AME 511 – Compressible gas dynamics

Units: 4
Spring 2024 - Tue & Thu 4:00-5:50pm

Location: OHE 100B.

Instructor: Iván Bermejo-Moreno
Office: OHE 500M and via Zoom (see website)
Office Hours: Tue, Thu 6:00-7:30pm in OHE 406
Contact Info: bermejom@usc.edu

- Allow 48 hours during weekdays for email replies.
- Use your USC email account for email communications.

Teaching Assistant: Naili Xu
Office Hours: Mon, Wed 5:00-6:30pm in OHE 406
Contact Info: nailixu@usc.edu

IT Help: https://viterbigrad.usc.edu/technical-support/
Contact Info: dentsc@usc.edu

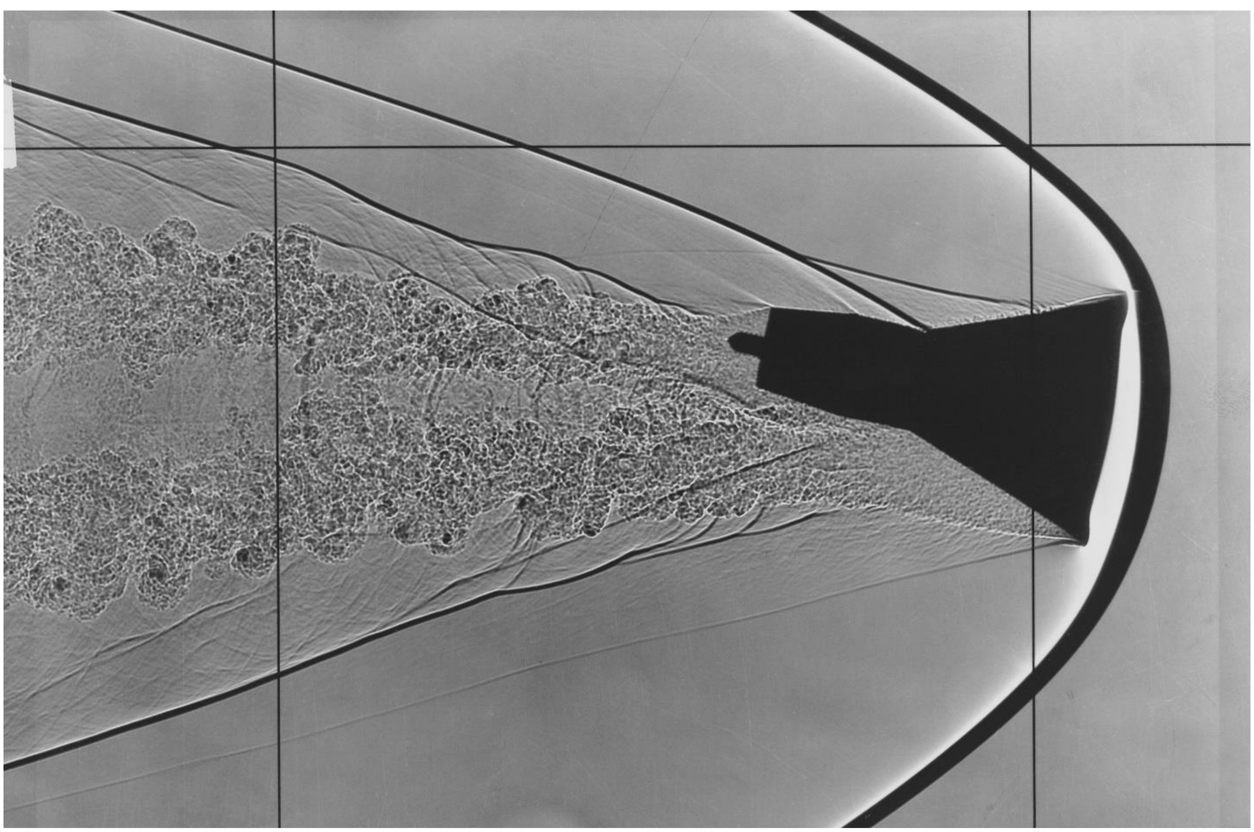

Photo credit: NASA (ID: ARC-1963-A-31214) Shadowgraph of Gemini capsule flight stability study

