Morrison CM3110 Videos—Outline of Topics

Part I: Momentum Transfer

Lecture 1

1. Why study fluid mechanics?
2. Fluid, Energy, and Math topics covered in prerequisite classes
    a. Steady macroscopic mass and energy balances
    b. MEB with and without friction, Pumps
    c. Fluid statics
    d. Using calculus and differential equations in fluid mechanics
    e. Momentum balance $F \quad ma$
3. New topics/tools/concepts to be covered (fluid mechanics)
    a. Continuum (density, velocity, stress fields)
    b. Control volume
    c. Stress in a fluid at a point (stress tensor)
    d. Stress and deformation (Newtonian constitutive equation)
    e. Microscopic and macroscopic momentum balances, engineering quantities of interest
    f. Internal flows – pipes, conduits
    g. External flows – drag, boundary layers
    h. Advanced fluid mechanics – complex shapes, dimensional analysis, correlations

Lecture 2

1. How do fluids flow?
2. Modeling fluids: How fluids behave?
    a. Viscosity – Newton's law of viscosity
    b. Drag – Drag coefficient, correlations for drag coefficient
    c. Boundary Layers – boundary layer separation, connection with drag
    d. Laminar versus Turbulent Flow – viscous and inertial effects e. Lift
    f. Supersonic, Surface Tension, Curved Streamlines, Magnetohydrodynamics
3. Control volume for momentum balances – versus balances on a body (mechanics). Adds the convective term

Lecture 3-4

1. Continuum mechanics/Control Volume
2. A first momentum balance: Shell balance for flow down an incline plane
    a. Sketch, choose coordinate system
    b. Choose control volume
    c. Perform microscopic mass and momentum balances
    d. Fluid stress components (the stress tensor $\tilde{\tau}$)
    e. No slip boundary condition; free surface boundary condition
    f. Solution for velocity field (or velocity profile, velocity distribution) and stress field (profile, distribution)
    g. Common assumptions for simple problems: steady, unidirectional, wide, long, constant density (incompressible fluid), constant viscosity (Newtonian).
    h. Calculate engineering quantities of interest: volumetric flow rate, average velocity, stress on the wall (integrals over velocity and stress distributions)

Lecture 5-6

1. From shell balances to general microscopic mass and momentum balances
    a. Microscopic mass balance (continuity equation)
    b. Microscopic momentum balance (Navier-Stokes equation)
2. Flow down an incline, *redux* (using Navier-Stokes)
3. Pressure driven flow in a tube (Poiseuille flow in a tube)
    a. Solution with Navier-Stokes
    b. Calculating engineering quantities of interest
4. Common Integrals Handout
5. Common Boundary Conditions handout

Lecture 7-8

1. More Complex Flows
2. Engineering Quantities of Interest in complex flows
3. Newtonian Constitutive Equation
4. Total stress tensor (pressure is isotropic stress, $p\underline{\underline{I}}$)
5. More complex boundary conditions
6. Pressure driven flow in a rectangular duct (Poiseuille flow in a duct)
7. Introduction to book examples on more complex flows (buoyancy, torque)

Lecture 9 (optional)

1. Non-Newtonian fluids (rheology)
2. Behavior of non-Newtonian fluids (Weissenberg effect, shear thinning/thickening, yield stress, shear-induced normal stresses)
3. Non-Newtonian constitutive equation – Power law generalized Newtonian fluid
4. Pressure-driven flow of a power-law generalized Newtonian fluid (overview)

Lecture 10

1. More Complicated flows: Internal flows, numerical solutions
2. Dimensional analysis Introduction- Combining analysis and measurements (data correlations)
3. a. Dimensional similarity
    b. Dynamic similarity
4. Non-dimensionalize pressure-driven flow in a tube
    c. Choose characteristic scale factors
    d. Non-dimensionalize individual variables
    e. Characteristic ratios appear: Reynolds number, Froude number
    f. Correct dimensional analysis means experimental measurements will correlate (engineering quantities of interest)
    g. Data correlations are used for engineering of complex systems
    h. Pipe flow
    i. Friction factor-Reynolds number correlations from dimensional analysis
5. Using dimensional analysis to address other complex practical problems
    a. Rough pipes – roughness scale ε, data correlation = Colebrook equation
    b. Non-circular ducts – Hydraulic diameter, Poiseuille number for laminar flow, data correlation = Moody chart or scaled Prandtl correlation
    c. Flow through a packed bed – treat as a non-circular duct, data correlation = Ergun equation

