In this lesson, we will:

- Discuss various ways to classify fluid flows (laminar vs. turbulent, compressible vs. incompressible, steady vs. unsteady, etc.)
- Define the **no-slip condition**
- Define **Mach number**
- Do an example problem

CLASSIFICATION OF FLUID FLOWS

1. Viscous vs. inviscid regions of flow

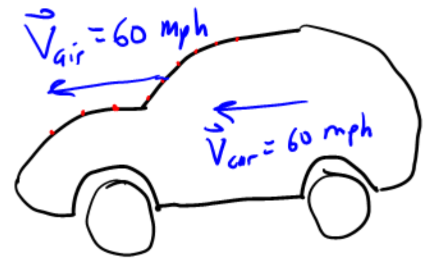
Viscous → friction between fluid particles

inviscid → misnomer

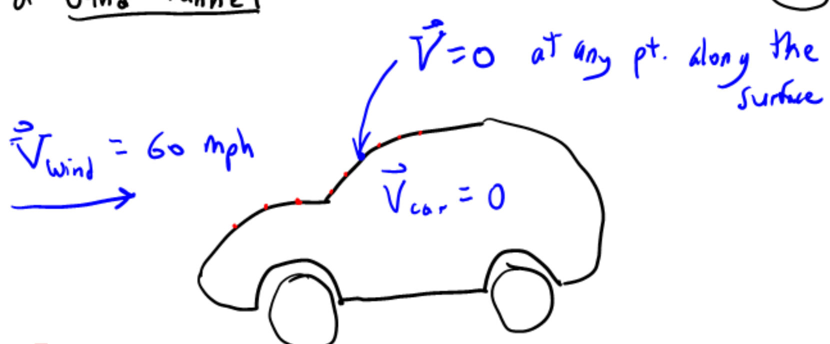
Inviscid does not mean the fluid has no viscosity! It means that viscous effects are negligible compared to inertial or pressure effects.

Viscous effects are always important near a wall

at a wall, $\vec{V}_{fluid} = \vec{V}_{wall}$ (At any pt along the surface)



OR, in a wind tunnel



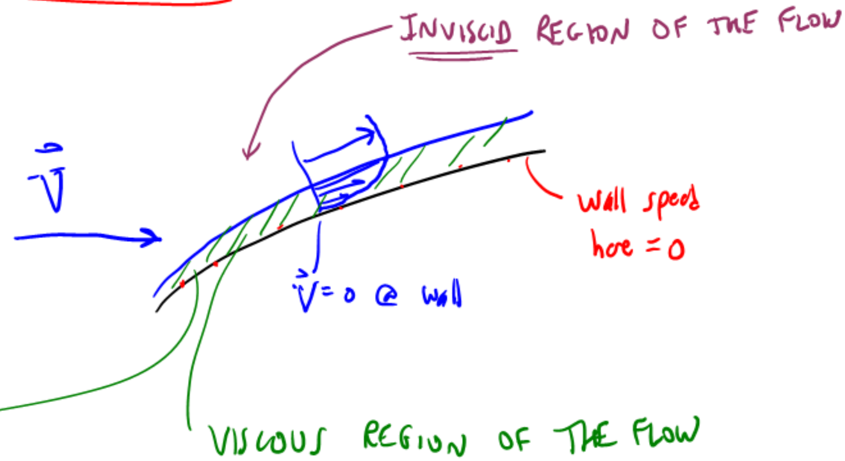
THE NO-SLIP CONDITION

Fluid near a wall is influenced strongly by friction (Viscous region)