Course Description

This course provides an introduction to compressible fluid flows, focused on applications in high-speed flight and propulsion. It starts by reviewing classical thermodynamics of gases in equilibrium and developing the general equations governing compressible flows. Simplified flow types are then described, emphasizing particularizations to calorically perfect gases, including: 1D and quasi-1D steady and unsteady flows, shock/expansion waves and their interactions. Application to nozzles, diffusers, shock-tubes, and shock-tunnels will be presented. Potential flow theory under small disturbances is then developed for subsonic, transonic, supersonic, and hypersonic flow regimes, with application to aerothermodynamics. Hypersonic and high-temperature flows are then addressed, emphasizing departures from the perfect and equilibrium gas assumptions. The effects of viscosity and radiation in gas dynamics will also be addressed.

Learning Objectives

- Describe characteristic physical features of different compressible flow regimes (subsonic, transonic, supersonic, and hypersonic).
- Identify and contrast theoretical formulations suitable to mathematically describe each flow regime and explain the range of applicability of the underlying assumptions.
- Solve idealized problems of practical relevance in gas dynamics using differential and integral analytical approaches, as well as computational methods (using commercial software).
- Explain prevalent aerodynamic design choices seen in state-of-the-art high-speed-flight vehicles from a flow physics standpoint, discussing current technological limitations.

Prerequisite(s): N/A **Co-Requisite(s):** N/A **Concurrent Enrollment:** N/A

Recommended Preparation: introductory courses in fluid- and thermo-dynamics, vectorial and tensorial calculus, and partial differential equations.

Course Notes

- The course uses DEN D2L online services (https://courses.uscden.net/d2l/login). All course material, including lecture videos, instructor's notes, slide-show presentations, formula sheets, tables and graphs, and announcements will be posted online in the course website on D2L.
- A Microsoft OneNote Class Notebook is available to students with the handwritten part of the lectures, digital versions of the presentations to facilitate annotation, and material covered during office hours. The notebook is shared with all students. Contact the instructor if you have not been granted access (e.g., if you enrolled after the first day of instruction).
- An online discussion forum will be used through the Piazza platform (http://www.piazza.com/). Please submit all questions related to homework, logistics, midterm and final exams to the discussion forum, so that other students can also benefit from the answers. You can submit questions anonymously if you so desire. If you are not automatically enrolled in Piazza, please contact the instructor. The course Piazza website is https://piazza.com/usc/spring2024/ame511
- Videoconferencing is available during office hours via Zoom. Contact the instructor if interested.

Technological Proficiency and Hardware/Software Required

- Basic use of plotting software will be required for some homework assignments. Any plotting software can be used (e.g., Python's matplotlib, gnuplot, Matlab, Microsoft Excel, etc.)
- ANSYS Fluent software (https://www.ansys.com/products/fluids/ansys-fluent) for fluid flow simulation will be used for a computational fluid mechanics (CFD) project. The software is provided via the Viterbi School Enhanced Virtual Desktop Infrastructure (https://itservices.usc.edu/vdi/).

Recommended textbooks

- John D. Anderson "Modern Compressible Flow," 3rd Ed, McGraw-Hill, Inc.
- Liepmann & Roshko "Elements of Gas Dynamics," Dover Publications.
- John D. Anderson Jr. "Hypersonic and High Temperature Gas Dynamics," 3rd Ed, AIAA

Paper-based copies of these books are available at USC's Science Library, physically located at 910 Bloom Walk, Los Angeles, CA 90089. Full electronic access to the book by Liepmann & Roshko is also available through USC's online library system (https://libraries.usc.edu/) and requires to log in with a USC account.

Grading Breakdown

- Homework: 30% of final grade, distributed evenly across 7 assignments.
- CFD Project: 10% of final grade.
- Midterm exam: 30% of final grade.
- Final exam: 30% of final grade.

