Fluid Flow

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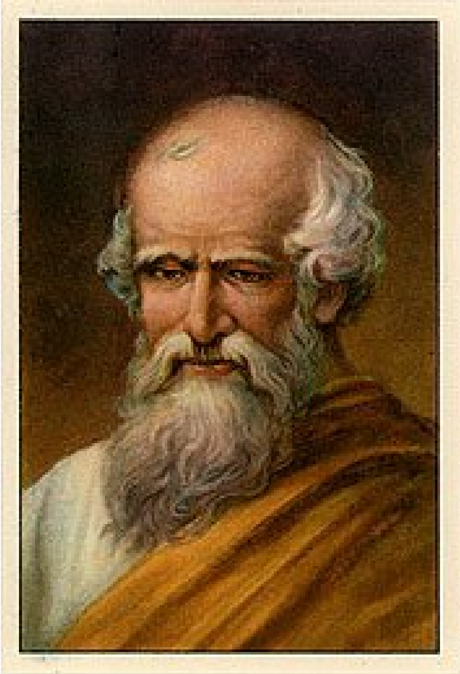
Introduction

- Short history on fluid dynamics
- Why bother studying fluid flow?
- Difference between Newtonian and Non-Newtonian Fluids
- Laminar vs. Turbulent Flow and the Navier-Stokes Equation
- Reynolds Number

Brief History

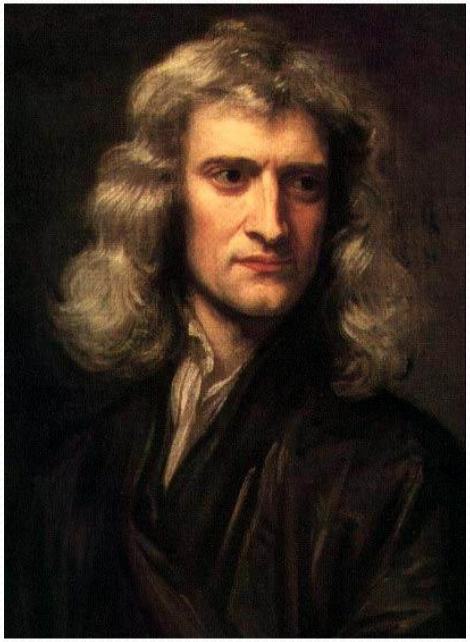
- Archimedes (285-212 B.C.) – formulated law of buoyancy and applied it to floating and submerged bodies



Brief History

- Isaac Newton (1642-1727) – postulated laws of motion and law of viscosity of linear fluids

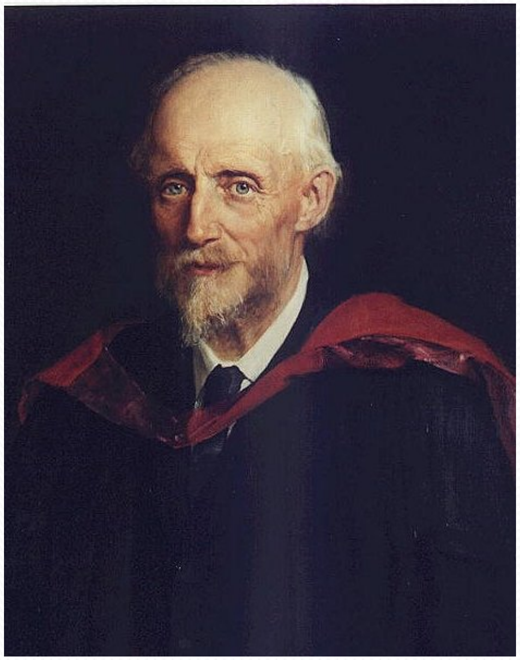
- Frictionless fluids – many problems solved by great mathematicians (Euler, Lagrange, Laplace, Bernoulli etc.)



http://psychogeeks.com/isaac-newton/

Brief History

- Osborne Reynolds (1842-1912) – classic pipe experiment illustrating importance of so-called 'Reynolds Number'



http://en.academic.ru/dic.nsf/enwiki/191600

Why Study Fluid Flow?