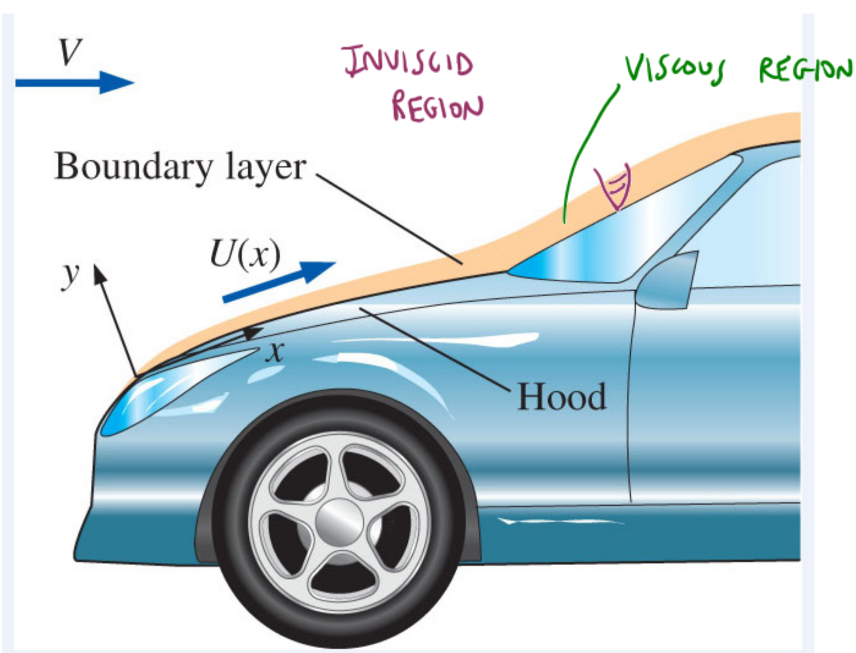
Fluid away from a wall is not strongly influenced " (inviscid ")

Viscous effects are due to a fluid property called **viscosity**, μ ✱

Boundary Layer

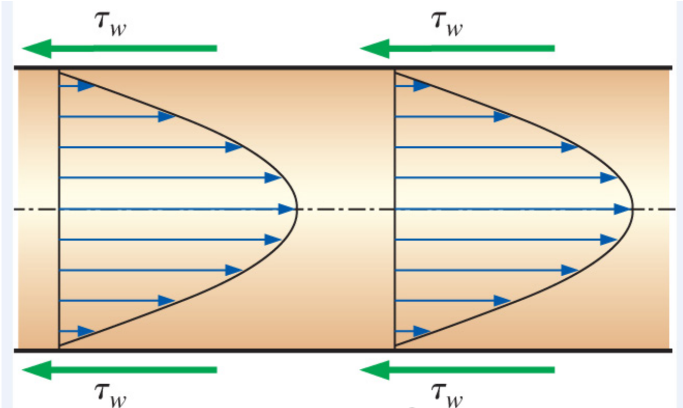


Define a BL → **BL = a thin layer near a wall where viscous effects are significant** ✱

