Introduction to Computational Fluid Dynamics

AME 535a, 3 Units

Fall 2024

Lecture 2:00 – 3:20, TTh, OHE 100C

Personnel:

Instructor	**Prof. J.A. Domaradzki, OHE 412D**, jad@usc.edu; (213) 740-5357
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Instructor Office Hours	TBD
TA	TBD
TA Office Hours	TBD

Course Objectives:

The goal of the course is to provide a description of fundamental and general techniques which are commonly used in solving numerically equations governing fluid flows. Finite difference, finite volume, and finite element methods will be discussed as different means of discretization of the fluid dynamics equations. A necessary theoretical background concerning accuracy, convergence, consistency, and stability of the numerical schemes will be provided. The numerical methods will be implemented on computers and applied to solutions of simple model problems which illustrate a variety of physical phenomena encountered in fluid mechanics: one-dimensional diffusion, multidimensional diffusion, and linear and nonlinear convection-dominated problems. The final project will require combining the developed techniques to solve a realistic fluid dynamics problem.

Recommended Preparation:

AME 526, "Introduction to Mathematical Methods in Engineering II" (or an equivalent course in partial differential equations). Although no previous background in numerical methods will be assumed, some knowledge of the elementary techniques (Dahlquist, Bjork, Anderson, ``Numerical Methods"; Press, Flannery, Teukolsky,

Vetterling, ``Numerical Recipes"; course AME 404, "Computational Solutions to Engineering Problems") will be helpful. An integral part of the course is the development of numerical programs, which requires knowledge of some high level programming language. Because of ease of use and availability of MATLAB through USC website https://software.usc.edu/free-to-campus/ MATLAB is recommended for this class. However, other high level programming languages such as FORTRAN or C++ can be used as well. The course materials include a complete set of computer programs written in FORTRAN 77, with those required for classwork provided also in MATLAB.

Lecture Schedule:

Week	Dates	Topics
1	First class 08/27	Partial differential equations; finite difference discretization of derivatives; accuracy of discretization; FTCS numerical scheme for the diffusion eq. (Program DIFF).
2		Definitions of convergence, consistency, and stability; Lax equivalence theorem; stability and consistency of the FTCS scheme.
3		Explicit methods for 1-D diffusion equation: FTCS, Richardson, DuFort-Frankel, three-level explicit scheme (Program DIFEX); fully implicit scheme; Crank-Nicolson scheme; stability conditions.
4		Solutions of tridiagonal and pentadiagonal systems (Programs BANFAC and BANSOL); implicit methods for 1-D diffusion equation (continued): three-level implicit scheme (Program DIFIM); stability conditions. Implementation of boundary and initial conditions. Semi-discretization and time stepping methods: Euler, midpoint, Runge-Kutta, trapezoidal, predictor-corrector, Adams-Bashforth.
5		Weighted residual methods: finite volume, collocation, Galerkin; finite volume method for Poisson eq. in geometrically complex domains (Program FIVOL).
6		Iterative numerical methods for linear systems of algebraic equations: Jacobi, Gauss-Seidel, SOR, conjugate gradient. Galerkin Finite Element Method; linear and quadratic interpolation. Midterm (in class, Thursday, Oct. 3).
7		Implementation of FEM for a flow in a square duct. Fall Break (ThF Oct. 10-11).
8		Implementation of FEM for a flow in a square duct continued (Program DUCT). Newton's method for steady nonlinear problems. Newton's method for 2-D steady Burgers' eq. (Program NEWTBU).

9		Direct numerical solvers for linear systems of algebraic equations: Gaussian elimination with pivoting; LU-decomposition (Programs FACT and SOLVE); pseudo-transient method. Multidimensional diffusion equation.
10		Multidimensional diffusion equation: stability for explicit and implicit schemes; alternating direction implicit method; approximate factorization (Program TWDIF); method of fractional steps; implementation of boundary and initial conditions for 2-D diffusion eq. solvers.
11		1-D linear advection equation; upwind differencing; CFL number and stability conditions for explicit and implicit methods; Lax-Wendroff scheme; (Program TRAN with s=0).
12		Numerical dispersion and numerical diffusion; modified equation approach. Linear transport (advection-diffusion) equation; implicit and explicit methods; stability conditions (Program TRAN).
13		Numerical schemes for two-dimensional transport equation (Program THERM). Nonlinear advection equation; generation of small scales and aliasing errors.
14		Thanksgiving week.
15	Last class 12/05/24	Explicit and implicit methods for the advection and 1-D Burgers' equation. Nonuniform grids. Special topics (including final project advisement).
		Final Project due (4 p.m., Dec. 12, 2024).

Course Materials:

Handouts, notes, and programs will be distributed in class.

The required textbook

- C.A.J. Fletcher, Computational Techniques for Fluid Dynamics, Vol. I, 2nd ed., Springer-Verlag, ISBN: 3-540-53058-4.