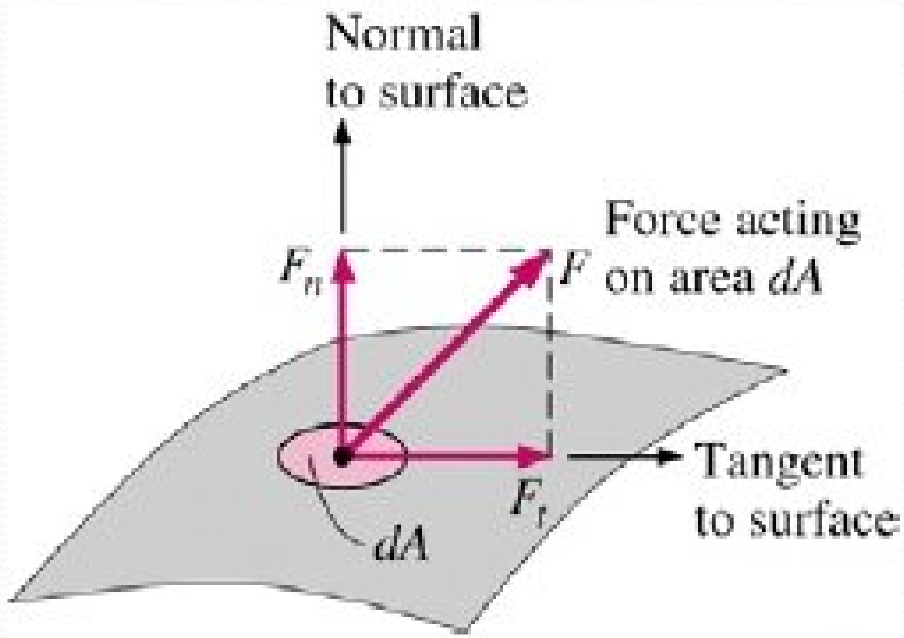
- Widely applicable to many phenomena: blood flow through arteries/veins, automotive design, aeronautics
- Deeper understanding can be used to design faster and more efficient ships/airplanes

Stress and Shear

- Stress: defined as force per unit area

-has magnitude and direction

- Can have both normal and tangential stresses



http://www.scribd.com/doc/10119418/Fluid-Mechanics-Lecture-Notes-I

Finding Newton’s Law of Viscosity

- We are going to model a ‘block of fluid’ as many sheets stacked on top of one another
- In this way we can figure out how the shear force is related to the viscosity

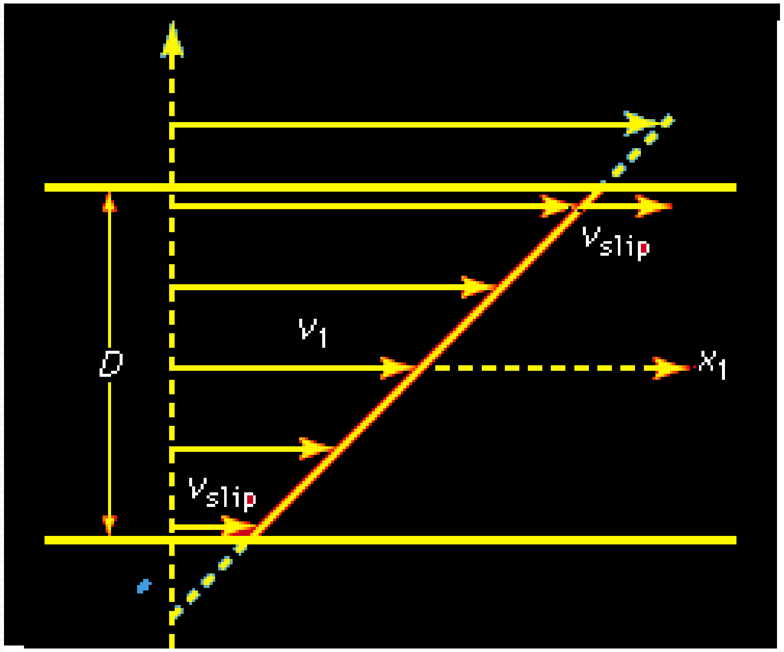
What is viscosity?

- Property of a fluid that describes its ability to resist flow
- It's a measure of the internal friction associated with this flow

Substance	Viscosity(kg/m*s)
Air	0.02
Water	1.00
Milk	1.13
Blood	4
Olive Oil	90
Motor Oil	320

