The University of British Columbia

MECH 479/587 -CFD
Winter Term 1, 2022
(Course Structure and Schedule)

August 31, 2022

This document will help you navigate through the different modules that we shall be looking at in this course. The course is intended to provide introductory concepts in computational fluid mechanics and heat transfer (aka CFD) for the advanced undergraduate student and/or first year graduate student, who has knowledge of calculus, introductory level computer programming and fluid mechanics. The emphasis of this course is on the practical aspects of various CFD techniques and formulations for academic as well as industrial settings. The course is structured into the following modules which will include theoretical details (slides and handouts), computer codes, examples and worked solutions, case studies and further reading materials.

Module 1 - CFD Intro and Review of Fluid Mechanics

CFD is a process of computing fluid flow and heat transfer using partial differential equations (e.g., Navier-Stokes/Euler, Lattice-Boltzmann equations) with the goal of dynamical predictions and physical insight. It is a multi-disciplinary subject and lies at the intersection of fluid mechanics, numerical analysis and computer science. This module will set the stage for the rest of the course. Before we get our feet wet with the discrete world of CFD, we will also review the basic governing equations (i.e., conservation laws) of fluid mechanics. Integral and divergence form (differential) of fluid flow equations will be covered. Representative (prototypical/canonical) convection and diffusion equations will be discussed, which contain many essential mathematical and physical natures of the full Navier-Stokes equations.

Module 2 - Ordinary and Partial Differential Equations

Many problems in Science, Engineering, and Finance can be described via ordinary differential equations (ODEs) and partial differential equations (PDEs). Most often, these equations are highly nonlinear and need to be solved over complex geometries in engineering applications. In this module we shall look at how we can adapt these equations to make numerical sense. Through simple coding examples, numerical solutions (warm-up exercise) of first-order ODE system will be covered to bring a sense of accuracy and stability during the numerical approximation. We shall also look at the basic differences between ODE vs. PDE and a broad classification of PDEs and how to make physical sense of these classes - this will also help us make crucial decisions on what numerical procedure to adopt once we have classified them.

Module 3 - Taylor Series and Finite Difference Approximation

In this module, we shall look at the Taylor series and its application to finite difference methods for solving partial differential equations in their strong form. Essentially, you will learn how to replace the partial derivatives in the governing equations (PDEs) to form finite difference equations (FDEs) which can be solved in an algebraic manner. In addition to finite difference approximation, general concepts such as stability, consistency, convergence will be explored. Furthermore, the essential details about boundary conditions, grid convergence, verification and validation will be presented which are crucial for CFD practitioners using academic and/or commercial software packages. Together with pen-and-paper exercises, computer-based implementations and codes (written in Matlab) will be covered in a Cartesian system. The sources of numerical errors and their implication to stability will be formally discussed.

Module 4 - Stability Analysis and Temporal Discretization

Based on the above module on FDE, we will take a deep dive into the mathematical understanding of numerical stability via Fourier (von Neumann) approach. We will go over several examples on the application of von Neumann stability analysis of canonical differential equations. We shall also look at the different temporal discretization methods such as explicit vs. implicit and other popular techniques (e.g., Crank-Nicolson, ADI), for time-dependent problems.

Module 5 - Hyperbolic PDEs and Integral Methods

Hyperbolic equations describe time-dependent phenomena in fluid mechanics and are characterized by a speed of information (wave speed) with a possibility of the formation of discontinuity (e.g., shock wave). There is a need for advanced numerical treatment for these equations. Several numerical techniques and concepts (e.g., upwinding) will be covered for a canonical 1D advection equation with application to inviscid compressible flow (Euler) equations. We will also discuss the concept of the weak or integral form of the hyperbolic equations and the application of finite volume approximation.

Module 6 - Training on Commercial CFD Software

This module will be distributed over several weeks during the whole term. The aim is to translate the CFD concepts and theoretical understanding into practical usage of commercial CFD solver. We will go over ANSYS Fluent Lab sessions and two projects based on the lab sessions. Hands-on training on Fluent will be provided to solve heat transfer and flow dynamics problems. Starting from problem definition, geometry preparation, meshing, solver settings to post-processing, analysis and verification/validation will be covered.

