3. Turbulent Flow

- 1. What is turbulence?
 - Phenomenon / Characterization
 - Why is it difficult to model?
- 2. Type of turbulent flows
 - Free turbulence
 - Boundary layers
- 3. Approach to modeling \rightarrow Later



Leonardo da Vinci drawing turbulence



3. Turbulent Flow - Objectives

- 1. Understand the influence of viscosity on flow
- 2. Understand basic differences between turbulent and laminar flow characteristics
- 3. Boundary layer theory



3. Turbulent Flow - Examples







<u>Flow visualization</u> of a turbulent jet, made by <u>laser-induced</u> <u>fluorescence</u>.



3. Turbulent Flow - Intro



https://www.youtube.com/watch?v=1 oyqLOqwnI



3. Turbulent Flow - Definitions

Turbulence is random and chaotic

Not predictable, and the flow development cannot be determined by forehand

Turbulence is a property of the flow

turbulence remains "the most important unsolved problem of classical physics"



3. Turbulent Flow - Intro

In turbulent flow, the velocity and pressure is highly unsteady. Their values are fluctuating

Turbulent flow is characterized by:

- 1. Disorder
- 2. Efficient mixing (Diffusive)
- 3. Vorticity (Irregularly distributed, 3-dimensional)

NB: Vorticity always present in viscous flow, therefore don't think vorticity is only related to turbulence



3. Turbulent Flow - Intro

- Experiments by Osborne Reynolds in 1880's
- Non-dimensional Reynolds number important to determine if flow is turbulent or laminar

"When the velocities were sufficiently low, the streak of colour extended in a beautiful straight line through the tube..."

(from O. Reynolds paper in the 1883)



 Re_{D}



Reynolds' experiments



https://www.youtube.com/watch?v=ontHCul6eB4



3. Turbulence Modeling – Free turbulence



Figure: *Streamwise* density gradient of plane turbulent mixing layer.



Figure: Free shear flow illustrating laminar, transition and turbulent phases in jet flow



3. Turbulence Modeling – Wake flow





Increased momentum exchange between free stream and boundary layer. Delay separation point \rightarrow smaller wake \rightarrow less drag



3. Turbulence modeling – *Turbulent boundary layer*





3. Turbulence modeling – *Turbulent boundary layer*



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