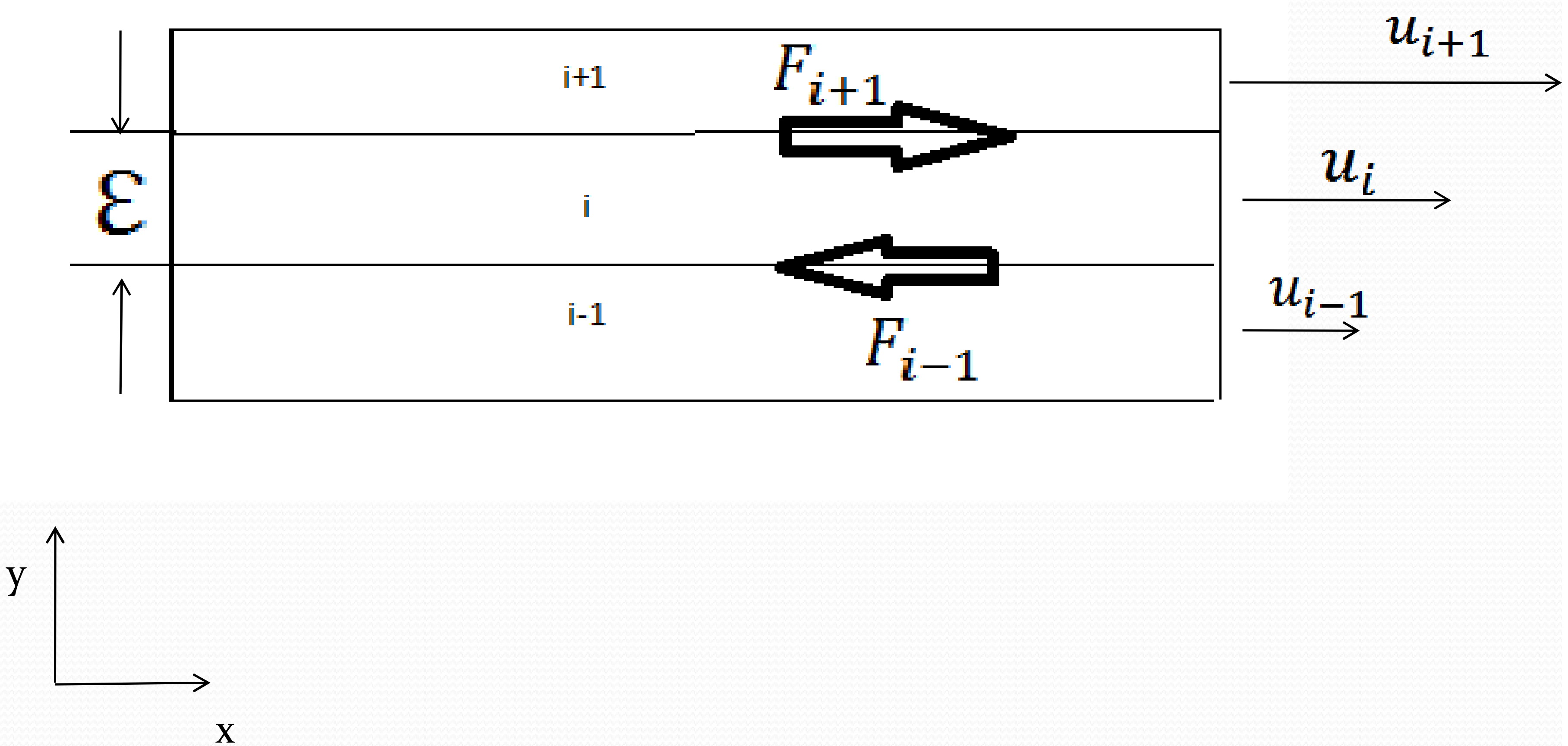
Stress and Shear

- Force in a fluid acts along the surface of each sheet and is proportional to the relative velocity



http://www.britannica.com/EBchecked/topic/211272/fluid-mechanic

Finding Shear Force



Finding Shear Force

- Forces act parallel to the sheets
- If we talk about force per unit area, find that:

$$\tau_{yx} \propto (u_{i+1} - u_i) + (u_{i-1} - u_i)$$

- As Ɛ gets smaller, the difference becomes a gradient

Shear Stress

- If we model a body of fluid as composed of many thin sheets, find that:

$$\tau_{yx} = -\eta \frac{du_x}{dy}$$

Velocity Gradient

Stress

Viscosity

Finding Shear Force

- Constant of proportionality here is the viscosity: η

- What are its units?

Units of Viscosity

$$[\eta] = \frac{N}{m^2}\left(\frac{m}{s}\frac{1}{m}\right)^{-1} = \frac{N * s}{m^2}$$

$$= \frac{kg}{m * s}$$

Newtonian vs. Non Newtonian Fluid

- Linear dependence of shear stress with velocity gradient: Newton's Law of Viscosity
- Viscosity will change only if temperature or pressure changes
- Don't resist much when a force is applied
- Ex: water

Newtonian vs. Non Newtonian Fluid

- Non-Newtonian fluids will change viscosity when a force is applied

- Can cause them to become thicker or thinner depending on the substance in question

DEMO!

