# AME 460 Aerodynamic Theory

## University of Southern California – Spring 2022

*Course Syllabus*

| | |
|---|---|
| **Term** | Spring 2022 (Jan. 10 – May 11 , 2022) |
| **Lectures** | Tuesdays & Thursdays, 9:30 – 10:50am, in GFS 108 |
| **Instructor** | Alejandra URANGA ▪ Email: auranga@usc.edu ▪ Office: OHE 500P<br>Office Hours: Tuesdays 11:00am – 12:30pm (by reservation)<br>Wednesdays 9:30 – 11:00am (walk-in) |

The most efficient way to communicate with the instructor 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**

Due to the COVID-19 pandemic, **some of the instruction may be conducted online**. Please check your email regularly and follow the course announcements from D2L (see below).

My goal is to make this class an exciting and challenging learning experience for all of you!
But it is a team effort, and **you will get the most out of this class by being active.**

In particular:

- If we need to move to online instruction, the **lectures** will be transmitted live at the lecture times and also recorded for asynchronous, on-demand, viewing. You are *expected to join the live lectures* via Zoom (see below), and the videos will be made available after each lecture to registered students only.
- While we cannot always 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, or the instructor individually. 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 via email as via the other channels.
  - If there is a specific circumstance that you would like to discuss with the instructor, don't hesitate to **request an individual online meeting** via Direct Message from Slack.
- If we must move to online instruction, **office hours** will be conducted live via Zoom and Slack 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.
- If you get sick or have any concerns during the semester contact the instructor without delay.

*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 concepts and techniques used in aerodynamics—the study of the flow of air about a body—as applied to subsonic, transonic, and supersonic regimes. Topics covered include conservation principles, incompressible flows, potential flows, thin airfoil and lifting line theories, quasi-one-dimensional compressible flows and shocks, small disturbance approximation, and an introduction to viscous flows and boundary layer theory.

## Learning Outcomes

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

a) Understand how the aerodynamic forces that a fluid exerts on a body are produced, and relate them to pressure and viscous stresses on the body's surface; Define lift and drag, and understand the importance of the lift-to-drag ratio in aerodynamics; Define and use lift, drag, moment, and pressure coefficients;

b) Understand and decide when the flow may be considered inviscid, and/or incompressible, and when the use of potential flow analysis is appropriate; understand and explain the major differences between: incompressible and compressible flow; viscous and inviscid flow; rotational and irrotational flow;

c) Understand and apply the conservation laws (continuity, momentum, and energy) in differential form, and understand flow kinematics; Explain the relation between streamline curvature, pressure gradient, and lift generation;

d) Relate lift to circulation, and be able to apply Thin Airfoil Theory and lumped vortex methods to 2D airfoils and problems in incompressible potential flow;

e) Understand and use loading distributions to determine the performance of wings, including through the use of lifting line theory concepts; Understand the source of induced drag and how to predict it;

f) Determine changes in flow properties due to changes in flow direction in compressible supersonic flow using shock-expansion theory, and understand the source of wave drag;

g) Understand and apply linearized potential flow to compressible subsonic and supersonic flows to determine forces over bodies;

h) Determine an airfoil's critical Mach number, and understand the particularities of transonic flow, including the detrimental effects of the drag divergence and how they can be mitigated.

## Textbook

John D. Anderson Jr., *Fundamentals of Aerodynamics*, 6$^{\text{th}}$ edition, 2016, McGraw-Hill (*Note: an older edition can also be used*)

## Required Preparation

- AME 309 Dynamics of Fluids, or equivalent course in fluid mechanics
- Basic physics, vector calculus, and differential equations, at a level common to 1$^{\text{st}}$ year college

## Grading

- Homework: 50% of final grade (two lowest grades dropped)
- Midterm exam: 30% of final grade (in-class and take-home parts)
- Final exam: 20% of final grade (in-class)

## References

We will be following Anderson's textbook closely, but there are a number of other good books on aerodynamics. The following references are good complements for those students who want to get another perspective or go in more depth on the material.

Fundamentals:

- J. Katz and A. Plotkin *Low-Speed Aerodynamics*, Cambridge University Press
- J.D. McLean, *Understanding Aerodynamics*, Wiley

Advanced Topics:

- M. Drela, *Flight Vehicle Aerodynamics*, MIT Press
- F.M. White, *Viscous Fluid Flow*, McGraw-Hill
- H. Schlichting, *Boundary Layer Theory*, Springer

## Resources

**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. **Note: We use D2L instead of Blackboard.**

**Zoom** https://usc.zoom.us

If we must move to online teach due to the pandemic, we will use Zoom to conduct live lectures and office hours. To join the lectures, log into the course's D2L page and select the "Online Instruction" tab from the top menu, where you will find links to join lectures and office hours.

***Do not hesitate to ask questions***, either by speaking up (interrupt me if you need to), via the chat, or by using the *Rise Hand* function.

Except when talking to the class, it is good practice to mute your microphone to reduce noise.

If you are new to Zoom, see https://keepteaching.usc.edu/students/student-toolkit/classroom/zoom/ for more information.

