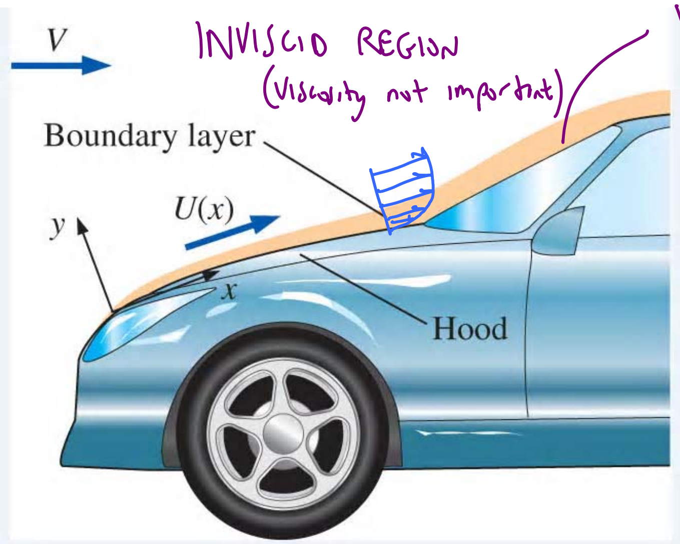
M E 320 Professor John M. Cimbala Lecture 02

Today, we will:

- Continue talking about classifications of fluid flow
- Quick review of dimensions, units, unit conversions, and significant digits
- Begin Chapter 2 – Properties of Fluids

B. Classification of Fluid Flows (continued)

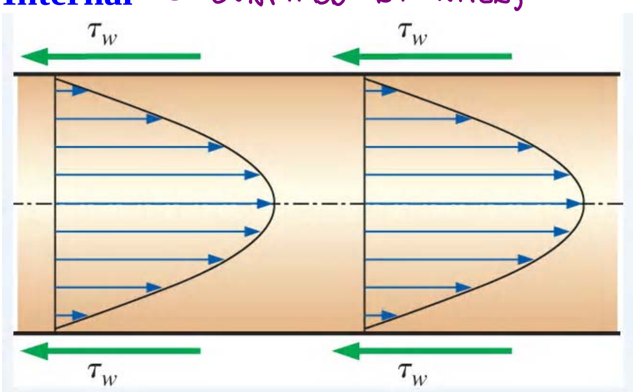
1. Viscous vs. inviscid regions of flow

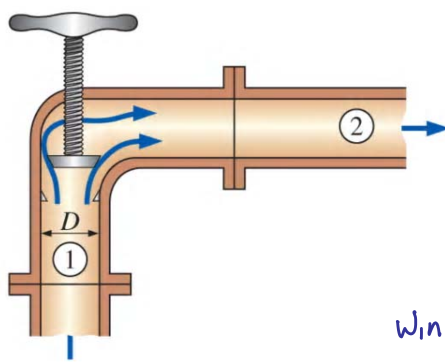


VISCOUS REGION
(viscosity is important)

2. Internal vs. external flow

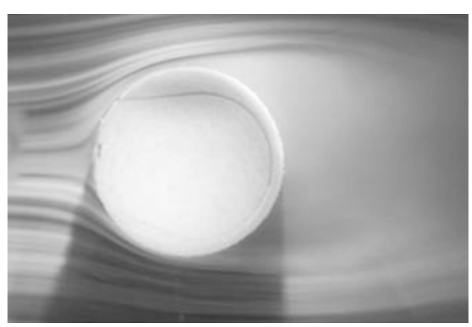
Internal = CONFINED BY WALLS





Wind tunnel wall

External = Not confined by walls



There still can be wall(s) like the ground or wind tunnel walls

B. Classification of Fluid Flows (continued)

3. Compressible vs. incompressible flow

Incomp → density $\rho = \frac{m}{V} \approx$ constant → (must be subsonic)

comp. ρ changes significantly (subsonic can be also compressible)

