ME 5311: Computational Methods of Viscous Fluid Dynamics

Spring 2020

Class meeting:	Wednesday 5–7:30 pm, UTEB 476
Instructor:	Prof. George Matheou
email:	matheou@uconn.edu
Office hours:	Monday 1–2 pm in UTEB 384
	Please email instructor for questions and meetings at other times

Description

The course is an introduction to the fundamentals of computational fluid dynamics (CFD), including thermal transport. The course will introduce the main computational techniques and methods, and analyze their properties. Strong emphasis will be given to the implementation and application of the methods. The course is *not* training on how to use commercial CFD software, and we do not use or discuss such software in the class. The course serves the needs of students that conduct CFD-related research or students who want to develop an in-depth understanding of the subject to critically assess the results CFD software.

Course objectives

- To introduce the basic techniques used to numerically solve the governing equations of incompressible fluid flow, including transport of scalar quantities, such as heat.
- To introduce the basic methods for analysis of the numerical approximations, e.g., determination of the order of accuracy, resolving power, stability properties, etc.
- Students will be able to understand the link between the properties of the numerical approximations and the quality/features of the resulting numerical solution.
- Understand the practical aspects of the application of the numerical methods and develop an appreciation the tradeoffs, e.g., accuracy, efficiency, need to control different types of model error.
- Students will be able to use the acquired understanding of the methods as a basis for the development of their own methods and solution techniques, including the utilization of CFD software packages, and be able to assess the quality of numerical solutions in general.

Prerequisites

Good working knowledge of engineering mathematics, including calculus, linear algebra and differential equations. Some familiarity with fluid mechanics, including the governing equations of fluid motion and heat transfer. Basic programming skills.

Grading

The final grade is composed of 50% homework and 50% Term Project. Final letter grades will generally follow 90–100% for an A, 80–89.9% for a B, etc. Plusses and minuses will extend up and down 2 percentage points at each major breakpoint, e.g., A- = 90–91.9 and B+ = 88–89.9, etc. The instructor may adjust this scale in the final analysis, but in no case, will scores higher than those listed be required to achieve the stated letter grades.

Homework

There will be seven homework assignments during the first half of the semester (before the Spring break) and one longer-term assignments, i.e., "term project," in the second half of the semester. Because homework solutions will be discussed in class, <u>no late homework will be accepted</u>, i.e., it will be graded 0. Assignments will be grated within a week. Feedback will be included in the graded assignments.

Programming and computing resources

Students are expected to write and execute computer code in a programming language of their choice, including Matlab. Most of the assignments will include implementation (i.e., programming), quantitative analysis, and plotting of results. Students are expected to implement their own solution methods and use of specialized functions or routines, e.g., Matlab functions to invert matrices, is not allowed.

Assignment solutions will be posted in Matlab.

If you plan to use a programming language other than a commonly used one (e.g., use any language other than C, C++, Fortran, or Matlab) please contact the instructor. Also, if you do not have access to programming and computing resources, please contact the instructor to make the appropriate arrangements.

Academic Honesty

Students are encouraged to discuss assignments with each other, but no copying is allowed from any source. Please turn in your own work, based on your own effort and understanding. Students are expected to abide by UConn's policy on academic integrity: http://community.uconn.edu/the-student-code-appedix-a.

Academic Accommodations

The University of Connecticut is committed to protecting the rights of individuals with disabilities and assuring that the learning environment is accessible. If you anticipate or experience physical or academic barriers based on disability or pregnancy, please let me know immediately so that we can discuss options. Students who require accommodations should contact the Center for Students with Disabilities (CSD), Wilbur Cross Building Room 204, (860) 486-2020 or email csd@uconn.edu and follow the process for requesting accommodations.

Textbooks

LPZ04	Lomax, H., T. H. Pulliam and D. W. Zingg. 2004: Fundamentals of Computational Fluid Dynamics. Springer.
FP13	Ferziger, J. H. and M. Peric, 2013: Computational Methods for Fluid Dynamics. Springer.

Further References

CHQT06	Canuto, C., M. Y. Hussaini, A. Quarteroni and T. A. Zang, 2006: Spectral methods, Springer
CJV08	Chapman, B., G. Jost and R. Van Der Pas, 2008: Using OpenMP: Portable Shared Memory Parallel Programming. MIT press.
GLS99	Gropp, W., E. Lusk and A. Skjellum 1999: Using MPI: Portable Parallel Programming with the Message-Passing Interface. MIT press.
GLT99	Gropp, W., E. Lusk and R. Thakur, 1999: Using MPI-2: Advanced Features of the Message-Passing Interface. MIT press.
P00	Pope, S. B., 2000, Turbulent Flows, Cambridge
QSS00	Quarteroni, A., R. Sacco and F. Saleri, 2000: Numerical Mathematics, Springer
S04	Strikwerda, J. C., 2004. Finite difference schemes and partial differential equations. Society for Industrial and Applied Mathematics.

Lecture		Topics	References	**Assignment** (Date of assignment. Due in one week)
1	January 22	• Error norms • Rate of convergence • Model equations: one-dimensional convection and diffusion equations	LPZ04 Ch. 1, 2 FP13 Ch. 1, 2	Monte Carlo simulation, convergence
2	January 29	• Interpolation and polynomial approximations	LPZ04 Ch. 3.1, 3.4.3	Time integration, Lorenz equations, Lyapunov exponent
3	February 5	• Numerical differentiation • Finite differences • Spectral/trigonometric approximations	LPZ04 Ch. 3.2, 3.3, 3.4	Derivative approximations: finite difference and spectral approximations
4	February 12	• Model PDEs • Consistency • Convergence	LPZ04 Ch. 2.3, 2.4. 2.5, 3.6, 7.8 S04 Ch. 1.4	One-dimensional convection equation
5	February 29	• Numerical stability • CFL Condition • Lax-Richtmyer equivalence theorem • Fourier error analysis	FP13 Ch. 3 LPZ04 Ch. 7.7 S04 Ch. 1.4, 2.2, 2.3	Fourier error analysis
6	February 26	• Dispersion and Dissipation • Modified PDE • Introduction to Spectral Methods	LPZ04 Ch. 3.5, 11.1, 11.2	Modified PDE, spectral method
7	March 4	• Analysis of time marching methods	LPZ04 Ch. 6, 7	Time marching method stability analysis
8	March 11	• Solution of linear systems	LPZ04 Ch. 8 QSS07 Ch. 3 & 4	No assignment!
*	Spring Recess			
9	March 25	• Navier–Stokes fundamentals • Pressure in incompressible flow • Pressure Poisson equation	FP13 Ch. 7	Project Part 1 assigned (due in two weeks)
10	April 1	• “Flavors” of Navier–Stokes • Pressure and incompressibility • Fractional step methods	FP13 Ch. 7	
11	April 8	• Grids and variable arrangement • Convection terms discretization • Boundary conditions	FP13 Ch. 7	Project Part 2 assigned (Part 1 due)
12	April 15	• Spectral methods • Conservation properties • Verification and validation	FP13 Ch. 7	
13	April 22	• Viscous terms discretization • Boundary conditions (revisited) • Introduction to the computation of turbulent flows	FP13 Ch. 7, 9 P00	Project Part 3 assigned (Part 2 due)
14	April 20	Introduction to parallel computing techniques	CJV08, GLS99, GLT99	