**Piazza Discussion Forum** https://piazza.com/usc/spring2022/20221ame460

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 homework assignments, *do not give out the answers to questions!* That would be a violation of the Collaboration Policy. Public posts related to graded assignments should only be for clarification purposes. *No posts are allowed while a take-home exam is out.*

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 460 course's channel: `spring22-ame-460-28830`.

Use Slack to ask questions or make comments to the whole class (instructor and TA included) and to connect with your fellow students (whose list you can see on the status bar at the top of the channel, under members). 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.

### Homework and Exam Submission and 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 can access the gradescope class page from the top menu bar in D2L, or directly at gradescope.com once you have registered.

## 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 rules will be strictly enforced.

### Collaboration

- Collaboration of any sort on all matters that are not graded is strongly encouraged.
- Students may discuss the homework problems with one another, but no written or digital material can be part of such exchanges. *If it's not in your head, it isn't yours.* The corollary is that *you must develop and write your own solutions*.
- *Absolutely no collaboration is allowed on take-home exams*: these are individual efforts, and you are not allowed to discuss them with anyone else than the instructor.
- We will be very strict about academic integrity violations and report them as appropriate.

### Homework Assignments

- Weekly homework will be assigned on Thursdays and due the following Thursday most weeks (except before exams). It is due *before* class begins on the due date. To be fair to everyone, late submissions will incur a 20% penalty after the due *time* (9:30am) and for each 24h delay.
- Homework must be submitted via **gradescope**.
- The two lowest homework grades will be dropped when computing the homework portion of the final grade. These can of course include homeworks that you do not submit.
- 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. The reasoning is as important as the solution. *This also applies to the exams*.

### Office Hours

- Office hours are held by the instructor (see first page for days and times) in person (or if we move to online learning online live via Zoom for audio and video capability), and via Slack (for instant messaging). Feel free to use either or both of these options.
- If we are teaching online, to join online office hours log into the course's D2L page and select the "Online Instruction" tab from the top menu, where you will find the Zoom links and meeting

information.

- If you cannot make any of the office hour times, send us a Direct Message on Slack to set a different time. We also strongly encourage you to **post your questions** on Slack and/or Piazza at any time.
- For a one-on-one meeting, use the reservation system (see instructions on the course's D2L page) to reserve a slot with the instructor.
- Office hours provide a good opportunity for you to get clarifications and better understand the course material. This time is best utilized when you 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.* So come often but come prepared.

## Topics and Tentative Schedule

*You are responsible for reading the chapter(s) in the textbook **before** the corresponding lecture.*

| Week | Date | Topics | Reading |
|---|---|---|---|
| 1 | JAN 11, 13 | **I.** Introduction<br>. Forces and moments<br>. Flow similarity<br>. Aerodynamic performance | Ch. 1 |
| 2 | JAN 18, 20 | **II.** Conservation laws<br>. Conservation of mass, conservation of momentum | Ch. 2 |
| 3 | JAN 25, 27 | . Intrinsic coordinates, streamlines, stream function | |
| 4 | FEB 1, 3 | **III.** Incompressible potential flows<br>. Equations, flow modeling | Ch. 3, 6 |
| 5 | FEB 8, 10 | . Non-lifting flow models | |
| 6 | FEB 15, 17 | . Lifting flow models | |
| 7 | FEB 22, 24 | . 2D aero modeling | Ch. 4 |
| 8 | MAR 1, 3 | . 3D aero modeling | Ch. 5 |
| 9 | MAR 8, 10 | **IV.** Shock-expansion theory<br>. Gas dynamics, energy equation<br>. Normal shocks | Ch. 7<br>Ch. 8 |
| 10 | MAR 15, 17 | *No class (Spring recess)* | |
| 11 | MAR 22<br>MAR 24 | Midterm review<br>**Midterm exam, in-class part** | |
| 12 | MAR 29<br>MAR 31 | **IV.** Shock-expansion theory (cont.)<br>. Oblique shocks, expansion waves<br>. Quasi 1D flows and applications<br>**Midterm exam, take-home part: due Thursday March 31** | Ch. 9<br>Ch. 10 |
| 13 | APR 5, 7 | **V.** Inviscid compressible aerodynamics<br>. Full potential flow<br>. Small disturbances, perturbation potential<br>. Linearized compressible potential flow<br>. Subsonic linearized potential flow, Prandtl-Glauert | Ch. 11, 12 |
| 14 | APR 12, 14 | . Supersonic linearized potential flow<br>. Transonic flows and design considerations | |
| 15 | APR 19, 21 | **VI.** Viscous flows and boundary layer theory<br>. Viscous flows fundamentals<br>. Boundary layer equations and integral parameters | Ch. 15<br>Ch. 17 |
| 16 | APR 26, 28 | . Laminar boundary layers<br>. Turbulent boundary layers<br>. Stability, transition, and other viscous flow considerations | Ch. 18<br>Ch. 19 |
| | MAY 10 | **Final exam Tuesday May 10, 8 – 10am** | |

## 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.