II. Fundamentals & Differential Theory

A. Lectures 14-15: Fluid Kinematics

Things you should know

- Identify whether a flow is 1D, 2D, 3D and/or axisymmetric
- The difference between a Lagrangian and Eulerian reference frame
- Meaning of the three basic modes of kinematic motion: translation, rotation and deformation
- Definition and physical meaning of streamlines and streaklines
- Definition and physical meaning of vorticity and irrotational flow
- Difference between local acceleration and the material derivative
- What the continuity equation is (compressible and incompressible), and what it means physically

Calculations you should be able to do

- Plot a velocity field.
- Find a vorticity given the velocity
- Determine if a flow field is irrotational.
- Find the streamfunction and plot streamlines given the velocity
- Find the velocity given the streamfunction.
- Calculate the local acceleration, convective acceleration, and/or the material derivative
- Use a shell balance to write a differential mass balance
- Find a missing velocity component using the continuity equation
- Determine if a flow field satisfies conservation of mass.

B. Lectures 15-16: Fluid Dynamics (Navier-Stokes)

Things you should know

- Definition and physical meaning of the rate-of-strain tensor and how it relates to deformation
- What the stress tensor means physically, including the difference between a normal and a shear stress
- Relationship between total stress tensor, pressure, viscous stress tensor
- Surface forces versus body forces
- Newton's law of viscosity (tensor version): what it is, what it means physically
- What the Cauchy momentum equation is and what the terms mean physically
- Assumptions needed for the Navier-Stokes equation
- Boundary conditions for NS: no-slip, no-penetration

Calculations you should be able to do

- Given the velocity, calculate components of the rate-of-strain and Newtonian viscous stress tensors.
- Given a rate-of-strain tensor and a direction, calculate the deformation.
- Calculate the total stress from the viscous stress and pressure.
- Given a stress tensor, find the force vector on a surface.
- Given 3 of the 4 expressions (v_x, v_y, v_z, P), find the 4^{th} using the NS equation
- Identify the correct BCs for a NS problem from a physical description of the problem

C. Lectures 18-21: Unidirectional Flow, Creeping/Invicid Flow

Things you should know

- Examples of unidirectional flow: Couette flow (simple shear), Poiseuille flow (pipe flow)
- What common assumptions (e.g. steady, 2D or axisymmetric, fully-developed, unidirectional) mean physically.
- Qualitative features of the velocity profile of pipe flow for a power-law fluid
- How the power-law Reynolds number is defined
- Non-dimensionalization of Navier-Stokes (high and low Re)
- What Stokes equation and Euler's equation mean and physical situations when they apply
- The connection between inviscid flow & irrotational flow

Calculations you should be able to do

- Simplify the NS equation using assumptions with physical names (e.g. steady, fully developed, unidirectional)
- Solve unidirectional flow problems (e.g. Couette & Poiseuille flow) using NS
- Find the average velocity, wall shear stress and/or the friction factor for pipe flow
- Solve unidirectional flow problems for a power-law fluid
- Simplify the drag force formula in cartesian coordinates
- Given pressure and velocity fields for a creeping/inviscid flow and a simplified drag force formula, calculate the form/friction/total drag force and/or the drag coefficient.

D. Lectures 22-24: Advanced Flow Concepts

Things you should know

- D'Alembert's paradox and resolution
- What the Boundary Layer equations are and when they apply
- Qualitative features of the boundary layer velocity profile
- Concept of average velocity profiles and why we need them in turbulent flow
- The concept of eddy diffusivity and how it applies to turbulent flow
- How the velocity profile of turbulent flow compares to laminar flow
- What CFD is and why it is useful
- What the pressure Poisson equation is

Calculations you should be able to do

- Use the Von-Kármán–Pohlhausen solution to find a boundary layer thickness and drag force/drag coefficient.
- Given an average velocity profile for turbulent pipe flow, calculate the friction factor.
- Run and interpret a CFD code
- Calculate discrete derivatives using finite differences
- Use CFD data and discretized derivatives to calculate a drag force.