AME 535a Introduction to Computational Fluid Dynamics

University of Southern California – Fall 2018

Course Syllabus

Term	**Fall 2018** (Aug 20 – Nov 30, 2018)
Lectures	Thursdays, 2:00 – 4:50pm, in OHE 100C and on DEN@Viterbi
Instructor	Alejandra URANGA ▪ Email: `auranga@usc.edu` Office Hours: Tues. 4:00pm–5:30pm in RRB 218 Wed. 5:00pm – 6:00pm online for DEN students only
Teaching Assistant	Tianbo (Raye) XIE ▪ Email: `tianboxi@usc.edu` Office Hours: Mon. & Wed. 11:00am – 1:00pm in VHE 202 Tues. 5:00pm – 6:00pm online for DEN students only *Questions related to the projects should be addressed to the TA*

Course Description

The goal of the course is to teach the fundamental techniques most commonly used to numerically solve partial differential equations (PDEs), with particular focus on the equations governing fluid flows. Finite difference, finite volume, and finite element methods are studied as different means of discretizing a range of equations central to applications in science and engineering. The theoretical background on accuracy, consistency, stability, and convergence of the numerical schemes is provided, as well as direct and iterative solution techniques for the discrete linear systems.

Learning Objectives

Upon completion of this course, students will be able to:

- Describe the major characteristics and general formulations of the three classes of numerical methods studied: finite differences (FD), finite volumes (FV), finite elements (FE)
- Understand and demonstrate the "well-posedness" of numerical methods for PDEs, including being able to prove consistency, stability, and convergence
- Derive and implement schemes for linear and non-linear PDEs, with and without time dependency, and prove their convergence and order of accuracy
- Define and implement Dirichled and Neumann type boundary conditions in a manner consistent with the numerical scheme
- Be aware of common issues arising during implementation of numerical schemes on finite-precision computers, and acquire basic good-practice coding habits
- Use iterative techniques to effectively solve systems of linear equations encountered after spatial discretization of PDEs

Recommended Preparation

- AME 526 Engineering Analytical Methods (or equivalent course in partial differential equations)
- Knowledge of a programming language (MATLAB, FORTRAN, C, C++, or Python).

Grading

- Projects 1 – 4: 18% each (72% total) of final grade
- Midterm exam: 28% of final grade (in-class, closed book, 1h30 duration)

Notes, Textbooks, and Resources

Lecture Notes

A set of notes will be distributed. Together with the lecture discussions and in-class exercises, these provides all the material needed for the course.

This course is based on MIT's *Numerical Methods for Partial Differential Equations* (MIT course number 16.920/2.097/6.339 as taught in 2006–2008), and on the notes developed by Jaime Peraire and Antony Patera, professors at MIT in the Departments of Aeronautics & Astronautics and Mechanical Engineering, respectively. The notes are shared with permission from the authors.

References

Some students will find it useful to refer to textbooks on numerical methods in order to better familiarize themselves with the material, see it from a different perspective, and/or find more details on some topics. The following reference books may be helpful:

- J.H. Ferziger and M. Peric, *Computational Methods for Fluid Dynamics*, Springer-Verlag [available online through USC Libraries]
- C.A.J. Fletcher, *Computational Techniques for Fluid Dynamics, Vol. 1: Fundamentals and General Techniques*, 2nd ed., 1991, Springer-Verlag, ISBN: 3-540-53058-4 [available online through USC Libraries]
- J.C. Tannehill, D.A. Anderson, and R.H. Pletcher, *Computational Fluid Mechanics and Heat Transfer*, Taylor & Francis [on reserve at the Science & Engineering Library (SSL)]

DEN@Viterbi https://courses.uscden.net

DEN@Viterbi's D2L online course management platform will be used used to distribute all course material, including assignments, and to submit your projects. Make sure you are able to log in and see the course, then familiarize yourself with the platform.

Piazza Discussion Forum https://piazza.com/usc/fall2018/ame535a/home

You are strongly encouraged to use the **Piazza discussion forum** (integrated within D2L) to ask questions, make comments, and answer questions from your peers. When discussing project assignments, *do not give out the answers to questions!* That would be a violation of the Collaboration Policy. If you are unsure whether you are revealing too much, you can post a private message that only the instruction team can see.

Homework and Exam Grading on gradescope https://gradescope.com

Assignments will be graded on **gradescope**. You will submit your projects on D2L, and then see your grade details and comments online on gradescope once they are graded.

You will receive an email to your USC email address with instructions on how to log in after the first project is graded.

Course Policies

These course policies are designed to help students learn the material effectively, and the course assessment system is designed to best test students on what they really know, and can effectively use, in a real-world context. To ensure fairness, the followint rules will be strictly enforced.

Collaboration

- Collaboration of any sort on all matters that are not graded is strongly encouraged
- Students may discuss the projects with one another, the TA, or the instructor, but absolutely no written transcript or material can be part of such exchanges. This includes online forums, chats, etc. *If it's not in your head, it isn't yours.* The corollary is that *you must develop and write your own code and solutions*.
- You may not in any case use solutions to problems from past years: these cannot be consulted in any way, and would constitute a violation of the above no-written-transcript rule.
- If you use material other than the course notes for the projects, you must *cite your references*.
- We will be very strict about academic integrity violations and report them as appropriate.

