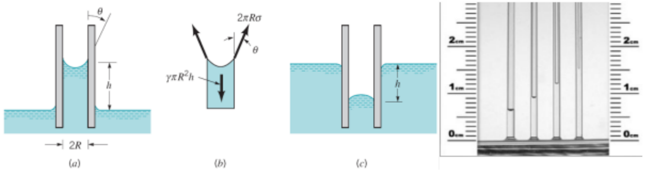


Figure: Examples of capillary action due to surface tension. Notice that in figure (a) surface tension is holding up the column of fluid.

[Capillarity and Surface Tension | Surface Tension | Physics - YouTube]

*Prof. Wayne Hacker's Lecture slides.

Surface Tension and Capillary Effect*

Surface tension's membrane behavior

Surface tension σ is the tension (force) divided by the boundary length on which the membrane is acting.

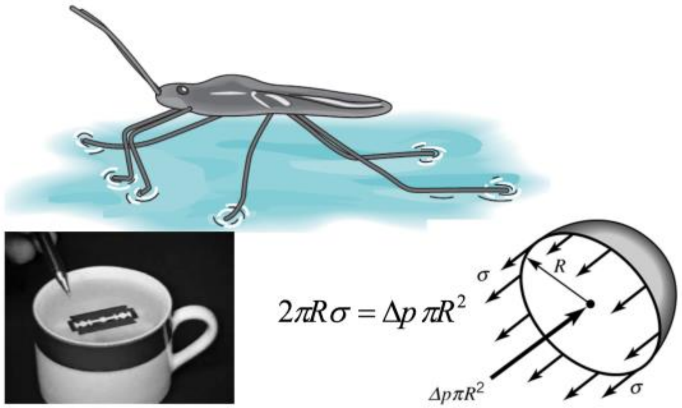


Figure: Cartoon of the source of surface tension in a liquid at the molecular level.

*Prof. Wayne Hacker's Lecture slides.

Surface Tension and Capillary Effect*

Example 14

In your physics lab a clean glass tube with small-diameter, D, is placed vertically into a pan of liquid (see figure). Due to capillary action, the fluid climbs up the tube to a height h above the surface level of the liquid. The contact angle, θ, between the fluid and the glass is measured and the density, ρ, of the liquid is known. Using the known data: h, θ, ρ, and D, derive an equation for the surface tension σ of the liquid.

Answer: $\sigma = \dfrac{\rho g D h}{4\cos\theta}$

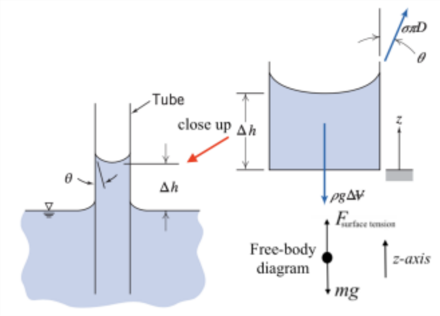


Figure: Cartoon of the effect of capillary action in a glass tube inserted into a pan of water. The force balance in the vertical is: $0 = F_{net,z} = \sigma\pi D\cos\theta - mg$.

*Prof. Wayne Hacker's Lecture slides.

Surface Tension and Capillary Effect*

Example 14 (cont.)

Applying Newton's second law to the free-body diagram:

$$
\begin{aligned}
0 = F_{\text{net},z} &= F_{\text{surface tension}} - F_{\text{gravity}} \\
&= (\sigma \cos\theta) \times \text{contact circumference} - mg \\
&= \sigma \cos\theta \pi D - mg \\
&= \sigma \cos\theta \pi D - \rho \forall_{\text{cyl}} g \qquad \left(\forall_{\text{cyl}} = \frac{\pi}{4} D^2 h\right) \\
&= \sigma \cos\theta \pi D - \rho \left(\frac{\pi}{4} D^2 h\right) g
\end{aligned}
$$

Solving this equation for σ gives a formula for the magnitude of surface tension.

$$
\Rightarrow \quad \sigma \cos\theta(\pi D) = \frac{\rho h D g}{4} (\pi D)
$$

$$
\xrightarrow{\div \pi D \cos\theta} \quad \sigma = \frac{\rho h D g}{4 \cos\theta}
$$

*Prof. Wayne Hacker's Lecture slides.

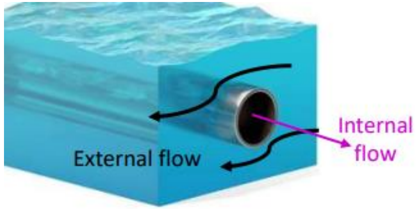
Description and Classification of Fluid Motions

- Differentiating between **viscous** ($\mu \neq 0$) and **inviscid** ($\mu = 0$) flows.

