AME 535a: Introduction to Computational Fluid Dynamics

University of Southern California – Fall 2021

Course Syllabus

Term	Fall 2021 (Aug. 23 – Dec. 15 , 2021)
Lectures	Tuesdays & Thursdays, 2:00 – 3:20pm Pacific Time in OHE 100C and on DEN@Viterbi
Instructor	Saakar BYAHUT ▪ Email: `byahut@usc.edu` Office Hours: in-person, Tues. and Wed. 9:00am – 10:00am in room TBD over Zoom, Wed. 6:00pm–7:00pm
Teaching Assistant	TBD ▪ Email: `TBD` Office Hours: TBD
IT Help	https://viterbigrad.usc.edu/technical-support/ Email: `dentsc@usc.edu` ▪ Phone: 213-740-9356

The most efficient way to communicate with the instructor or the TA is via Piazza or Slack.
If you reach out via email, please use your USC email account and allow 2–3 days to receive a reply.

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).

Technological Proficiency and Hardware/Software Required

This course requires access to a personal computer with internet access, and either MATLAB or a text editor and compiler (FORTRAN, C, C++, or Python). MATLAB is made available to students by USC's ITS (https://software.usc.edu/matlab/). Students will also need access to a scanner or camera to produce digital files for uploading assignments and exams.
Visit https://viterbigrad.usc.edu/technical-support/ for information about technical requirements and electronic tools.

Grading

- Projects: 70% of final grade
- Midterm exam: 20% of final grade
- Final exam: 10% of final grade

Notes, Textbooks, and Course 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. Their notes and other material are used and shared with permission from the authors, and such a use is consistent with their Creative Commons License. This year, the course follows closely the material offered by Prof. Alejandra Uranga in 2020. Her notes and materials have been adapted for use with permission.

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

Desire2Learn (D2L, DEN@Viterbi Course's Page) 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 send announcements. Make sure you are able to log in and see the course, then familiarize yourself with the platform.

WebEx (links for available on the D2L course page)

If you are new to WebEx, see https://viterbigrad.usc.edu/technical-support/webex/
For on-campus students wishing to attend lectures remotely, and for DEN students, live lectures will be conducted over WebEx. To join the lectures, log into the course page and select the "Virtual Meetings" tab from the top menu. ***Do not hesitate to ask questions***, either through the WebEx chat (preferred) or by speaking up (interrupt me if you need to). Except when talking to the class, it is good practice to mute your microphone to reduce noise.

Piazza Discussion Forum https://piazza.com/usc/fall2021/ame535a

You are strongly encouraged to use the **Piazza discussion forum** to ask questions, make comments, and answer questions from your peers. Piazza is great for asking technical questions, since you can enter mathematical formulae, and insert images and attachments. 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 use a private post that only the instruction team can see (under "Post to" select "Individual Student(s) / Instructor(s)" and then type "Instructors" in the corresponding field).

Slack https://uscviterbiclass.slack.com

Slack is a messaging platform accessible via an internet browser, or desktop and mobile apps. We we will use it for instant-messaging type communication and to create a sense of community.

Make sure to register with your USC account and learn about Slack by reading the guide at https://keepteaching.usc.edu/students/student-toolkit/classroom/slack/ .
Once registered, you will have access to the USC Viterbi School of Engineering Classes workspace (https://uscviterbiclass.slack.com) and to the AME 535a course channels:

`fall20-ame-535a-general`: *(preferred)* general, announcements, questions, comments
`fall20-ame-535a-28896`: *(auto generated by Viterbi)* for on-campus students
`fall20-ame-535a-29065`: *(auto generated by Viterbi)* for DEN students

Use Slack to ask questions or make comments to the whole class (instructor and TA included), to connect with your fellow students (whose list you can see on the status bar at the top of the channel, under members), and to collaborate in general. You can also reach the instructor and the TA individually (or any other USC member for that matter) by sending them a Direct Message. Customize your Slack notifications settings so you you can stay up to date.

The instruction team will check Slack ***twice a day on weekdays and less frequently over the weekend***. **You are encouraged to jump in and answer questions from others**. Use the threads functionality as much as possible to keep things organized (hover over the relevant message, and select "Reply to thread" text bubble icon from the contextual menu).

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

We will use **gradescope** for assignments and exam grading. You are responsible for uploading your assignments electronically on time, and you will see your grade and comments once they are graded. You will receive an email to your USC email address with instructions on how to register.

Office Hours

Office hours will be held by the instructor (see first page for days and times) online live via Zoom (for audio and video capability, particularly for DEN students) and in-person. Find the Zoom links on the course page under the Content topic "Office Hours"). If you cannot make any of the office hour times, send me an email or a private message on Piazza to set a different time. I also strongly encourage you to **post your questions** on Piazza at any time.

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.*

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 (2–3 days delay 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. And if your question is not that simple, then the fastest (and often most efficient) way to get help is via Piazza.

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 following 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 in two parts:
  1) a **PDF file for the report** uploaded to **gradescope**
  2) a **zip or tar file with your source code** via the project submission box in D2L
- 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*.