Grading Scale

Course letter grades will be determined using the following scale from the final numerical grade:

A	91.5-100.0%
A-	82.5-91.5%
B+	75.0-82.5%
B	66.5-75.0%
B-	57.5-66.5%
C+	50.0-57.5%
C	41.5-50.0%
C-	32.5-41.5%
D+	25.0-32.5%
D	16.5-25.0%
D-	8.5-16.5%
F	0.0-8.5%

Assignment Submission Policy

- Each homework assignment should be **submitted electronically as a single PDF file** via the course Gradescope page, accessible from the D2L DEN website at https://courses.uscden.net/d2l/login). If you have a paper-based version of your homework assignment, you can use a scanner or any existing smart phone apps that use the phone camera as a scanner. Please make sure to append all pages into a single PDF document before submitting. **Please make sure to assign the pages corresponding to each problem on the Gradescope interface.**
- Ensure that you provide legible and logically organized solutions that explicitly include all necessary steps and assumptions (if any) made. Both hand-written and typed solutions are acceptable.
- Discussion of homework assignments with your classmates is allowed but each student should develop and write their own original solution.
- Late submission of homework assignments will be penalized by a 25% deduction in the assignment grade every 24 hours late, unless due to an emergency situation excused by the instructor. Email the instructor as soon as possible to discuss alternate arrangements due to an emergency.

Grading Timeline

- Graded homework assignments and numerical grades will posted online on the Gradescope course website (accessible from DEN D2L) within approximately 10 days after the submission deadline.

Additional Policies

- Students who require a laptop to complete any of their work can check one out through the Laptop Loaner Program https://itservices.usc.edu/spaces/laptoploaner/

Course Schedule: A Weekly Breakdown

Week	Topics/Daily Activities	HW	Due Dates
1	Introduction; concepts from classical thermodynamics.	**1**	**Week 3**
2	Conservation laws in integral and differential form.		
3	Crocco's theorem, constitutive equations, equations in indicial form.	**2**	**Week 5**
4	Rotational and irrotational (potential) flow. Sound speed and Mach number. Stagnation and characteristic variables		
5	One-dimensional steady compressible flow; Normal shock waves. One-dimensional steady flow with heat addition (Rayleigh flow) One-dimensional adiabatic steady flow with friction (Fanno flow)	***3***	**Week 7**
6	Oblique shocks; hodograph, shock polar, pressure-deflection plane. Regular and singular (Mach) shock reflections. Oblique shocks in wedges, cones and blunt bodies. Crocco's theorem applied to shock waves.		
7	Prandtl-Meyer expansions. Shock-expansion theory; wave drag; aerodynamic coefficients. Wave reflections, intersections and interactions.	**4**	**Week 9**
8	Quasi-1D steady isentropic flow. Area-Mach relations Nozzles, diffusers and wind tunnels.		
9	1D unsteady homentropic flow; Riemann invariants. Unsteady wave motion; acoustic, finite and shock wave propagation.	**5**	**Week 11**
10	**MIDTERM EXAM: March 19, 4:00pm-5:50pm** CFD Kickoff meeting Propagation and reflection of shock and expansion waves. Shock-tubes and shock-tunnels.		
11	Potential flow and linearized potential theory.	**6**	**Week 13**
12	Transonic flow; small perturbation theory and similarity parameter. Critical Mach number; Drag divergence; Area rule; Supercritical airfoils		
13	Hypersonic flow; Phenomenology. Hypersonic limit of shock and expansion wave relations.	**7**	**Week 15**
14	Mach number independence principle; Newtonian theory. Small disturbance theory and hypersonic similarity. Shock layer theory		
15	Viscous effects in gas dynamics. Shock wave boundary layer interactions. High-temperature gas dynamics. Departures from calorically and thermally perfect gases. CFD Project Final Presentations	**CFD Project**	**Presentation and Report due**
	FINAL EXAM: May 2 – 4:30pm-6:30pm		

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 the USC Student Handbook, page 11: https://policy.usc.edu/studenthandbook/ .
Other forms of academic dishonesty are equally unacceptable. See additional information in *SCampus* and university policies on scientific misconduct, https://ooc.usc.edu/research-compliance/scientific-integrity/.

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://safety.usc.edu/resources/counseling/
https://sites.usc.edu/counselingandmentalhealth/

The Office of Student Accessibility Services
Provides certification for students with accessibility requirements and helps arrange relevant accommodations.
https://osas.usc.edu/

Relationship and Sexual Violence Prevention and 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://sites.usc.edu/clientservices/

Office of Equity, Equal Opportunity, and Title IX (EEO-TIX) – (213) 740-5086
Works with faculty, staff, visitors, applicants, and students around issues of protected class. https://eeotix.usc.edu/

Campus Support and Integration
Assists students and families in resolving complex issues adversely affecting their success as a student EX: personal, financial, and academic. https://campussupport.usc.edu/

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

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. https://www.suicidepreventionlifeline.org

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. https://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. https://dps.usc.edu/