ASEN 5151: Fundamentals of Gas Dynamics

Spring 2026

Time:			
Instructor:	Prof. Robyn Macdonald	**Email:**	robyn.macdonald@colorado.edu
Teaching Assistant:		**Email:**	

Course Page: https://canvas.colorado.edu/

Office Hours:

Text: There is no required textbook for this course. Notes will be posted on the course website for each section. Some useful references are listed below which are available digitally or in the course reserves at the Gemmill Library. At the beginning of the notes for each section is a list of sources from which the notes were compiled.

- Anderson, J. D., Jr., *Modern Compressible Flow with Historical Perspective,* Second Edition, McGraw-Hill, 1990. Available in course reserves.
- Zucrow, M. J. and Hoffman, J. D., *Gas Dynamics,* Vol. I, Wiley, 1976. Available in course reserves.
- Zucrow, M. J. and Hoffman, J. D., *Gas Dynamics,* Vol. II, Wiley, 1977. Currently checked out of CU Library.

Prerequisites: A first course in fluid mechanics or aerodynamics, including ASEN 3111 or ASEN 3711. I will assume that you are familiar with typical topics from an introductory compressible flow course, including isentropic flow with area change, normal shock waves, oblique shock waves, Prandtl-Meyer flow, associated applications such as converging and converging-diverging nozzles, etc. I expect students to be proficient with programming which will be used for some assignments.

Grading Policy: Homework (40%), Exam 1 (25%), Exam 2 (35%).

Homework: Homework will be assigned periodically as the appropriate material is covered, and will include both handwritten problem sets and programming assignments (most assignments will include some of both). There will be approximately 6 homework assignments. The due date for each assignment will be announced when the assignment is made. All students will submit assignments

through the course Gradescope website. The late penalty for homework will be 10% per day, for up to 5 days. Beyond 5 days late, the assignment is worth 0%. You may receive help from a classmate or the instructor/TA on homework assignments, but the submitted assignment must be your own work. This includes both handwritten solutions, as well as programming assignments.

Exams: There will be two exams in this course. The first will cover material from the first half of the class (to be specified later) and the second will be cumulative, but focusing on material in the second half of the course. Students registered for the asynchronous remote section will have the option to take the exam remotely with a proctor. You should coordinate a proctor and communicate with Professor Macdonald the details on your proctor at least two weeks before the exams. The exam dates are as follows:

Class format: This class operates in two modalities: in-person and asynchronous remote. All lectures will be recorded via Classroom Capture and will be made available to all students.

Honor Code: All students enrolled in a University of Colorado Boulder course are responsible for knowing and adhering to the Honor Code. Violations of the Honor Code may include but are not limited to: plagiarism (including use of paper writing services or technology [such as essay bots]), cheating, fabrication, lying, bribery, threat, unauthorized access to academic materials, clicker fraud, submitting the same or similar work in more than one course without permission from all course instructors involved, and aiding academic dishonesty. Understanding the course's syllabus is a vital part of adhering to the Honor Code.

All incidents of academic misconduct will be reported to Student Conduct & Conflict Resolution: StudentConduct@colorado.edu. Students found responsible for violating the Honor Code will be assigned resolution outcomes from Student Conduct & Conflict Resolution and will be subject to academic sanctions from the faculty member. Visit Honor Code for more information on the academic integrity policy.

Accommodation for Disabilities, Temporary Medical Conditions, and Medical Isolation: If you qualify for accommodations because of a disability, please submit your accommodation letter from Disability Services to your faculty member in a timely manner so that your needs can be addressed. Disability Services determines accommodations based on documented disabilities in the academic environment. Information on requesting accommodations is located on the Disability Services website. Contact Disability Services at 303-492-8671 or DSinfo@colorado.edu for further assistance. If you have a temporary medical condition, see Temporary Medical Conditions on the Disability Services website.

If you have a temporary illness, injury or required medical isolation for which you require adjustment due to a missed in-person assessment (exam), please alert Professor Macdonald of your absence via email but do not include specific information about your illness due to privacy laws. Because attendance is not required in this class, if you miss a class you do not need to inform Professor Macdonald but can watch the lecture asynchronously on Canvas.