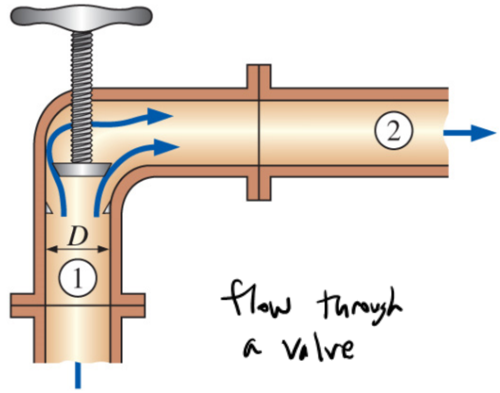


2. Internal vs. external flow

Internal — confined by walls or between walls

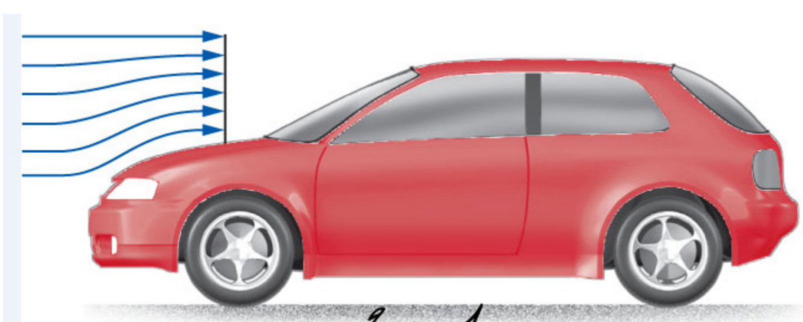


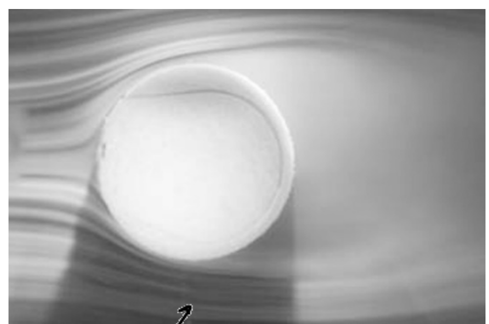
pipe flow



flow through a valve

External — flow not confined by walls





can have some walls, but "far away" or part of the flow field

3. Compressible vs. incompressible flow

Incompressible → if density $= \rho = \frac{m}{\forall} \approx$ constant

Compressible → if changes in ρ are significant

V = speed
$\vec{V}$ = velocity
$\forall$ = volume

Define Mach number

$$Ma = \text{Mach } \# = \frac{V}{c}$$

V — speed of the fluid
c — speed of sound in the fluid

ρ changes by $\approx 5\%$ when $Ma \approx 0.3$

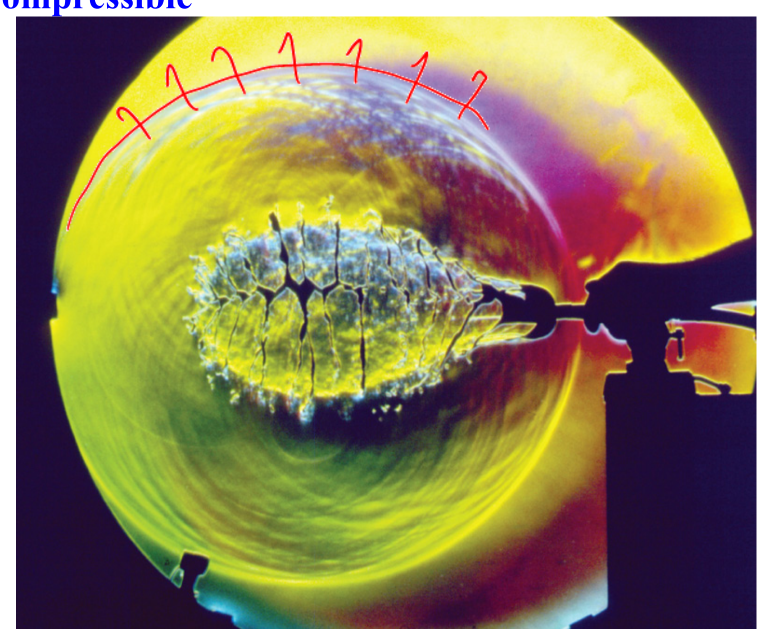
So, if $Ma \lessapprox 0.3$, we approximate the flow as incompressible

NOTE: AIR IS A COMPRESSIBLE FLUID – But we can approximate it as incompressible at low Ma.

Incompressible

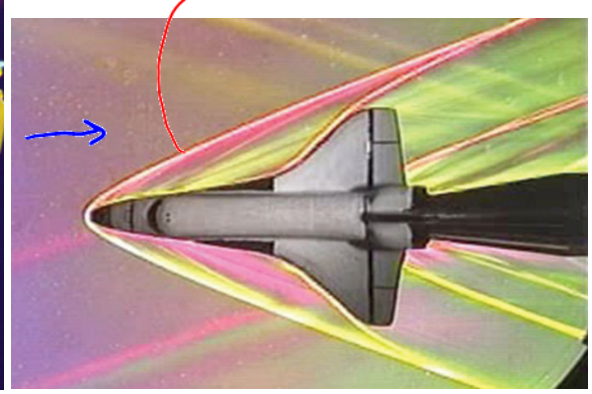
plane at low speed

Compressible



If $V > c$, $Ma = \frac{V}{c} > 1$ SUPERSONIC

oblique shock



Speed of Sound in Air

Air is approximated as an ideal gas

c = speed of sound (some books use a)

$$c = \sqrt{kRT}$$

where $k = \frac{c_p}{c_v}$ = ratio of specific heats

R = specific gas constant

$$R = \frac{R_u}{M}$$

R_u: UNIVERSAL GAS CONST.

