MECE E4100 Mechanics of Fluids (Spring 2022)

Course Meeting Times

Lectures: 1 session / week, Wed 4:10-6:40pm at Mudd 327.

Office Hours

Prof. Vedula: TBA, Mudd 220BA (and by appointment, vv2316@columbia.edu)

Course Assistant: TBA

Prerequisites

MECE E3100 or equivalent

Description

This is an intermediate-level fluid dynamics course that introduces and develops the fundamental principles governing the flow of fluids and its applications. Topics include basic continuum mechanics, dimensional analysis, transport theorem and control volume analysis, the Navier-Stokes equations, flows at low and high Reynolds numbers, boundary layers and secondary flows, introduction to transition and turbulence, vorticity dynamics, ideal/potential flows, and additional selected topics (aerodynamics, turbomachinery, biofluids).

Textbooks

For course readings I am strongly recommending:

- P.K. Kundu, I.M. Cohen, & D.R. Dowling, Fluid mechanics. 6th ed. Academic Press, 2015.
- Panton, Incompressible Flows, 4th ed., Wiley, 2013.

Recommended additional reading:

- F. White, Fluid Mechanics, McGraw-Hill, 2015.
- G. K. Batchelor, An Introduction to Fluid Dynamics, Cambridge University Press.
- Milton van Dyke, An Album of Fluid Motion, Parabolic Press, 1982.
- Theodore von Kármán, The Wind and Beyond, Little Brown and Company, 1967 (for fun and historical perspective of classical fluid mechanics).

Videos: http://web.mit.edu/hml/ncfmf.html

Certain books and journal articles will be recommended for specific topics during the course.

Grading

- Homework (40%)
- Exam I (25%)
- Exam II (35%)

Syllabus

Week 1 (Jan 19, 2022):

- Review of key concepts from fluid mechanics
- Mathematical concepts
- Introduction to dimensional analysis

Week 2 (Jan 26, 2022):

- Kinematics: Lagrangian and Eulerian descriptions
- Control volume analysis
- Reynolds Transport Theorem (RTT)

Week 3 (Feb 2, 2022):

- Dynamics of inviscid flows
- Bernoulli's principle
- Streamline coordinates
- Euler-s and Euler-n equations

Week 4 (Feb 9, 2022):

- Applications of control volume analysis and Bernoulli
  - Momentum theorem, jets and jet pumps, wakes, sudden expansions, etc.
  - Moment of momentum theorem (lawn sprinkler example)
- Effects of compressibility
- Unsteadiness (unsteady Bernoullli)
  - Pipe connected to a large tank
  - Bubble expansion in an infinite fluid (Rayleigh's equation)

Week 5 (Feb 16, 2022):

- Introduction to viscous effects
- Couette flow, plane Poiseuille flow
- Unsteady flows (Rayleigh's 1st and 2nd flows, Womersley flow)

Week 6 (Feb 23, 2022):

- The Navier-Stokes equations
- Inertia-free flows (low Re, Stokes flow)
- Introduction to viscous boundary layers (high Re)

Week 7 (Mar 2, 2022):

- Solutions to boundary layer equations (Blasius, Falkner-Skan)
- Similarity solutions
- Momentum integral equation (von-Kàrmàn – Pohlhausen's approach)
- Secondary flows

Week 8 (Mar 9, 2022): Exam I

Week 9 (Mar 16, 2022): Spring Break

Week 10 (Mar 23, 2022):

- Introduction to stability and transition
- Linear stability analysis
  - Kelvin-Helmholtz instability
  - Stability analysis for nearly-parallel viscous flows (Orr-Sommerfeld equation)
  - Inviscid instability (Rayleigh's and Fjortoft's criteria)
- Introduction to turbulence
  - Characteristics
  - Governing Equations (RANS)

Week 11 (Mar 30, 2022):

- Turbulence
  - Closure problem
  - Correlations, mean and turbulent kinetic energy
  - Energy cascade, Kolmogorov's theory
- Introduction to vorticity dynamics
  - Helmholtz's decomposition
  - Vorticity transport equation

Week 12 (Apr 6, 2022):

- Vorticity dynamics
  - Significance of vortex stretching
  - Kelvin-Helmholtz circulation theorem
  - Biot-Savart law
- Potential flows
  - Mathematical formulation
  - Classical examples (plane flows, source/sink, vortex, dipole, cylinder in a stream)

Week 13 (Apr 13, 2022):

- Introduction to aerodynamics
  - Conformal mapping
  - Two-dimensional airfoil theory
  - Finite wing theory, drag due to lift (induced drag)

Week 14 (Apr 20, 2022):

- Introduction to turbomachinery
  - Centrifugal pump
  - Mixed and axial flow pumps
  - Pump performance and characteristics
  - Turbines (gas, impulse, reaction, wind)

Week 15 (Apr 27, 2022):

- Introduction to biofluid mechanics
  - Blood flow and circulatory system
  - Fluid mechanics of plants

Week 16 (May 4, 2022): Study Week (Review)

Week 17 (May 11, 2022): Exam II