Students should expect to receive accommodations for a timed assessment (e.g., exam) only if their faculty instructor(s) receive the student's accommodations letter at least 5 business days before the

assessment, as a departmental policy, in order to facilitate administering the assessment.

Accommodation for Religious Obligations: Campus policy requires faculty to provide reasonable accommodations for students who, because of religious obligations, have conflicts with scheduled exams, assignments, or required attendance. Please communicate the need for a religious accommodation in a timely manner. In this class if you must miss an in-class assessment (exam) due to a religious obligation, please contact Professor Macdonald at least two weeks prior to coordinate an accommodation. See the campus policy regarding religious observances for full details.

Preferred Student Names and Pronouns: CU Boulder recognizes that students' legal information does not always align with how they identify. If you wish to have your preferred name (rather than your legal name) and/or your preferred pronouns appear on your instructors' class rosters and in Canvas, visit the Registrar's website for instructions on how to change your personal information in university systems.

Classroom Behavior: Students and faculty are responsible for maintaining an appropriate learning environment in all instructional settings, whether in person, remote, or online. Failure to adhere to such behavioral standards may be subject to discipline. Professional courtesy and sensitivity are especially important with respect to individuals and topics dealing with race, color, national origin, sex, pregnancy, age, disability, creed, religion, sexual orientation, gender identity, gender expression, veteran status, marital status, political affiliation, or political philosophy.

Additional classroom behavior information

- Student Classroom and Course-Related Behavior Policy.
- Student Code of Conduct.
- Office of Institutional Equity and Compliance.

Sexual Misconduct, Discrimination, Harassment and/or Related Retaliation: CU Boulder is committed to fostering an inclusive and welcoming learning, working, and living environment. University policy prohibits protected-class discrimination and harassment, sexual misconduct (harassment, exploitation, and assault), intimate partner abuse (dating or domestic violence), stalking, and related retaliation by or against members of our community on- and off-campus. The Office of Institutional Equity and Compliance (OIEC) addresses these concerns, and individuals who have been subjected to misconduct can contact OIEC at 303-492-2127 or email OIEC@colorado.edu. Information about university policies, reporting options, and OIEC support resources including confidential services can be found on the OIEC website.

Please know that faculty and graduate instructors are required to inform OIEC when they are made aware of incidents related to these concerns regardless of when or where something occurred. This is to ensure the person impacted receives outreach from OIEC about resolution options and support resources. To learn more about reporting and support a variety of concerns, visit the Don't Ignore It page.

Mental Health and Wellness: The University of Colorado Boulder is committed to the well-being of all students. If you are struggling with personal stressors, mental health or substance use concerns that are impacting academic or daily life, please contact Counseling and Psychiatric Services (CAPS), located in C4C, or call (303) 492-2277, 24/7.

Acceptable Use of AI in This Class: You may **NOT** use generative AI tools on any assignments in this course. Generative AI use in this course will not enhand student learning, nor serve the topic

at hand. If generative AI use is suspected on an assignment, I will consult with you and ask that you redo the assignment using no generative AI within 1 week of our meeting. In the case of subsequent infractions of this policy, you will receive a zero on the assignment(s) in question.

Course Outline:

1. Review of Fluid Mechanic and Thermodynamic Principles
    I. Governing Equations for a Control Volume
        A. Reynolds' Transport Theorem
        B. Conservation of Mass (Continuity)
        C. Linear Momentum Equation (Newton's Second Law)
        D. First Law of Thermodynamics (Energy Equation)
        E. Second Law of Thermodynamics
    II. Thermodynamics of Ideal Gases
        A. Equation of State
        B. Energy/Specific Heat Relations
        C. Entropy Changes/Isentropic Processes
        D. Speed of Sound/Mach Number
        E. Static and Stagnation Properties
2. Generalized One-Dimensional Flow
    I. Introduction
    II. Analysis
    III. Table of Influence Coefficients
    IV. Isentropic Flow with Area Change
    V. One-Dimensional Flow with Heat Addition (Rayleigh Flow)
    VI. One-Dimensional Flow with Friction (Fanno Flow)
    VII. Solution Procedure for Generalized 1D Flow
    VIII. Qualitative Features of Generalized 1D Flows
        A. $dG < 0$
        B. $dG = 0$
        C. $dG > 0$
        D. $dG < 0$, $dG = 0$, $dG > 0$
        E. $dG > 0$, $dG = 0$, $dG < 0$
    IX. Numerical Solution Near the Critical Point, $M = 1$, $dG = 0$
    X. Solution Technique for a Flow with a Sonic Point
3. Partial Differential Equations Governing Inviscid Compressible Flow
    I. Partial Differential Equations in Conservation Form
        A. Continuity Equation
        B. Linear Momentum Equation
        C. Energy Equation
        D. Second Law of Thermodynamics
    II. Partial Differential Equations in Nonconservation Form

   A. Continuity Equation
   B. Linear Momentum Equation
   C. Energy Equation
   D. Second Law of Thermodynamics
   E. Speed of Sound Equation
III. Kelvin's Circulation Theorem
IV. Crocco's Theorem
V. Compressible Potential Equation
   A. Mathematical Features of the Potential Equation
   B. Elliptic Equations
   C. Parabolic Equations
   D. Hyperbolic Equations
   E. Canonical (Characteristic Coordinate) Form of PDEs
   F. Classification of Systems of First-Order PDEs
   G. Boundary Conditions for the Compressible Potential Equation
VI. Compressible Stream Function
VII. Orthogonal Curvilinear Coordinates
   A. Metric Coefficients
   B. Vector Operators in Orthogonal Curvilinear Coordinates

4. Linearized Flows/Analytical Techniques

I. Linearization of the Governing Equations
   A. Perturbation Velocity Potential
   B. Classification of the Perturbation Potential Equation
   C. Linearized Boundary Condition at a Solid Surface
   D. Linearization of the Pressure Coefficient
II. Subsonic Flow Over a Wavy Wall
III. Supersonic Flow Over a Wavy Wall
IV. Summary: Features of Subsonic and Supersonic Flow Over a Wavy Wall
V. Transonic Flow in the Throat Region of Axisymmetric Nozzles

5. Supersonic Flow Over a Cone

I. Properties of Supersonic Flow Over a Cone
II. Analysis
III. Numerical Algorithm for Supersonic Flow Over a Cone
IV. Numerical Integration of the Coupled ODEs
   A. Predictor-Corrector
   B. Fourth-Order Runge-Kutta
V. Results and Physical Aspects of Supersonic Flow Over a Cone

6. Steady, Two-Dimensional Supersonic Flow

I. Definition of Characteristics
II. MOC Analysis for Steady 2D Planar or Axisymmetric Irrotational Supersonic Flow
III. Numerical Implementation of MOC for Steady 2D Planar or Axisymmetric Irrotational Supersonic Flow
    A. Interior Point Algorithm
    B. Domain of Dependence and Range of Influence
    C. Axis of Symmetry Point Algorithm
    D. Wall Point Algorithm
    E. Direct and Inverse Marching Methods
IV. Example: Design of Uniform Flow Supersonic Nozzles
V. Intersection of Characteristics of the Same Family
VI. MOC for Steady 2D Planar or Axisymmetric Rotational Supersonic Flow

7. Unsteady, One-Dimensional Flow

I. Governing Equations
II. MOC Analysis
III. Special Case: Planar Flow of an Ideal Gas
IV. Numerical Implementation of MOC for Unsteady 1D Homentropic Flow
    A. Interior Point Algorithm
    B. Solid Boundary Point Algorithm
    C. Inflow/Outflow Point Algorithms
V. Physical Features of Unsteady 1D Homentropic Flow
    A. Definitions
    B. Simple Compression and Expansion Waves
    C. Centered Waves
    D. Reflection of Compression and Expansion Waves
    E. Intersection of Continuous Waves
VI. Example: Shock Tube (Riemann Problem)
VII. MOC Analysis for Unsteady 1D Isentropic Flow