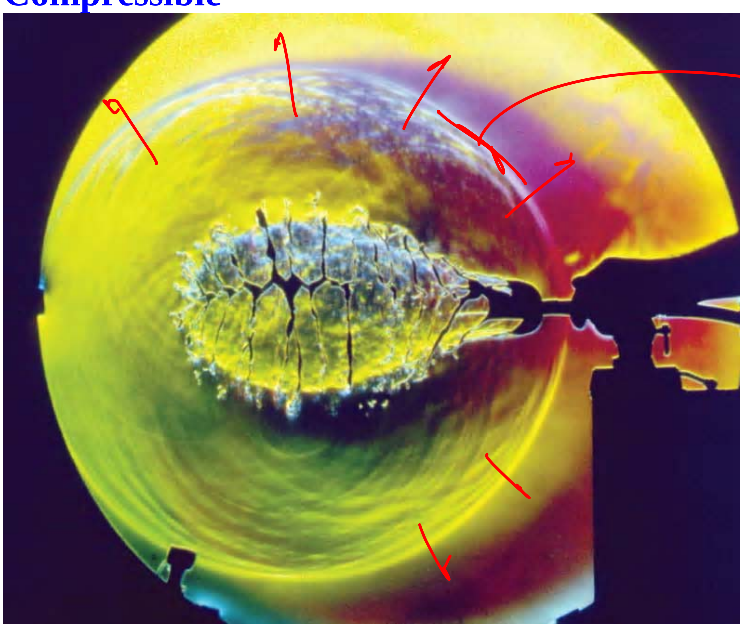
Define Mach number $= Ma = \frac{V}{c}$ — V: speed of object; c: speed of sound

ρ varies by $\lesssim 5\%$ when $Ma \lesssim 0.3$ → if $Ma \lesssim 0.3$, we approximate flow as incompressible

Air is a compressible gas → but in air at low speeds, flow can be approximated as an "incompressible" flow

Incompressible

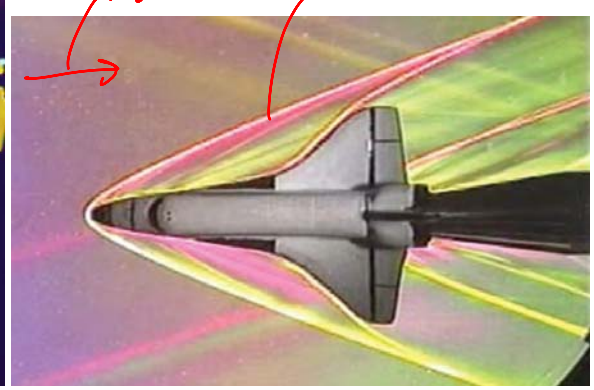
Compressible



Shock wave — Travels @ V > c

Ma > 1

Ma > 1 Oblique shock waves



B. Classification of Fluid Flows (continued)

4. Laminar vs. turbulent flow → chaotic, unsteady, random motion of eddies (vortices) → can be steady in the mean

smooth, orderly, typ. steady but can be unsteady or periodic

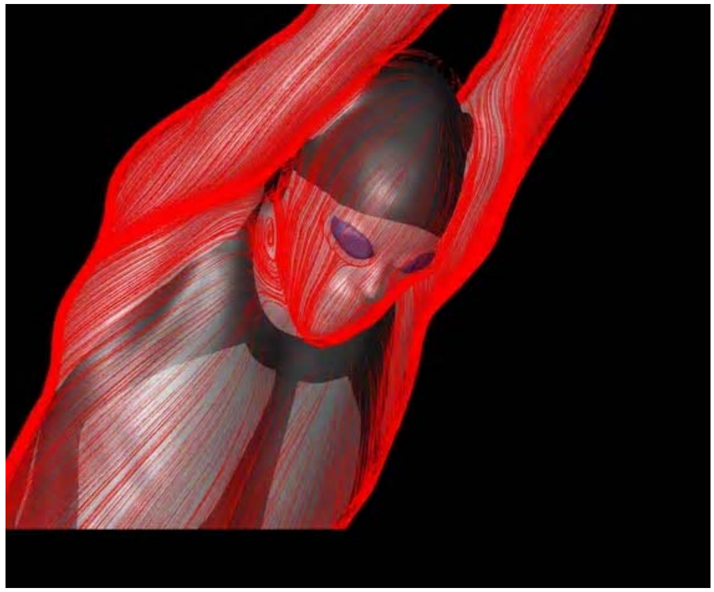
Laminar flow

Turbulent flow

Turbulent flow is always unsteady, but if it is steady in the mean we call it "stationary flow"

B. Classification of Fluid Flows (continued)

5. Natural vs. forced flow

Natural – Flow is not forced

Forced – Flow is forced (by fan, by muscles, etc)