M: molecular weight

Example: @ $T = 20.0°C$ (air), calc c

Soln:

$$c = \sqrt{kRT}$$

$$= \sqrt{k \frac{R_u}{M_{air}} T}$$

MUST BE ABSOLUTE T !!

$$= \sqrt{(1.40) \frac{8.314 \frac{kJ}{kmol \cdot K}}{28.97 \frac{kg}{kmol}} (20.0 + 273.15) K \left(\frac{kN \cdot m}{kJ}\right)\left(\frac{1000\ kg \cdot m}{s^2 \cdot kN}\right)}$$

unity conversion factors (ratios)

$c = 343.19\ m/s$

$$c = 343\ \frac{m}{s}$$

Example: Compressible vs. Incompressible Flow

Given: A military jet flies at 464 miles per hour through a region of the atmosphere where the ~~speed of sound is 278 m/s~~. temperature is 20.0°C.

To do: Calculate the Mach number and determine whether this flow is subsonic or supersonic, compressible or nearly incompressible.

Solution:

$$V = 464 \ \frac{mi}{h}$$

$$c = 343.19 \ \frac{m}{s} \quad \text{(previous pg.)}$$

$$Ma = \frac{V}{c} = \frac{464 \ \frac{mi}{h}}{343.19 \ \frac{m}{s}} \left(\frac{1 \ h}{3600 \ s}\right)\left(\frac{1609.3 \ m}{mi}\right) = 0.60440 \ [-]$$

unity conv. ratios

no units

Ans. $Ma = 0.604$

Since $Ma < 1$, Subsonic

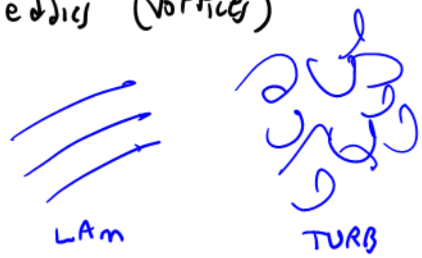
Since $Ma \gtrsim 0.3$, this is Compressible

If run an experiment in water with a model (incompressible) you could have significant error

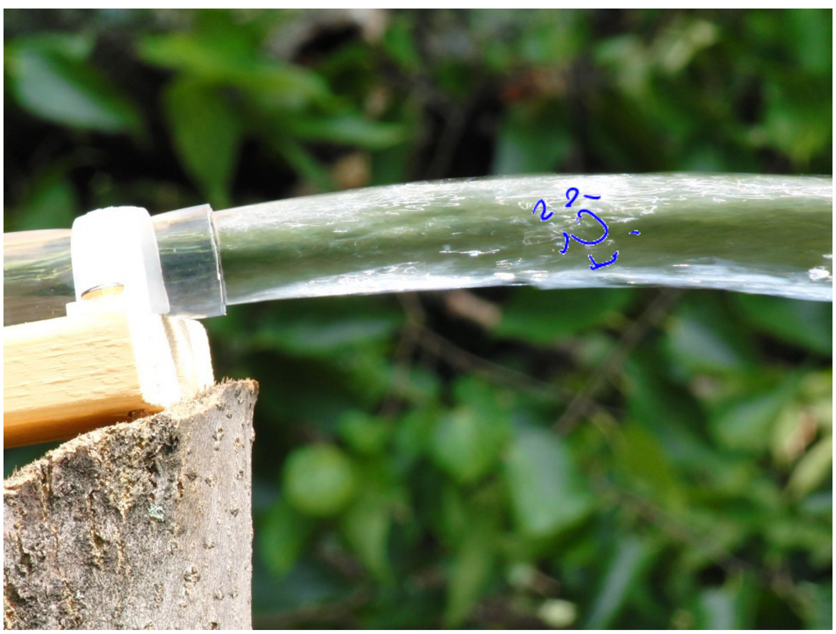
4. Laminar vs. turbulent flow

Laminar: Smooth & orderly, typically steady but can be unsteady

Turbulent: chaotic, unsteady, random eddies (vortices)