- Recognizing the visual characteristics of **laminar and turbulent flows**, and understanding how the Reynolds number (**Re = UL/v**) aids in determining the likelihood of a flow being laminar or turbulent.

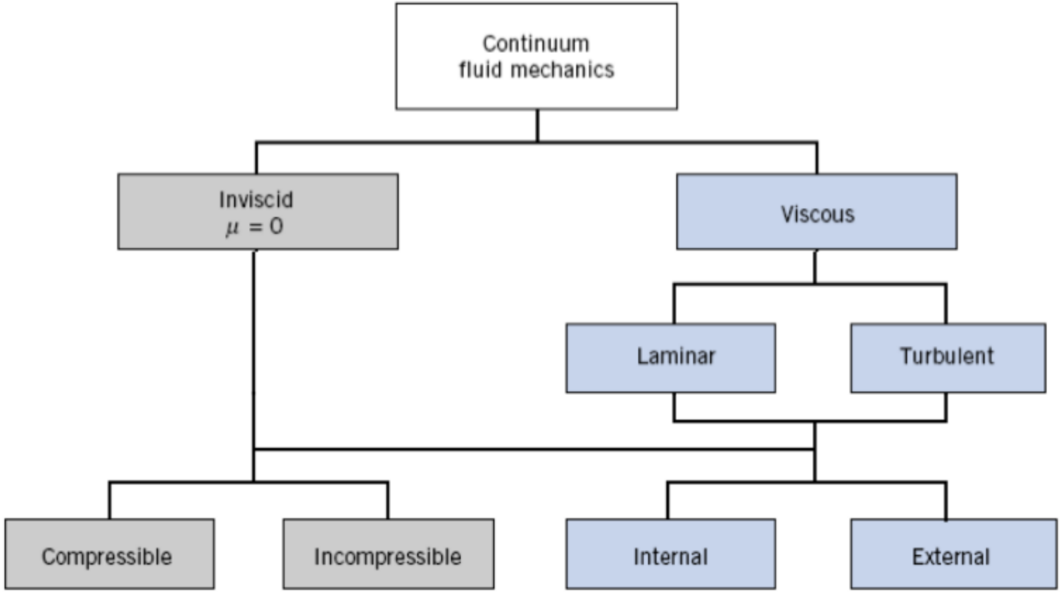
- Distinguishing between **compressible** ($\rho \neq$ constant) and **incompressible** (ρ = constant) fluids.

- Categorizing **internal, external**, and **channel** flows:
  - An instance of internal flow is exemplified by pipe or duct flow.
  - External flow can be illustrated by the motion of an aircraft through the atmosphere.

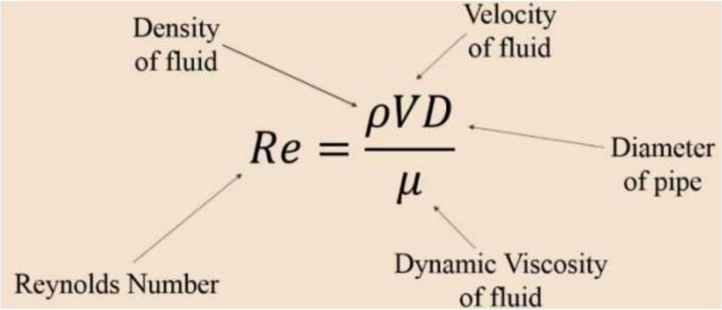


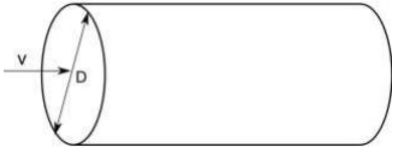
*Yunus A. Cengel, John M. Cimbala, Fluid Mechanics: Fundamentals and Applications, 4th edition (SI Unit). Mc Graw Hill. Published July 2, 2019.

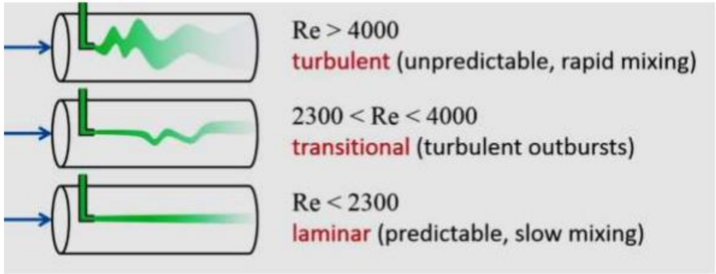
Description and Classification of Fluid Motions