It is available through a publisher's website

https://link.springer.com/book/10.1007/978-3-642-58229-5

where it can be purchased as eBook or accessed for free through USC. The best way is to Install the LibKey Nomad browser extension (used by many at USC)

https://libguides.usc.edu/libkey.
After LibKey Nomad is installed, you may use directly the publisher URL and a button will appear after a link to full-text is clicked. Access through USC directly may be sometimes confusing because a search function is less robust. You should login to USC libraries https://libraries.usc.edu/ (note you have to sign in with your USC credentials in the top right corner) and type "C.A.J. Fletcher, Computational Techniques for Fluid Dynamics, Vol. I" in the search box. That procedure will take you to the textbook and several related books, including Vol. II and the solution manual. Finally, you may try to find it through many textbook websites. Start with a search word `textbooks' in Google.

Additional textbooks in CFD (not required):

- J.H. Ferziger and M. Peric, Computational Methods for Fluid Dynamics, Springer-Verlag.
- R. Peyret and T.D. Taylor, Computational Methods for Fluid Flow, Springer-Verlag.
- J.C. Tannehill, D.A. Anderson, and R.H. Pletcher, Computational Fluid Mechanics and Heat Transfer, Taylor & Francis.
- J. Tu, G.H. Yeoh, and C. Liu, Computational Fluid Dynamics, A Practical Approach, Elsevier.

Grading:

- 20% Homework (normally assigned each week and due the following week)
- 40% Midterm (theoretical concepts)
- 40% Final (programming project)

USC Technology Support Links:

Learning Technology Tools
Software available to USC Campus

Statement on Academic Conduct and Support Systems

Academic Conduct:

Plagiarism – presenting someone else's ideas as your own, either verbatim or recast in your own words – is a serious academic offense with serious consequences. Please familiarize yourself with the discussion of plagiarism in *SCampus* in Part B, Section 11, "Behavior Violating University Standards" policy.usc.edu/scampus-part-b. Other forms of academic dishonesty are equally unacceptable. See additional information in *SCampus* and university policies on scientific misconduct, http://policy.usc.edu/scientific-misconduct.

Support Systems:

A number of USC's schools provide support for students who need help with scholarly writing. Check with your advisor or program staff to find out more. Students whose primary language is not English should check with the *American Language Institute* http://dornsife.usc.edu/ali, which sponsors courses and workshops specifically for international graduate students. *The Office of Disability Services and Programs* http://sait.usc.edu/academicsupport/centerprograms/dsp/home_index.html provides certification for students with disabilities and helps arrange the relevant accommodations. If an officially declared emergency makes travel to campus infeasible, *USC Emergency Information http://emergency.usc.edu* will provide safety and other updates, including ways in which instruction will be continued by means of blackboard, teleconferencing, and other technology.

Student Counseling Services (SCS) – (213) 740-7711 – 24/7 on call
Free and confidential mental health treatment for students, including short-term psychotherapy, group counseling, stress fitness workshops, and crisis intervention.
engemannshc.usc.edu/counseling

National Suicide Prevention Lifeline – 1 (800) 273-8255
Provides free and confidential emotional support to people in suicidal crisis or emotional distress 24 hours a day, 7 days a week. www.suicidepreventionlifeline.org

Relationship and Sexual Violence Prevention Services (RSVP) – (213) 740-4900 – 24/7 on call
Free and confidential therapy services, workshops, and training for situations related to gender-based harm. engemannshc.usc.edu/rsvp

Sexual Assault Resource Center
For more information about how to get help or help a survivor, rights, reporting options, and additional resources, visit the website: sarc.usc.edu

Office of Equity and Diversity (OED)/Title IX Compliance – (213) 740-5086

Works with faculty, staff, visitors, applicants, and students around issues of protected class. equity.usc.edu

Bias Assessment Response and Support
Incidents of bias, hate crimes and microaggressions need to be reported allowing for appropriate investigation and response. studentaffairs.usc.edu/bias-assessment-response-support

The Office of Disability Services and Programs
Provides certification for students with disabilities and helps arrange relevant accommodations. dsp.usc.edu
Student Support and Advocacy – (213) 821-4710
Assists students and families in resolving complex issues adversely affecting their success as a student: personal, financial, and academic. studentaffairs.usc.edu/ssa

Diversity at USC
Information on events, programs and training, the Diversity Task Force (including representatives for each school), chronology, participation, and various resources for students. diversity.usc.edu

USC Emergency Information
Provides safety and other updates, including ways in which instruction will be continued if an officially declared emergency makes travel to campus infeasible. emergency.usc.edu

USC Department of Public Safety – UPC: (213) 740-4321 – HSC: (323) 442-1000 – 24-hour emergency or to report a crime.
Provides overall safety to USC community. dps.usc.edu

Page last updated: June 13, 2024.
Weekly information will be updated without notice. Change in policies, important dates, and project content will be announced in class.