6. Steady vs. unsteady

Steady: not changing with time

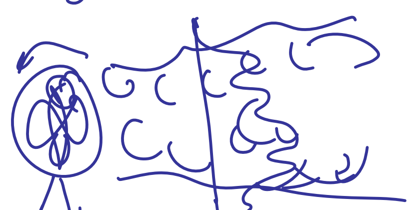
Unsteady: changes with time

Many flows are unsteady, but steady in the mean

Steady in the mean

Unsteady instantaneously

Eg. fan



Unsteady instantaneously

In mean, it looks steady

B. Classification of Fluid Flows (continued)

7. One-, two-, or three-dimensional

Fully 3-D → $\vec{V} = \vec{V}(x, y, z)$ — flow over a car is fully 3-D

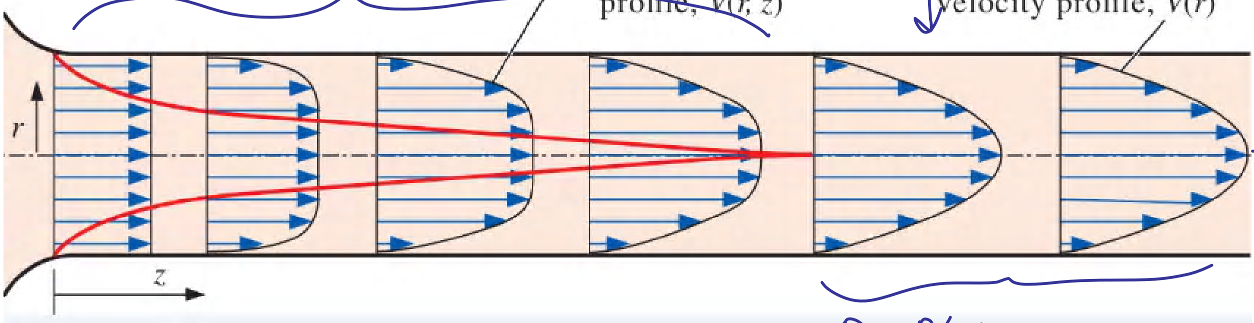
But, Flow around the antenna is approx. 2-D

$\vec{V} = \vec{V}(r, \theta)$

Eg. Developing pipe flow

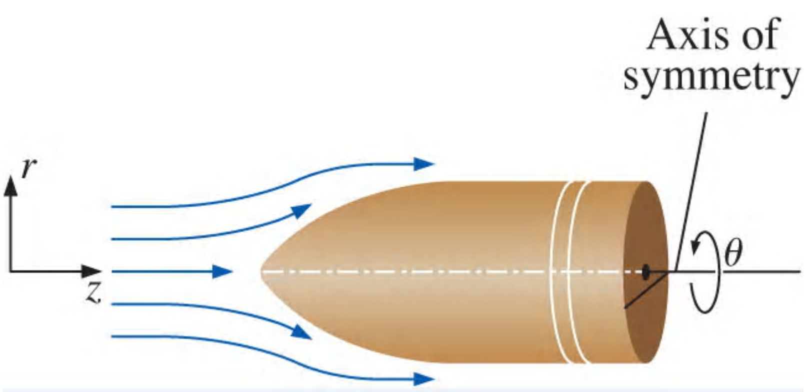
$\vec{V} = \vec{V}(r, z)$ in this region

$\vec{V} = \vec{V}(r)$ — 1-D in r in this region



$P = P(z)$ — 1-D in z

$\vec{V} = \vec{V}(r)$ → 1-D in r



When $\vec{V} = \vec{V}(r, z)$ we call it axisymmetric — a type of 2-D flow (not fnc. of θ)

C. Dimensions, Units, and Significant Digits

1. **Dimension =** characterization of a variable w/o a number   e.g. length

2. **Unit =** a way to assign a number to a dimension   e.g. 30.2 cm

3. **Unit conversions, unity conversion ratios**

Use unity conversion ratios = 1, no dimensions, (no net dimensions)

e.g. $\left(\frac{12\ \text{in}}{\text{ft}}\right) = 1 \quad \left(\frac{60\ \text{s}}{\text{min}}\right) = 1 \quad \left(\frac{1\ \text{kg}}{2.205\ \text{lbm}}\right) = 1$

Example: Unit conversions

Given: The mass of an object is $m = 2.00$ kg.

To do: How much does this mass weigh on earth in units of lbf?

