AE 320/706: Computational Fluid Dynamics

January -- April 2017
Department of Aerospace Engineering, IIT Bombay

General information

- Instructors:
  - Prof. Kowsik Bodi
  - Prabhu Ramachandran
- Slot 3:
  - Mon: 10:30, Tue: 11:30, Thu: 8:30
- Venue LC 002
- Office hours: TBD
- TAs: TBD

Course Structure

- Flipped class!
- NPTEL lectures by Prof. M. Ramakrishna

What do we do in class?

- Q&A, doubts
- Assignments
- Tutorials/Demos
- Supplementary material/tools

But why?

- Lecture material is solid
- Accompanied with a text book
- Connects things nicely: unusual perspective
- Excellent teacher
- Lets us focus on your learning and not on preparing lectures!
- Can learn at your pace

Grading Structure

- Quizzes: 20 marks
- End sem: 25 marks
- Assignments: 55 marks
- < 40% of top mark is FR

Introduction to CFD

- Analytical solutions are not enough
- Experiments are hard to setup

Motivation ...

- Semi-analytical solutions
  - Perturbations
  - Matched solutions, similarity solutions
  - Integral equation methods
  - MOC
- Numerical solutions

Computational revolution

9 orders of magnitude change in computing today!

Computational revolution

- Its easy to miss how big a change that is
- Distance from earth to moon is about 4×10^6 kms
- Distance from earth to sun is about 1.5×10^8 kms
- Imagine a vehicle that takes you near the sun and back about 10 seconds
- Consuming about a litre of fuel!
- The size of your phone

So why CFD?

Solving PDEs

- Mathematical complexities
- Difficult equations
  - Non-linear
  - Difficult boundary conditions
  - Complex physics

Challenges

- Physics
- Mathematics
- Numerics
- Computational
- Reproducibility

Complexities of the Physics

- Fluid mechanics is hard
  - Non-linearity
  - Turbulence
  - Complex boundary conditions
  - Scaling

Complexities of the Physics

- Continuum vs non-continuum
- MHD
- Plasmas
- Multiple species
- Free surfaces
- FSI
- Chemical reactions
- Weather modeling

Difficulties in the Math

- Non-linear PDEs
- Nature of PDE changes
  - Elliptic
  - Parabolic
  - Hyperbolic
- Mixed!

Difficulties in the Math ...

- Existence and uniqueness
- Representation of geometries
- BCs
- Discontinuities
- Weak formulations
  - Differential equation for discontinuity?

Numerical issues

- Floating point math
- Approximation of functions
- Stability
- Convergence

Computational issues

- Performance
- Availability
- Storage
- Memory
- Compute power
- Implementation

Computational issues

- Data structures/algorithms
- Programming models
- Parallelization
- Memory hierarchies
- CPU vs GPU

Validation and verification

- Correct model?
- Correct solution?
- Benchmark problems
- Grid Convergence
- Manufactured solutions

Reproducibility

- Most research papers are not reproducible
- See: http://reproducibility.cs.arizona.edu
- 2015: Only 217/601 CSE papers could be **built**!
- 2011 study: only 6% of medical studies were reproducible
- 2012: 6/53 cancer related papers were reproducible!

Software engineering

- Version control
- Testing
- Automation

CFD packages

- Often black boxes
- Use Open Source Software!

What is this course about?

- Understanding the basic mathematical ideas
- Introductory CFD
- Assignments

NPTEL lectures

- Introduction to CFD
- Prof. M. Ramakrishna, AE, IIT Madras
- http://nptel.ac.in/courses/101106045/
- https://www.youtube.com/playlist?list=PLbMVogVj5nJR_10rwYXD-X5QWLYIcfcc9
- 39 lectures

Outline of lectures

- Introduction, Why and how we need computers
- Representing Arrays and functions on computers
- Representing functions - Box functions
- Representing functions - Polynomials & Hat functions
- Hat functions, Quadratic & Cubic representations
- Demo - Hat functions, Aliasing

Outline of lectures

- Representing Derivatives - finite differences
- Finite differences, Laplace equation
- Laplace equation - Jacobi iterations
- Laplace equation - Iteration matrices
- Laplace equation - convergence rate
- Laplace equation - convergence rate Continued

Outline of lectures

- Demo - representation error, Laplace equation
- Demo - Laplace equation, SOR
- Laplace equation - final, Linear Wave equation
- Linear wave equation - Closed form & numerical solution, stability analysis
- Generating a stable scheme & Boundary conditions
- Modified equation

Outline of lectures

- Effect of higher derivative terms on Wave equation
- Artificial dissipation, upwinding, generating schemes
- Demo - Modified equation, Wave equation
- Demo - Wave equation / Heat Equation
- Quasi-linear One-Dimensional wave equation
- Shock speed, stability analysis, Derive Governing equations

Outline of lectures

- One-Dimensional Euler equations - Attempts to decouple
- Derive Eigenvectors, Writing Programs
- Applying Boundary conditions
- Implicit Boundary conditions
- Flux Vector Splitting, setup Roe's averaging
- Roe's averaging
- Demo - One Dimensional flow

Outline of lectures

- Accelerating convergence - Preconditioning, dual time stepping
- Accelerating convergence, Intro to Multigrid method
- Multigrid method
- Multigrid method - final, Parallel Computing

Outline of lectures

- Calculus of Variations - Three Lemmas and a Theorem
- Calculus of Variations - Application to Laplace Equation
- Calculus of Variations -final & Random Walk
- Overview and Recap of the course

Some questions

- Math/Physics requirements
  - Basic calculus
  - PDE classifications
  - Basic Gas dynamics
- Programming requirements
  - Basic Python/Scilab
  - Not too difficult programming
- Audit policy
- Attendance: 80%

What we plan to cover

- Floating point numbers
- Finite difference schemes
- Laplace equation
- Linear advection
- Euler equation
- Roe's scheme
- SIMPLE scheme?

Task for next class

- See video 1
- See video 2