I. Phenomenology & Dimensional Analysis

A. Lectures 2-3: Math and Python Review

Things you should know

- The difference between a linear and nonlinear equation
- What a scalar, vector and tensor are

Calculations you should be able to do

- Use Newton's method to find the root of a nonlinear equation
- Vector products (dot product, cross product) and vector partial derivatives (graident, divergence, curl) in Cartesian coordinates
- Surface and volume integals in Cartesian, polar/cylindrical or sphereical coordinates.

B. Lectures 4-6: Fluid Properties and Dimensional Analysis

Things you should know

- Definition of a fluid
- What the continuum approximation means
- What incompressibility means and whether liquids or gases are incompressible
- What density, surface tension and viscosity mean physically
- The concept of a dimensions and a unit system
- Identify common stress scales (viscous, intertial, etc.) in a fluid
- Definition and meaning of common dimensionless numbers (e.g. f, Re, Ca, C_D)
- Definition of similarity and its relation to dimensional analysis

Calculations you should be able to do

- Use density, specific gravity, specific weight, viscosity, & surface tension in calculations
- Use and convert between SI and English units
- Non-dimensionalize an equation
- Use the Pi theorem to determine the number of dimensionless groups and then find dimensionless groups that characterize a system
- Reason about scales and make order of magnitude estimates based on dimensionless numbers
- Use similarity to scale a process

C. Lectures 7-9: Pipe Flow

Things you should know

- Qualitative understanding of pressure drop and wall shear stress
- Definition and meaning of the friction factor & Reynolds number
- Identify and explain the qualitative regimes (laminar, turbulent) on the Moody chart; identify the transition Reynolds number.
- Definition and meaning of the dynamic pressure
- Newton's law of viscosity and non-Newtonian (shear-thickening, shear-thinning) constitutive laws

Calculations you should be able to do

- Given Q and D, calculate Re, f and/or ΔP for a circular, smooth pipe in laminar or turbulent flow using either a correlation or the Moody chart
- Calculate Re, f and/or ΔP for a pipe with height changes, wall roughness or non-circular pipes
- Calculate Re_{PL}, f and/or ΔP for a power-law fluid

D. Lectures 10-11: Drag

Things you should know

- Definition and meaning of the drag coefficient
- Difference between form and friction drag; what is streamlining
- Identify and explain the qualitative regimes (laminar, turbulent wake/laminar boundary layer, turbulent wake/turbulent boundary layer) of external flow on blunt objects of C_D versus Re; identify the transition Reynolds numbers.
- Explain the qualitative behavior of boundary layers on flat plates

Calculations you should be able to do

- Calculate the drag force for a blunt object using drag coefficient correlations or a plot of C_D
- Calculate the drag force for a flat plate using drag coefficient correlations or a plot of C_f
- Determine whether a boundary layer is laminar or turbulent and calculate its thickness
- Calculate a terminal velocity or use a terminal velocity to calculate a drag force

II. Fundamentals & Differential Theory

A. Lectures 12-13: Fluid Statics

Things you should know

- Pascal's law
- What a differential balance is and how to derive the static pressure equation
- What the static pressure equation is and what it means
- How manometers, barometers and hydraulics work

Calculations you should be able to do

- Determine pressures, forces, heights, etc. in manometers, barometers and hydraulics
- Determine the force due to pressure on boundaries (e.g. dams)
- Determine the force on submerged objects (e.g. buoyancy) due to pressure

B. 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.

C. 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$^{\text{th}}$ using the NS equation
- Identify the correct BCs for a NS problem from a physical description of the problem

D. 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.

E. 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.

III. Macroscopic Engineering Systems

A. Lecture 25-28: Integral Balances

Things you should know

- Purpose of integral and differential balances. Identify when either type of balance is appropriate
- Identify the physical meaning of terms in the general integral mass balance
- Assumptions needed to obtain the engineering mass balance from the integral mass balance
- The definition and physical meaning of the generalized integral property balance
- Identify the physical meaning of terms in the general integral momentum balance
- Assumptions needed to obtain the engineering momentum balance from the integral momentum balance
- Assumptions needed to obtain the engineering mechanical energy balance from the integral mechanical balance
- Identify the physical meaning of terms in the general integral mechanial energy balance
- Origin, meaning and differences between "Bernoulli's equation" and "Bernoulli's engineering equation"
- Know the stages of the engineering design process

Calculations you should be able to do

- Simplify a part of the general integral mass balance given a control volume and a physical assumption
- Solve problems using the engineering mass balance
- Simplify a part of the general integral momentum balance given a control volume and a physical assumption
- Solve problems using the engineering momentum balance
- Simplify a part of the general integral momentum balance given a control volume and a physical assumption
- Solve problems using the engineering Bernoulli Equation
- Use the engineering design process to solve problems where multiple engineering balances are needed

B. Lectures 29-31: Pipe Networks

Things you should know

- The concept of major losses
- Types and origins of minor losses
- The concept of an entrance length
- The concept of a system demand curve
- Identify serial and parallel piping network elements
- How flow rates and heads combine in serial and parallel configurations

Calculations you should be able to do

- Calculate the head loss in a pipe due to major and minor losses using a friction factor and loss coefficients
- Solve pipe flow design problems (pressure drop, pipe length, pipe diameter or flow rate) in single pipelines with major and/or minor losses.
- Use a system demand curve to solve single pipeline design problems
- Solve pipe flow design problems (pressure drop, pipe length, pipe diameter or flow rate) in piping networks with serial and/or parallel elements.
- Use a system demand curve to solve pipe network design problems

C. Lectures 32-34: Valves and Pumps

Things you should know

- Practical things about pipes: difference between pipes and tubes, nominal diameter versus inner diameter
- Identify and describe different types of valves and their pros and cons
- Identify and describe different types of methods for measuring pressure and their pros and cons
- Identify and describe different types of method for measuring flow and their pros and cons
- Identify and describe different types of pumps and their pros and cons
- Identify and describe different types of turbines and their pros and cons
- The origin and meaning of the pump performance curve
- The meaning of NPSH and NPSH_{req}
- How the head and flow rates of pumps and turbines combine in serial and parallel configurations.

Calculations you should be able to do

- Use an orifice loss coefficient to account for globe valves in pipelines or to calculate a flow rate for an obstruction flow meter
- Calculate the local velocity using a Pitot tube

- Use a pump or turbine performance curve to calculate the operating point of a piping network
- Calculate the efficiency of a pump or turbine
- Calculate the needed NPSH for a flow rate or the critical flow rate using NSPH_{req}
- Piping networks with pumps and turbines in parallel

D. Lecture 35: Compressible Flow

Things you should know

- The three different types of compressible flow (buoyancy, isothermal, adiabatic)
- What the Mach number is, what it means
- The meaning of choked flow

Calculations you should be able to do

- Use the mach number to determine if a flow is adiabatic compressible or not
- Calculate the flow rate of a compressible fluid out of an orifice and determine if the flow is or is not choked.