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 look professional. 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, and stick to the nomenclature in the handout.
- 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 often be useful. If your answer/derivation to a question is particularly long, a summary at the end might be a good idea (including for yourself if you are to use the derived result later on or code it).

- 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 D2L 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.
- If you know something is wrong with your code/answer, state so even if you don't know what's causing it. Remeber: we are trying to assess your understanding.
- **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	Dates	Topics (due times are in Pacific Time)	Reading*
1	24,26 AUG	I. Introduction Review of linear algebra, floating point arithmetic Overview of PDEs and Overview of numerical methods	OV1, OV2
2	31 AUG, 2 SEP	II. Finite Differences: elliptic problems Consistency, stability and convergence Formulae: Lagrange interpolation, undetermined coefficients **Project 1: FD — *out***	FD1, FD2
3	7,9 SEP	II. Finite Differences: elliptic problems (cont.) Eigenvalue problem, non-rectangular domains	
4	14,16 SEP	**Project 1, Part A: FD theory — *due 14 Sept., 2:00pm*** II. Finite Differences: time-dependent linear problems	FD3
5	21,23 SEP	II. Finite Differences: Convection-diffusion **Project 1, Part B: FD implementation — *due 23 Sept., 2:00pm***	FD4
6	28,30 SEP	III. Finite Volumes: Hyperbolic scalar conservation laws Discretization, conservative methods **Project 2: FV — *out***	FV1
7	5,7 OCT	III. Finite Volumes: Entropy-satisfying schemes, TVD methods **Project 2, Part A: FV theory — *due 7 Oct., 2:00pm***	FV2
8	12 OCT	IV. Solving linear systems: direct methods: Gaussian elimination, LU decomposition	
	14 OCT	*No class: fall recess*	
9	19 OCT	IV. Solving linear systems: iterative methods: Jacobi, Gauss-Seidel, Over/Under-Relaxation, SOR	SM1
	21 OCT	Multigrid methods **Project 2, Part B: FV implementation — *due 21 Oct., 2:00pm*** **Project 3: SM — *out***	SM2
10	26 OCT	Midterm review session	
	28 OCT	**Midterm Exam**	
11	2,4 NOV	V. Finite Elements: Introduction Formulations: strong form, minimization principle, weak form **Project 3: SM — *due 4 Nov., 2:00pm*** **Project 4: FE — *out***	FE1
12	9,11 NOV	V. Finite Elements: Discretization: bases, projections, mass matrix **Project 4, Part A: FE theory — *due 12 Nov., 2:00pm***	FE2
13	16,18 NOV	V. Finite Elements: implementation	FE3, FE4
14	23 NOV	V. Finite Elements: implementation (cont.)	
	25 NOV	*No class: Thanksgiving Break*	
15	30 NOV	Extra: Special considerations for Navier-Stokes equations	
	2 DEC	*(last day of classes)* Final Review **Project 4, Part B: FE implementation — *due 2 Dec., 2:00pm***	
16	9 DEC	**Final Exam**	

* reading material is from the notes by Peraire & Patera

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
https://engemannshc.usc.edu/counseling/
Free and confidential mental health treatment for students, including short-term psychotherapy, group counseling, stress fitness workshops, and crisis intervention.

National Suicide Prevention Lifeline – 1-800-273-8255 – 24/7 on call
http://www.suicidepreventionlifeline.org
Free and confidential emotional support to people in suicidal crisis or emotional distress 24 hours a day, 7 days a week.

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

Office of Equity and Diversity (OED) | Title IX – (213) 740-5086
https://equity.usc.edu, http://titleix.usc.edu
Information about how to get help or help a survivor of harassment or discrimination, rights of protected classes, reporting options, and additional resources for students, faculty, staff, visitors, and applicants. The university prohibits discrimination or harassment based on the following protected characteristics: race, color, national origin, ancestry, religion, sex, gender, gender identity, gender expression, sexual orientation, age, physical disability, medical condition, mental disability, marital status, pregnancy, veteran status, genetic information, and any other characteristic which may be specified in applicable laws and governmental regulations.

Bias Assessment Response and Support – (213) 740-2421
https://studentaffairs.usc.edu/bias-assessment-response-support
Avenue to report incidents of bias, hate crimes, and microaggressions for appropriate investigation and response.

The Office of Disability Services and Programs – (213) 740-0776
http://dsp.usc.edu
Support and accommodations for students with disabilities. Services include assistance in providing readers/notetakers/interpreters, special accommodations for test taking needs, assistance with architectural barriers, assistive technology, and support for individual needs.

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

Diversity at USC – (213) 740-2101
https://diversity.usc.edu Information on events, programs and training, the Provosts Diversity and Inclusion Council, Diversity Liaisons for each academic school, chronology, participation, and various resources for students.

USC Emergency – UPC: (213) 740-4321, HSC: (323) 442-1000 – 24/7 on call
http://dps.usc.edu, https://emergency.usc.edu
Emergency assistance and avenue to report a crime. Latest updates regarding safety, including ways in which instruction will be continued if an officially declared emergency makes travel to campus infeasible.

USC Department of Public Safety – UPC: (213) 740-6000, HSC: (323) 442-120 – 24/7 on call
http://dps.usc.edu
Non-emergency assistance or information.