1. Introduction
Some Basic Concepts
1. What is a fluid?
2. What Properties Do Fluids Have?

- Density
- Pressure
- Temperature
- Viscosity
- Velocity
- Compressibility

Fourier’s Law of Heat Conduction

Newton’s Law of Viscosity
3. What Constrains Fluid Motion?

Vanguard Class Submarine
Two Important Parameters

Rate of change of momentum (inertial force) = Sum of pressure forces, viscous forces and body forces

NACA 0012 Airfoil, Re = 1000000, M ~ 0  
Large Eddy Simulation  
Institute of Computational Fluid Dynamics  
Japan
3a. Ideal Flow

Viscous and compressible effects small (large Re, low M). Flow is a balance between inertia and pressure forces, i.e. acceleration vector balances the pressure gradient vector.

Streamline:
3a. Viscous Flow

Importance of viscous effects governed by

\[ \text{Re} = \frac{VL}{\nu} \]

Boundary layer:

What is the pressure gradient across a boundary layer?

No-slip condition:
3b Viscous Flow

Viscous region not always confined to a thin layer

Separation:
Separation and Wake Formation

Circular cylinder, $Re = 100000$, $M \sim 0$
Large Eddy Simulation
Institute of Computational Fluid Dynamics
Japan
3b Viscous Flow

Turbulence:

Laminar Flow:
Turbulence

$Re_0 = 3500$, Turbulent boundary layer
Guezenec and Nagib
Illinois Institute of Technology
3c. Compressibility

Importance of compressibility effects governed by \( M = \frac{V}{c} \)

- Incompressible Regime
- Subsonic Regime
- Transonic Regime
- Supersonic Regime
Flow Past a Circular Cylinder

Re = 10,000 and Mach approximately zero

Re = 110,000 and Mach = 0.45

Re = 1.35 M and Mach = 0.64

Pictures are from “An Album of Fluid Motion” by Van Dyke
Flow Past a Circular Cylinder

Mach = 0.80  Mach = 0.90  Mach = 0.95  Mach = 0.98

Pictures are from “An Album of Fluid Motion” by Van Dyke
Flow Past a Sphere

Mach = 1.53

Mach = 4.01

Pictures are from “An Album of Fluid Motion” by Van Dyke
3c. Compressibility

Some Qualitative Effects

Shock wave:

Hypersonic vehicle re-entry
NASA Image Library
3c. Compressibility

Some Qualitative Effects

- Expansion or isentropic compression wave:

Cone-cylinder in supersonic free flight, Mach = 1.84.
Picture from “An Album of Fluid Motion” by Van Dyke.
Summary

• What a fluid is. Its properties. The governing laws
• Reynolds number. Mach number
• How Newton’s 2\textsuperscript{nd} Law works as a vector equation
• Viscous effects: no-slip condition, boundary layer, separation, wake, turbulence, laminar
• Compressibility effects: Regimes, shock waves, isentropic waves.
• Initial ideas of concepts such as streamlines/separation
• Qualitative understanding