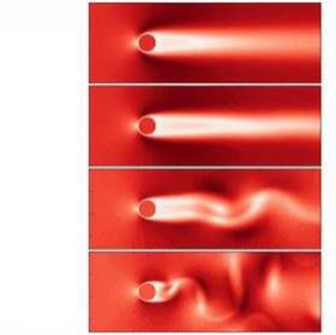


Reynolds Number









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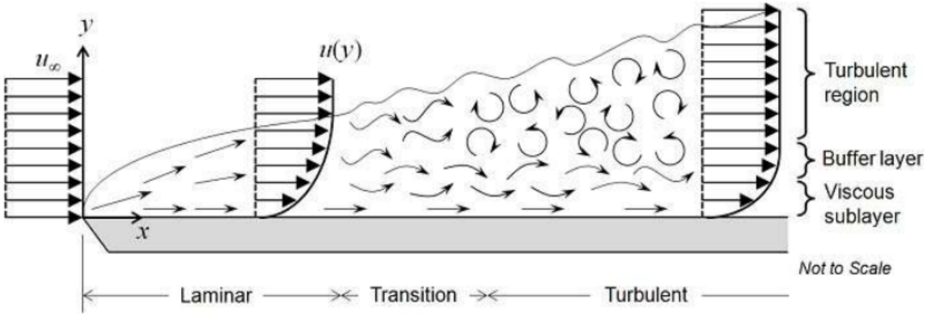
Reynolds Number for External Flows*



$$Re_x = \frac{\rho V x}{\mu} = \frac{V x}{\nu}$$

Where x is the characteristic length

A generally accepted value for the Critical Reynold number

$$Re_{cr} = \frac{\rho V x_{cr}}{\mu} = 5 \times 10^5$$

$Re < 5 \times 10^5$ (Laminar flow)

$Re > 5 \times 10^5$ (Turbulent flow)

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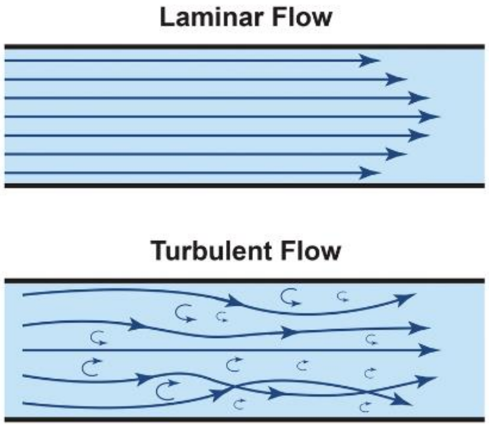
Laminar versus Turbulent Flow

Laminar flow refers to a well-organized movement of fluid marked by the presence of seamless layers. This type of flow is commonly observed when high-viscosity fluids like oils move at **slow speeds**. Note that laminar flow is associated with low Reynolds number (Re).

On the other hand, **turbulent flow** is an erratic motion of fluid that arises at high speeds and is defined by variations in velocity. This type of flow is typically seen in the movement of low-viscosity fluids such as air **at elevated velocities**.

Transitional flow, as the term suggests, is a type of fluid movement that oscillates between being laminar and turbulent.



Compressible and Incompressible Flows*

Incompressible Flow: This refers to a situation where the density of the flowing fluid remains relatively constant throughout the process, as seen in the case of liquid flow.
Compressible Flow: In contrast, compressible flow arises when the density of the fluid changes while it is in motion, such as in high-speed **gas flow** (i.e., Ma > 0.3).
Compressible Flow (air) Incompressible Flow (water)

$$\text{Ma} = \frac{V}{c} = \frac{\text{Speed of flow}}{\text{Speed of sound}}$$

Ma: Mach number
c = 343 m/s at 20ºC air

- When the Mach number (Ma) is equal to 1: *Sonic Flow*
- When the Mach number (Ma) is less than 1: *Subsonic Flow*
- When the Mach number (Ma) is greater than 1: *Supersonic Flow*
- When the Mach number (Ma) is greater than 4: *Hypersonic Flow*

When studying systems involving high-speed gas flows like rockets and spacecraft, the flow velocity is frequently described in terms of the Mach number.

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Steady versus Unsteady Flow

- The term **steady** denotes the absence of temporal variation at a specific point. Its counterpart is **unsteady**. In the realm of fluid mechanics, "unsteady" is a broad term encompassing any flow that lacks steadiness; however**, transient** is more commonly used for flows in the process of development.
- The term **periodic** is employed for describing a specific type of unsteady flow characterized by oscillations around a consistent average.
- Numerous machines such as turbines, compressors, boilers, condensers, and heat exchangers endure extended periods of operation under **constant conditions**, categorizing them as steady-flow devices.

Uniform versus Nonuniform Flow

The term uniform indicates a lack of spatial variation within a designated area.
Uniform flow signifies that all characteristics of the fluid, including velocity, pressure, temperature, and more, remain consistent across positions.

The flow immediately following the entrance of a smoothly contoured pipe is essentially uniform, with the exception of an exceedingly thin boundary layer near the surface.

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