Lecture 11

1. Macroscopic momentum balance (rectangular coordinates)
2. Non-parabolic velocity profile parameter β
3. Use to find force on the walls in complex, especially turbulent, flows
4. Solution to Macro Momentum balance problem: force on reducing bend
5. How to choose among fluids tools?
    a. MEB
    b. Navier-Stokes
    c. Macroscopic momentum balance

Lecture 12

1. More Complicated flows: External flows
2. Using dimensional-analysis approach
3. Flow around an obstacle (skydiver problem)
    a. Choose simple flow (creeping flow around a sphere)
    b. Solve; note the characteristics of the physics and of the solution
    c. Calculate engineering quantities of interest
    d. Dimensional analysis
    e. Data correlations from experiments (drag coefficient versus Reynolds number) f. Correct answers!
4. Look at information learned from the experiments (boundary layers, vortices, etc.)

Lecture 13

1. More Complicated flows: Boundary Layers
2. Using dimensional analysis approach
3. Flow near walls
    a. Choose simple flow (flow over a flat plate)
    b. Solve; note the characteristics of the physics and of the solution
    c. Calculate engineering quantities of interest
    d. Dimensional analysis
    e. Data correlations from experiments (drag coefficient versus Reynolds number) f. Correct answers!
4. Look at information learned from the experiments (boundary layer separation, form drag, role of pressure distribution)
5. Using dimensional analysis to address other complex practical problems (fluidized beds)
6. Compressible flow (supersonic flow)
7. Numerical solutions to fluid mechanics problems (COMSOL)

Part II: Heat Transfer (steady state) and Unit Operations

Lecture 14-15

Lecture 14

1. Recap and intro to heat transfer
2. Heat flux field $\underline{q}/A$
3. Thermal conductivity, Fourier's Law
4. Microscopic energy balance

Lecture 15

5. 1D conduction in a slab with temperature BC
6. Heat transfer resistances in series-rectangular
7. 1D conduction with Newton's law of cooling BCs (heat transfer coefficient)

Lecture 16

1. 1D Heat Radial Transfer
2. Heat transfer resistances in series-radial
3. Newton's law of cooling BC in radial heat conduction
4. More complex microscopic energy balance solutions (with generation, with flow)

Lecture 17

1. Complex problems in heat transfer—Dimensional analysis
2. DA for forced convection heat transfer—heat transfer coefficient h
3. Data correlations for Nusselt number (forced convection, Seider-Tate)
4. Correlations for forced convention use bulk average temperature for mat'l properties

Lecture 18

1. Complex problems in heat transfer, DA for natural convection
2. DA follows a pattern used in all kinds of physics
3. Data correlations for Grashof number (natural convection)
4. Correlations for natural convection use film temperature for mat'l properties

Lecture 19

1. Applied heat transfer-double-pipe heat exchanger
2. Overall heat transfer coefficient, U
3. Average driving force for heat transfer (ΔT_{LM})
4. Applied heat transfer-shell-and-tube heat exchangers
5. Average driving force for heat transfer ($F_T \Delta T_{LM}$)
6. Heat exchanger effectiveness (good when inlet conditions are known)
7. Fouling

Lecture 20

1. Heat transfer with phase change-boiling
2. Heat transfer with phase change-condensation (dropwise, film)
3. Applied heat transfer—Evaporators (types), condensers

Lecture 21-22

1. Introduction to radiation
2. Absorption-Stefan-Boltzmann law
3. Emission-black versus gray bodies
4. Kirchhoff's law
5. Radiation heat transfer coefficient
6. Applied radiation-heat shields

Lecture 23 (no slides)

1. Course review and final exam preparation