Turbulent Pipe Flow

Learning Objectives:
- Explain laminar, transitional, and turbulent flow
- Explain the terms "turbulent stress" and "Reynolds decomposition"
- Describe the velocity profile in turbulent pipe flow and explain why it is "flatter" than in laminar flow.

Motivational Question:
- What would respiration be like if our blood flow were not turbulent?
Turbulent Pipe Flow:

As valve opens slowly:

Reynolds Decomposition:

Once we reach stationary turbulence with $\bar{u} = \text{const.}$:

$$u(t) = \bar{u} + u'(t)$$

Note:

- $u' = \emptyset$ positive/neg. values cancel
- $\bar{u}^2 = \emptyset$ and $\bar{u}u' = ?$ (unknown)
- positive values accumulate
Physics of Shear Stress.

Wind $\mathbf{v}$

$\tau = \mu \frac{\partial u}{\partial y}$

No slip $y = 0$

$\tau = \tau_w$

Flat plate

Analogy: heat diffusion.

$q = \text{flux of heat} = -k \frac{dT}{dy}$

Conductivity.

Physics Continued.

$u \sim$ related to momentum

$T \sim$ related to heat.

$L \cdot \mu$ is rate of diffusion of momentum.

Occurs by drag (friction) on neighboring fluid particles.

Brownian motion causes exchange.
Turbulent Mixing:

Recall videos: Turbulence ENHANCES mixing.

Boundary Layer:

Laminar $\rightarrow$ slow diffusion of momentum (velocity)

Turbulent $\rightarrow$ rapid diffusion of momentum.

Pipe Velocity Profiles:

Laminar, $\tau = \mu \frac{\partial u}{\partial y}$

Turbulent, $\tau = \eta \frac{\partial u}{\partial y} = -\frac{2}{3} u'v'$

Eddy viscosity.
Calculations:

Reynolds Number:
Predicts turbulent state

\[ Re = \frac{VD}{\nu} \]

> 4000 = turbulent in pipe.

Shear velocity:
Used to study shear stress
near pipe wall.

\[ \sqrt{\frac{\tau_w}{\rho}} = u_* \]

Units of velocity.

Turbulence Intensity:
Measure of "strength" of
the turbulence

\[ \varepsilon = \sqrt{\overline{u'^2}} \]

\[ \frac{\text{standard deviation}}{\text{average of } u} \]