Navier-Stokes Equation

- Set of non-linear partial differential equations that describe fluid flow

- Also used to model weather patterns, ocean currents, and airflow around objects

- Very difficult equation to solve

Navier-Stokes Equation

$$\rho\left(\frac{\partial \mathbf{v}}{\partial t} + \mathbf{v}\cdot\nabla\mathbf{v}\right) = -\nabla p + \mu\nabla^2\mathbf{v} + \mathbf{f}$$

Rate Change in
Momentum Density

Pressure Gradient

Viscous
Term

Body
Forces

Reynolds Number

- Ratio of inertial forces to viscous forces in a fluid
- Describes the relative importance of each term
- Important factor in determining the transition from laminar to turbulent flow

Reynolds Number

- Can be calculated from the Navier-Stokes equation
- More intuitively:

$$\frac{F_{inertial}}{F_{viscous}} = \frac{\frac{E_{kinetic}}{d}}{\tau * d^2}$$

$$= \frac{\frac{\rho u^2 d^3}{d}}{\eta \frac{u}{d} d^2}$$

Reynolds Number

$$Re = \frac{\rho u d}{\eta}$$

- η - viscosity
- ρ – density
- u - velocity
- d – characteristic length

Reynolds Number Units?

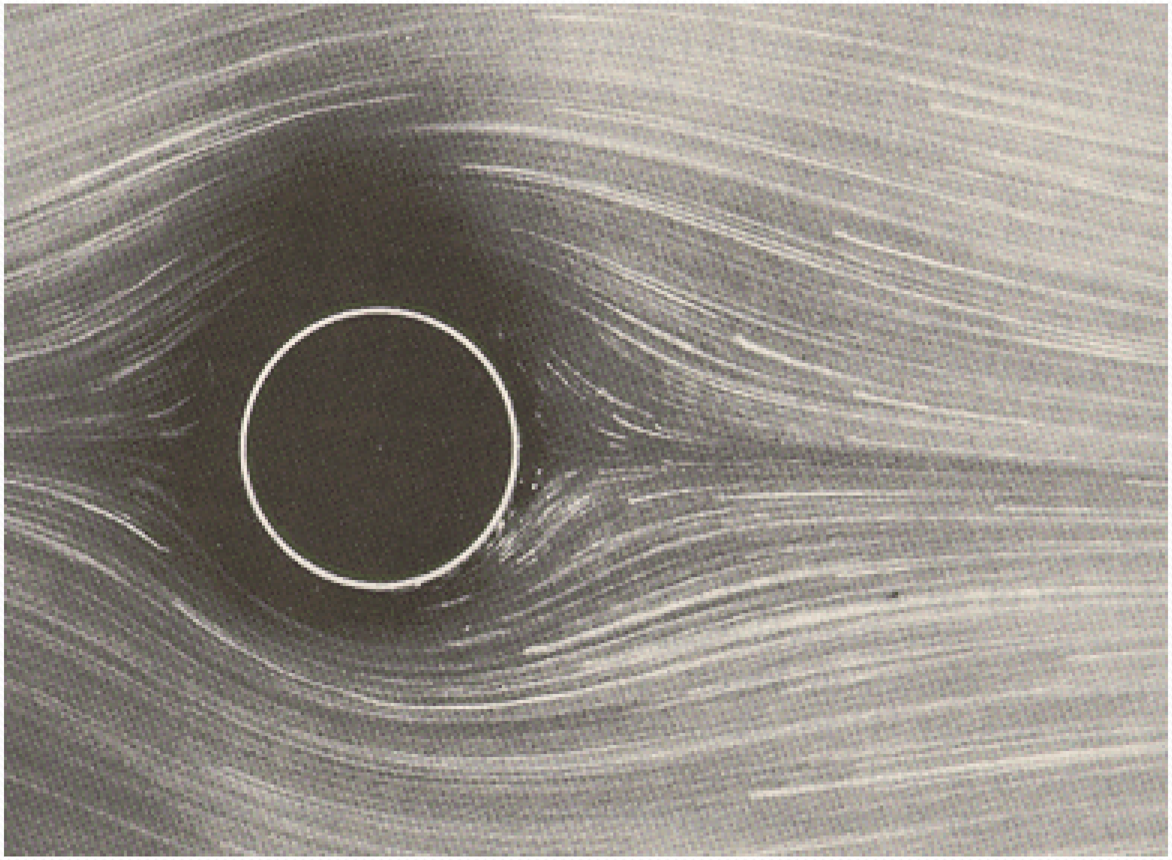
$$[Re] = \frac{\left(\frac{kg}{m^3}\right)\left(\frac{m}{s}\right)(m)}{\left(\frac{kg}{m*s}\right)}$$

- Reynolds number is dimensionless!