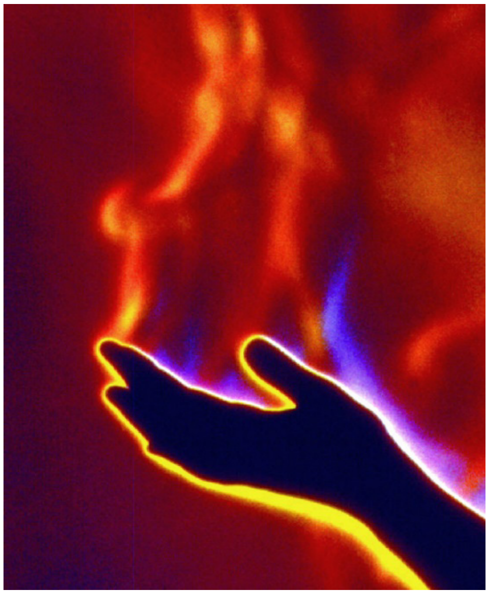
Laminar flow (Typ. low speed)

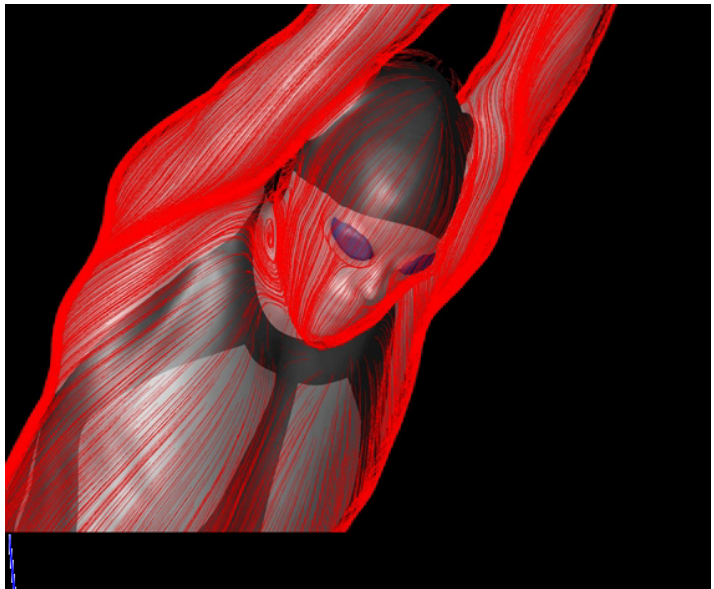


Turbulent flow (Typ at high speed)

Turbulent flow can be steady in the mean

5. Natural vs. forced flow





Natural – No fan or anything forcing the flow

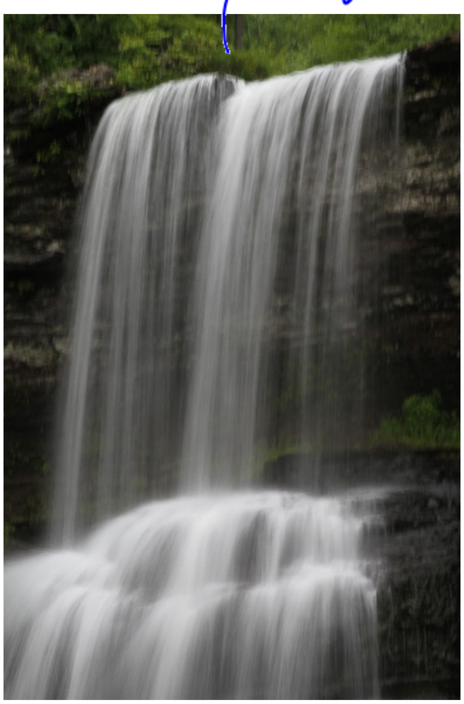
Forced — fan or muscles, etc. forcing the flow

