

AME 535a Introduction to Computational Fluid Dynamics

University of Southern California – Fall 2020

Course Syllabus

Term	Fall 2020 (Aug. 24–Dec. 9, 2020)
Lectures	Tuesdays & Thursdays, 2:00–3:20pm Pacific Time
Instructor	Alejandra URANGA ▪ Email: auranga@usc.edu <u>Office Hours</u> : Tues. 5:00pm–6:00pm & Wed. 9:00–10:00am or by reservation Tues. 9–10am
Teaching Assistant	Tianbo (Raye) XIE ▪ Email: tianboxi@usc.edu <u>Office Hours</u> : by reservation Mon. 2–3:30pm, Wed. 5–6:30pm, Fri. 9–10am
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.

IMPORTANT NOTE ABOUT ONLINE TEACHING

Due to the COVID-19 pandemic, **all instruction will be conducted online**. My goal is to take this as an opportunity to create an enhanced learning experience for all of you!

You will get the most out of this class by being active. In particular:

- The **lectures** will be transmitted live at the lecture times and also recorded for asynchronous, on-demand, viewing. You can join the live session via WebEx (see below), and the videos will be made available after each lecture. ***If your schedule allows it, we strongly encourage you to join live and participate.*** If you have questions about the lecture,
- While we cannot meet in person, there are several ways for us to interact:
 - The **Piazza discussion forum** (see below) is the best way to ask technical questions about course material and assignments. Keep an eye on it to benefit from everyone else's posts.
 - **Slack** (see below) is a messaging platform from which you can reach the whole class, the instructor, and the TA. If you want to have a private exchange with someone, you can send a Direct Message (for instance by right-clicking someone's name and selecting Message).
 - And there is also the good old **email**, which you are free to use if you prefer a more formal communication, or if there are things you would like to have a record of. Just remember that the instruction team is not as responsive as via the other channels.
 - If there is a specific circumstance that you would like to discuss with the instructor, you can **request an individual online meeting** via Direct Message from Slack.
- **Office hours** will be conducted online live via WebEx (for audio/video capability) and Slack (for instant messaging) for the entire classroom. You can also post questions on Slack and/or Piazza at any time. For one-on-one help, use the reservation system (see below under Office Hours).
- Visit <https://keepteaching.usc.edu> for information on USC's digital resources and <https://viterbigrad.usc.edu> for comprehensive Viterbi graduate student information.

These are particularly challenging times; do not hesitate to reach out for support.

We are here to help!

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 Dirichlet 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.

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 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/> Live lectures and office hours 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 by speaking up (interrupt me if you need to) or via the WebEx chat. Except when talking to the class, it is good practice to mute your microphone to reduce noise.

Piazza Discussion Forum <https://piazza.com/usc/fall2020/20203ame535a>

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://kepteaching.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's channels:

fall120-ame-535a-general	:	general topics, announcements, questions
fall120-ame-535a-officehours	:	for use to ask questions during live office hours
fall120-ame-535a-assignments	:	messages related to the project assignments
fall120-ame-535a-lab	:	messages related to the optional lab module

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 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 exams. You are responsible for uploading your work 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 WebEx (for audio and video capability) and Slack (for instant messaging) **for the entire class**. Feel free to use either or both of these options (find the WebEx links on the course's page under the Content topic "Office Hours"). For **one-on-one help**, use the reservation system (instructions posted on the course's D2L page) to reserve a slot with either the instructor or the TA. We also strongly encourage you to **post your questions** on Slack and/or 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.*

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.*
- There is an **optional lab module** that presents an **introduction to commercial CFD software** (ANSYS packages). It is organized around weekly labs (theory, demonstration, and exercises) which you can complete on your own schedule, and you will have access to a remote desktop system with the software. It culminates in a lab project which you can choose to submit in place of one of the other projects (for 10% of your final grade).

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. Remember: 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	25,27 AUG	I. Introduction Review of linear algebra, floating point arithmetic Overview of PDEs and Overview of numerical methods	OV1, OV2
2	1,3 SEP	II. Finite Differences: elliptic problems Consistency, stability and convergence Formulae: Lagrange interpolation, undetermined coefficients Project 1: FD — out	FD1, FD2
3	8,10 SEP	II. Finite Differences: elliptic problems (cont.) Eigenvalue problem, non-rectangular domains	
4	15,17 SEP	Project 1, Part A: FD theory — due 15 Sept., 2:00pm II. Finite Differences: time-dependent linear problems	FD3
5	22,24 SEP	II. Finite Differences: Convection-diffusion Project 1, Part B: FD implementation — due 24 Sept., 2:00pm	FD4
6	29 SEP, 1 OCT	III. Finite Volumes: Hyperbolic scalar conservation laws Discretization, conservative methods Project 2: FV — out	FV1
7	6,8 OCT	III. Finite Volumes: Entropy-satisfying schemes, TVD methods Project 2, Part A: FV theory — due 8 Oct., 2:00pm	FV2
8	13 OCT	IV. Solving linear systems: direct methods: Gaussian elimination, LU decomposition	
9	15 OCT 20,22 OCT	IV. Solving linear systems: iterative methods: Jacobi, Gauss-Seidel, Over/Under-Relaxation, SOR Multigrid methods Project 2, Part B: FV implementation — due 22 Oct., 2:00pm Project 3: SM — out	SM1 SM2
10	27 OCT 29 OCT	Midterm review session Midterm Exam	
11	3,5 NOV	V. Finite Elements: Introduction Formulations: strong form, minimization principle, weak form Project 3: SM — due 12 Nov., 2:00pm Project 4: FE — out	FE1
12	10,12 NOV	V. Finite Elements: Discretization: bases, projections, mass matrix Project 4, Part A: FE theory — due 19 Nov., 2:00pm	FE2
13	17,19 NOV	V. Finite Elements: implementation	FE3, FE4
14	24 NOV	(last day of classes) V. Finite Elements: implementation (cont.) Project 4, Part B: FE implementation — due 5 Dec., 2:00pm	
15	3 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 Provost’s 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.