Laminar Flow

- Fluid travels smoothly in similar paths
- No mixing between adjacent 'sheets' of fluid
- Sheets slide over one another
- All flow properties constant at any given point (velocity, pressure, etc.)

Laminar Flow

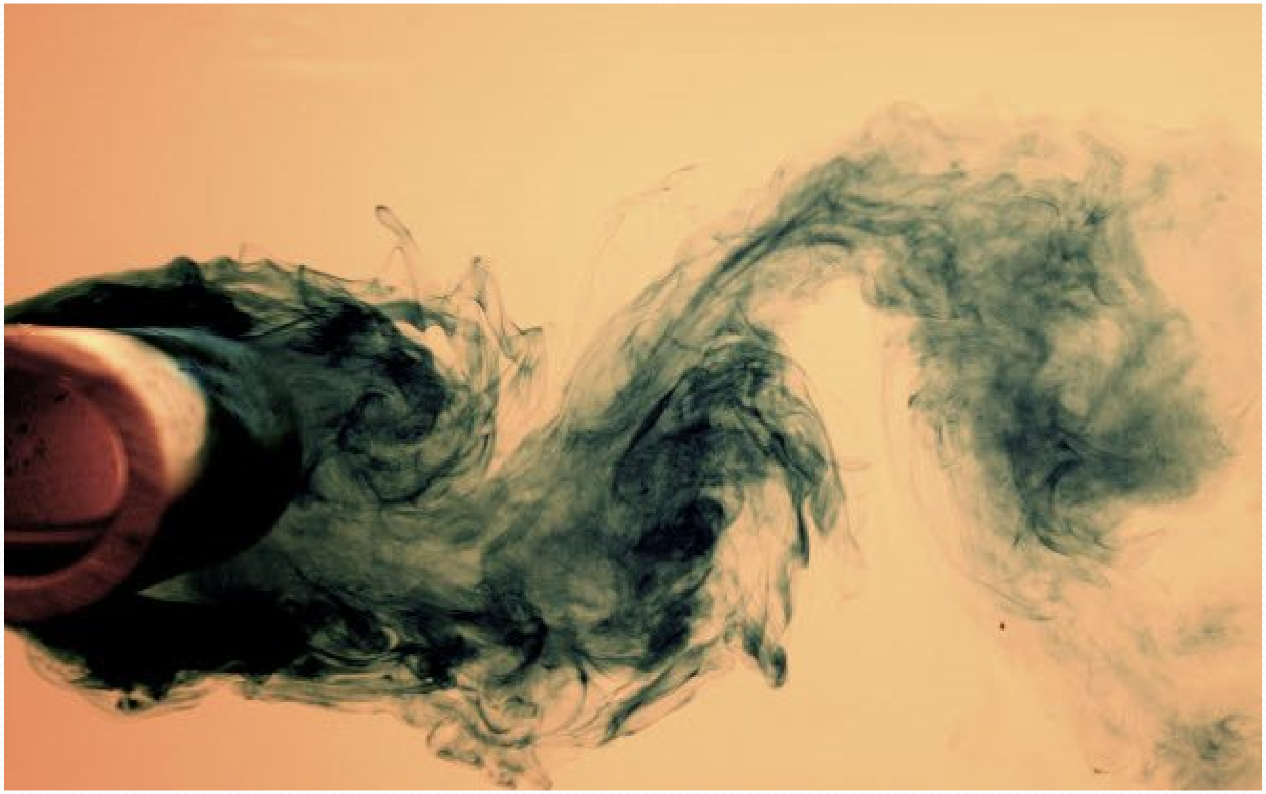


https://wiki.brown.edu/confluence/display/PhysicsLabs/PH

Turbulent Flow

- Formation of eddies and vortices associated with high Reynolds number fluids
- Flow becomes chaotic
- Complete description of turbulent flow still an unsolved problem of physics

Turbulent Flow



http://www.colorado.edu/MCEN/flowvis/gallerie/2010/Team-1/FV_popup1-8.htm

Laminar vs. Turbulent Flow

- Fluids behave very differently depending on the value of the Reynolds number

- Low Re – Laminar Flow
- High Re – Turbulent Flow

Questions?