Module 7 - Advanced CFD Discretization Techniques

In this module, we will cover the fundamental of variational Galerkin techniques for complex geometries and unstructured grid. Galerkin finite element method will be discussed for simple elliptic PDEs and heat transfer problems. In addition to the Galerkin method, brief discussions on spectral methods and lattice Boltzmann techniques will be provided.

- Describe how the method of weighted residuals can be used to calculate an approximate solution to a PDE.
- Describe the differences between the method of weighted residuals, the collocation method, and the least-squares method for approximating a PDE.
- Understand the Galerkin method of weighted residuals.
- Describe the choice of approximate solutions (i.e., the test functions or interpolants) used in the finite element method.

Module 8 - Solutions of Incompressible Navier-Stokes Equations

We finally come to the numerical solution techniques to the Navier-Stokes equations. Specifically, we shall be studying the incompressible Navier Stokes equations, the inherent difficulties in solving them numerically and how we address these issues. You will learn the primitive variable approach in staggered and colocated grid arrangements. The popular pressure correction techniques (e.g., Marker-and-Cell, Projection/Fractional methods, SIMPLE) will be algorithmically explored via computer implementation. By the end of this module, you will have a basic working code for solving the Navier-Stokes equations.

Module 9 - Advanced Topics

We shall end our course with a look at some of the topics of active interest within the CFD community today - the modeling of turbulence, multiphase flows and combustion, FSI, aeroelasticity and the application of machine learning and data-driven computing to CFD.

Attached below is the tentative schedule for the MECH 479 course for the Academic Year 2020-2021 (Winter Term 1). Any changes to the schedule will be communicated via Canvas.

Tentative Schedule for MECH 479 (Term 1, 2022/23)

Week of	Mon	Tue	Wed	Thurs	Fri
Sept 5		Imagine UBC		Lec: Intro Fluid and CFD (Module 1)	
Sept 12		Lec: ODE vs. PDE (Module 2)		Lec: PDE understanding & classification (Module 2)	
Sept 19	Lab 1: Matlab (Module 6)	Lec: PDE understanding & classification (Module 2) HW #1: PDE classification		Lec: PDE understanding & classification (Module 2)	
Sept 26	Lab 2: ANSYS Fluent (Module 6)	Lec/Tut: Taylor Series and FDM (Module 3) HW #2: Taylor Series		Public Holiday	
Oct 3	Lab 3: ANSYS Fluent (Module 6)	Lec/Tut: Taylor Series and FDM (Module 3)	Project #1	Lec: Stability Analysis (Module 4)	
Oct 10	Lab 4: ANSYS Fluent (Module 6)	Lec: Stability Analysis (Module 4) HW#3: Stability Analysis		Lec: Temporal Discretization (Module 4)	
Oct 17	Lab 5: ANSYS Fluent (Module 6)	Lec: Temporal Discretization (Module 4)	Due Project #1	Tut: Temporal Discretization (Module 4)	
Oct 24	Lab 6: ANSYS Fluent (Module 6)	MIDTERM EXAM		Lec: Hyperbolic PDEs and Shock Wave (Module 5)	
Oct 31	Lab 7: ANSYS Fluent (Module 6)	Lec: Integral Methods (Module 5)	Project #2	Lec/Tut: Finite volume and finite element methods (Module 5)	
Nov 7	Lab 8: ANSYS Fluent (Module 6)	Lec: Advanced CFD Discretization Techniques (Module 7) HW#4: Upwind and finite volume/element		Mid-term break	
Nov 14	Lab 9: ANSYS Fluent (Module 6)	Lec: Techniques for Incompressible NS equations (Module 8)	Due Project #2	Lec: Techniques for Incompressible NS equations (Module 8)	Project #3: Coding Navier-Stokes
Nov 21	Lab 10: ANSYS Fluent (Module 6)	Lec: Techniques for Incompressible NS equations (Module 8)		Lec: Advanced CFD Topics: Turbulence Modeling Mesh generation Machine Learning	
Nov 28		Tut: Course Review Questions and Examples		Review	Due Project #3
Dec 11-22	FINAL EXAM				

Important Dates

Dates	Description
Sep-6	Imagine day
Sep-30	National Day for Truth and Reconciliation
Oct-10	Thanksgiving Day
Oct-25	Mid-term exam
Nov 9 - Nov 11	Midterm break
Dec-7	Last day of class
Dec 11 - Dec 22	Final exam period