Solution:

Newton $\vec{F} = m\vec{a}$

$\vec{W} = m\vec{g}$

$\downarrow \vec{W} \quad \downarrow \vec{g}$ same direction, so we can use scalars

$$W = mg = (2.00\ \text{kg})\left(9.807\ \frac{\text{m}}{\text{s}^2}\right)\left(\frac{\text{N}}{\text{kg}\cdot\text{m}/\text{s}^2}\right)\left(\frac{1\ \text{lbf}}{4.44822\ \text{N}}\right) = 4.409404\ \text{lbf}$$

unity conversion ratios

≈ 4.41 lbf

other unity conversion ratios

$1\ \text{lbf} = \text{slug}\ \frac{\text{ft}}{\text{s}^2} \rightarrow \left(\frac{\text{lbf}}{\text{slug}\cdot\text{ft}/\text{s}^2}\right)$ or $\left(\frac{\text{lbf}}{32.174\ \text{lbm}\ \text{ft}/\text{s}^2}\right)$

C. Dimensions, Units, and Significant Digits (continued)

4. Significant digits

- When mult. or dividing, answer should have the same # of sig. digits as the variable with the least # of sig. digits

- When adding or subtracting, align decimal place & choose the left-most least sig. digit

e.g. $3.02 + 0.00803$

Solve:

$$\begin{array}{r} 3.02 \\ +\ 0.00803 \\ \hline 3.02803 \end{array}$$

→ Ans $= 3.03$

Example: Significant digits

Given: A = 45.8023. B = 1.2. → A + B

To do: How many significant digits should you display in your answer?

Solution:

$$\begin{array}{r} 45.8023 \\ +\ 1.2 \\ \hline 47.0023 \end{array}$$

3 digits

Example: Speed of sound and significant digits

Given: An aircraft flies at speed V = 423.1 m/s through air at T = 300.3 K. The ratio of specific heats of air is k = 1.40, and the specific gas constant for air is R_{air} = 287.0 $m^2/(s^2K)$.

To do: Calculate the aircraft's Mach number to the correct number of significant digits.

Solution: Recall, $c = \sqrt{kRT}$ and Ma = V/c.

$$Ma = \frac{V}{c} = \frac{V}{\sqrt{kRT}} = \frac{423.1 \text{ m/s}}{\sqrt{(1.40)\left(287.0 \frac{m^2}{s^2 K}\right)(300.3 \text{ K})}} = 1.218037$$

k is limiting factor (3 digits)

$$Ma = 1.22$$

D. Properties of Fluids (Chapter 2)

1. **Kinematic properties** → Prop's related to fluid motion

   e.g. $\vec{V}$, $\vec{a}$ [see Ch. 4]

2. **Thermodynamic properties** → Prop's that determine the state

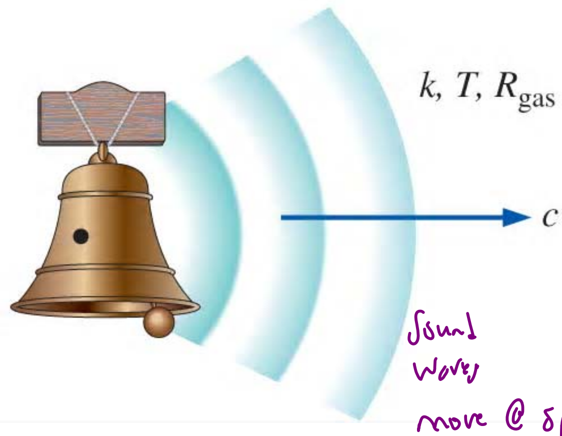
   e.g., T, P, v, u ⌒ specific internal energy

   ↑ specific volume $= \frac{Vol}{mass}$ → Thermo, we use v

   In fluids, we use ρ instead of v $\quad \rho = \frac{1}{v}$ $\quad \boxed{\rho = \frac{Mass}{Vol}}$

3. **Other (miscellaneous) properties**

   a. speed of sound



Sound waves move @ speed c

Sound waves are pressure waves (changes in pressure)

Ideal gas → $\boxed{c = \sqrt{kRT}}$

↑ ✩ Always use absolute T (K) not (°C)

R = specific gas constant

$\boxed{R = \frac{R_u}{M}}$ → R_u universal gas const, → M molecular weight

typical → air @ 20°C $\quad c = 343.2$ m/s

water @ 20°C $\quad c = 1480$ m/s

[recall, Ma = Mach # $= \frac{V}{c}$]