6. Steady vs. unsteady

Long-time exposure

"Steady" in the mean

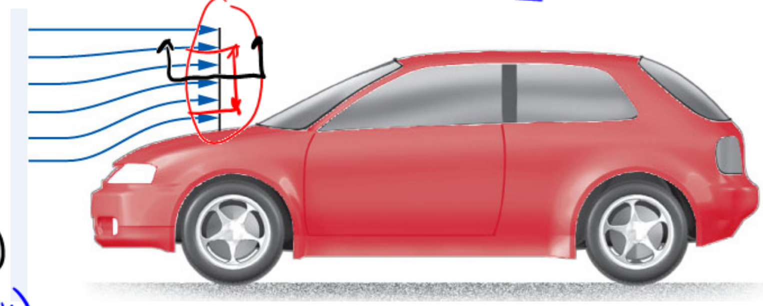
unsteady (instantaneous snap shot)



Steady in the mean **Unsteady instantaneously**

Steady in the mean

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



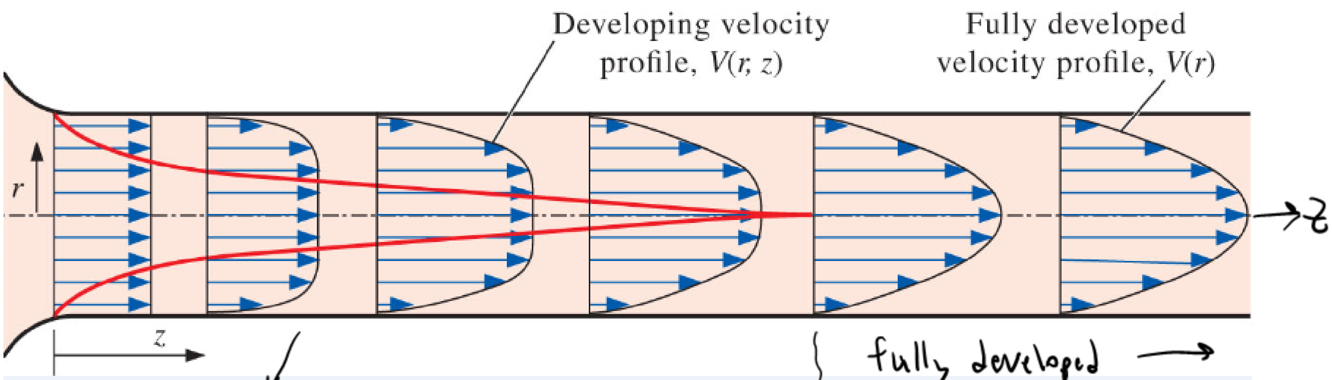
- Flow over a car is 3-D

$$\vec{V} = \vec{V}(x, y, z)$$

- Flow over the antenna can be approximated as 2-D $\vec{V} = \vec{V}(r, \theta)$

or $\vec{V} = \vec{V}(x, y)$

Eg. Pipe flow



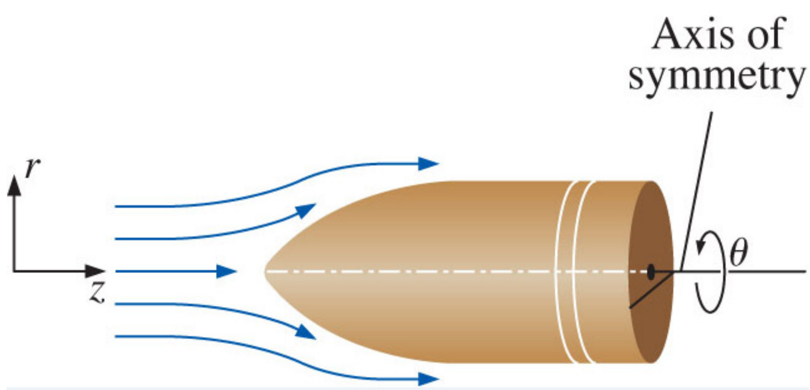
$\vec{V} = \vec{V}(r, z)$ — 2-D

fully developed →

$\vec{V} = \vec{V}(r)$ only — 1-D

$P = P(z)$ only — 1-D

Axisymmetric



$\vec{V} = \vec{V}(r, z)$ $\vec{V}$ not a fnc. of θ 2-D

3-D $\vec{V}$ = fnc of 3 variables

2-D " — " " 2 "

1-D " — " 1 "