Project Assignments

- Projects require a significant amount of work and code debugging, so *plan ahead!*
- The projects are due *before* class begins on the due date. To be fair to everyone, late submissions will incur a 20% penalty after the due *time* (2:00pm) and for each 24h delay.
- Assignments must be submitted electronically via the course's DEN@Viterbi page, and should include: a **PDF file for the report** and a **zip or tar file with your source code**.
- In order to receive full credit, solutions must be presented in a clear manner, and show evidence of work: magical one-line answers do not make the cut. *This also applies to the midterm*.

Office Hours

Office hours are best utilized when students come with *clear questions* and at least *an attempt at a solution*. The goal is for us to help you clarify the concepts and guide you through your thought process. *It is not meant as a way for you to effortlessly obtain the solutions.*

In addition to on-campus office hours, online office hours are held *exclusively* for DEN students. Login information will be provided in the DEN@Viterbi course page.

You are welcome to contact the instructor or the teaching assistant with questions outside of office hours *via email*. However, do not expect an immediate reply (1–2 days delays might be more typical), and keep in mind that some questions are hard to answer in text form: better to keep your emails clear and concise.

Recommendations for Projects

- If you have doubts about the material or what you are being asked to do, ask questions.
- Code for your projects must be written in one of the following programming languages: MATLAB, FORTRAN, C, C++, Python.
- The project report you submit should be close to a journal/conference paper. Organize the sections following the project questions, pay attention to the writing and grammar, and cite your sources. Try placing your figures close to the question to which they correspond.
- Stick to the nomenclature in the handout as much as possible.
- You are not required to type your report, but if you do decide to handwrite, please try and write neatly so that we can read you.
- You should explain your procedures and the reader must understand what you are doing without looking at your code. Every step should be documented, and any "educated" reader must be able to reproduce what you have done without guessing. Pseudo-code can be useful. If your answer/derivation to a question is particularly long, a summary at the end might be a good idea (especially if you are to use the derived forms or schemes later on).
- If you use a built-in MATLAB function or a programming library, say so and explain what the function does. If you don't know what's under the hood, you shouldn't be using it.
- As a general rule, a correct final answer will not give you full credit; your derivation is at least as important.
- Many questions ask for comments/explanations of the results; these are important. If a question asks you to make a comparison but does not explicitly request an explanation (e.g. compare the convergence rates of the different methods), you are still expected to provide one. *We want you to try and think critically about your findings.*
- Submit your code online in a single file (accepted formats: zip, gz, tar, tar.gz) named with your last name, e.g. `Uranga.zip`, and upload it to the DEN@Viterbi course page in the corresponding project section.
- Do not modify your numerical results even if you can't get the correct result in the end. We will test your code for consistency with the submitted results.
- Do not copy code or any other written material from another student, and do not allow other students to see your work. Plagiarism is much easier to detect than you might think, and we'll use plagiarism-detection tools to check all the submitted programs and reports. Be mindful of the Collaboration policy.

Topics and Tentative Schedule

Week	Date	Topics	Reading
1	23 AUG	Introduction Review of linear algebra Floating point arithmetic Overview of PDEs Overview of numerical methods	 OV1 OV2
2	30 AUG	Finite Differences: elliptic problems Poisson equation Consistency, stability and convergence Formulae: Lagrange interpolation, undetermined coefficients **Project 1: FD — *out***	FD1, FD2
3	06 SEP	Finite Differences: elliptic problems (cont.) Eigenvalue problem Non-rectangular domains	
4	13 SEP	**Project 1: FD — *due*** Finite Differences: time-dependent linear problems	 FD3
5	20 SEP	Finite Differences: convection-diffusion **Project 2: FV — *out***	FD4
6	27 SEP	Finite Volumes: Hyperbolic scalar conservation laws Discretization, conservative methods, entropy-satisfying schemes	 FV1 FV2
7	04 OCT	**Project 2: FV — *due*** Finite Volumes: TVD methods *Midterm review session*	
8	11 OCT	**Midterm 2:00pm–3:30pm** Solving linear systems: direct methods: Gaussian elimination, LU decomposition	
9	18 OCT	Solving linear systems: iterative methods: Jacobi, Gauss-Seidel, Over/Under-Relaxation, SOR Multigrid methods **Project 3: Solution Methods — *out***	 SM1 SM2
10	25 OCT	Midterm solution Finite Elements: Introduction	
11	01 NOV	**Project 3: Solution Methods — *due*** Finite Elements: Dirichlet and Neumann boundary conditions Formulations: strong form, minimization principle, weak form Discretization: bases, projections, mass matrix	FE1, FE2
12	08 NOV	Finite Elements: implementation **Project 4: FE — *out***	FE3, FE4
13	15 NOV	Finite Elements: theory	
14	22 NOV	*No class: Thanksgiving Break*	
15	29 NOV	**Project 4: FE — *due*** Various topics	

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" https://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

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. https://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. http://www.suicidepreventionlifeline.org

Relationship & 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. https://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: http://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. https://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. https://studentaffairs.usc.edu/bias-assessment-response-support/

Student Support & Advocacy – (213) 821-4710
Assists students and families in resolving complex issues adversely affecting their success as a student EX: personal, financial, and academic. https://studentaffairs.usc.edu/ssa/

Diversity at USC
Tabs for Events, Programs and Training, Task Force (including representatives for each school), Chronology, Participate, Resources for Students https://diversity.usc.edu/