AE 2010 - Thermodynamics and Fluids Fundamentals

Instructor
Prof. Sedina Tsikata
Office hours: Wed. 10:45am – 12:45pm | Office: Guggenheim 447
Contact: stsikata@gatech.edu

Graduate teaching assistant: Kyoungeun Lee – klee954@gatech.edu
Office hours: Thurs. 10am - 12pm | Location: Loewy Library, Montgomery Knight 3rd floor

Undergraduate teaching assistant: Ethan Cordeiro – ecordeiro3@gatech.edu
Recitations: Wed. 6:30pm | Location: Guggenheim 442

Hours: 4-0-4

Catalog description

Thermodynamic and fluid properties. Conservation laws. Isentropic flow, shocks and expansions, introduction to flows with friction and heat transfer. Applications to aerospace devices.

Required texts

- Steven R. Turns, Thermodynamics: Concepts and Applications, 2nd ed.
- John D. Anderson, Fundamentals of Aerodynamics, 6th ed.
- Course lecture notes

Course platforms: Canvas and Gradescope

Prerequisites

- MATH 2401 Minimum Grade of C / MATH 2411 Minimum Grade of C / MATH 24X1 Minimum Grade of T / MATH 2551 Minimum Grade of C / MATH 2561 Minimum Grade of C / MATH 2X51 Minimum Grade of T
- PHYS 2211 Minimum Grade of C / PHYS 2231 Minimum Grade of C
- CHEM 1310 Minimum Grade of C / CHEM 1211K Minimum Grade of C

Course objectives

1) Provide students with a fundamental understanding of the conservation laws and properties used to analyze fluids, flows and energy conversion devices
2) Enable students to analyze basic compressible flows, including applications to nozzles, diffusers and simple airfoils

Learning outcomes

Students will gain a master level understanding of:

1. Properties of fluids (temperature, density, pressure, viscosity, speed of sound)
2. Thermodynamic properties and state equations (including gases, incompressible substances and two-phase mixtures)
3. Basic concepts of thermodynamics (systems, work, heat)
4. 1st and 2nd Laws

5. Application of conservation equations (integral and differential forms) to fluid mechanical and energy conversion devices
6. Static and stagnation Properties
7. Propagation of and property variation due to disturbances (Mach, shock, compressions, and expansions)
8. Quasi 1D analysis of compressible internal flows
9. Bernoulli equation, hydrostatics, streamlines
10. Physical characteristics and similarity parameters associated with continuum flow regimes (subsonic, transonic, supersonic, hypersonic, steady, unsteady, viscous, inviscid)

Students will gain a basic level understanding of:

11. Derivation of the basic conservation equations for thermodynamics and fluid mechanics

Students will gain an exposure level understanding of:

12. Relevant applications to aerospace systems

Graded Components

Assignment	Weight (%)
Homework	**10%**
Engagement check-ins	**5%**
Mid-term exam 1	**20%**
Mid-term exam 2	**30%**
Final Exam	**35%**

Homeworks will generally be assigned on a weekly basis and must be turned in on time. Homework is intended primarily as a formative component of the course, providing structured practice that directly prepares students for the reasoning and problem-solving expected on exams.

Assignments will be posted on Gradescope and Canvas and submissions will be due on Gradescope (pdf file upload). Students can receive **a short extension (2 days) on a maximum of 3 assignments without penalty**; all other late submissions will receive points deductions. There is no need to request permission ahead of time to use an authorized homework extension. Students have **1 week** after assignment grades are released by the TA to request regrades.

Engagement check-ins are brief, in-class activities designed to encourage regular participation and provide quick opportunities to assess understanding of key concepts.

These check-ins will be unannounced, administered periodically and electronically, and may occur at any point during a class. Each check-in will be typically 5 minutes and will include a brief attendance verification and one or more conceptual questions related to the material being discussed. Full credit for this component is earned by completing at least 90% of the check-ins; students completing fewer will receive proportional credit. The 90% threshold is intended to accommodate occasional absences or technical difficulties, so individual make-up check-ins will not normally be offered. Students must be physically present in class to submit a check-in unless otherwise authorized.

Grading Scale
Final grades will be assigned as a letter grade according to the following scale:

Letter Grade	Percentage
A	**90-100%**
B	**80-89%**
C	**70-79%**
D	**60-69%**
F	**0-59%**

All grades are **final**. Unless an error has been made in grading an exam/assignment, no additional partial credit will be given. The offering of extra credit is at the professor's discretion.

Accommodations for Students with Disabilities
If you are a student with learning needs that require special accommodation, contact the Office of Disability Services as soon as possible to make an appointment to discuss your special needs and to obtain an accommodations letter. Please also e-mail the instructor to discuss your learning needs.

Attendance
Class attendance is expected. Consistent attendance and participation will significantly enhance your learning experience and performance. Students with conflicts or Institute-approved absences should contact the instructor individually and as soon as the conflict/approved absence is known. Emergency situations should be communicated immediately to the instructor.

Academic Integrity
Students are expected to attempt to work through assignments on their own first, before any discussion/collaboration with other students. Copying from another person's draft/final work is unethical and unacceptable. Use of anyone else's work is a direct violation of the GT Academic Honor Code. All violations will be adjudicated per GT policy; a description of theacademic misconduct process can be reviewed at https://osi.gatech.edu/process/academicmisconduct-process. For any questions involving these or any other Academic Honor Code issues, please consult the instructor or www.honor.gatech.edu.

Instructor's Right Policy
The instructor reserves the right to adapt the course within Georgia Tech policy. Due dates are tentative for general information and may be adjusted at the discretion of the instructor.

AI Policy
Using generative AI tools in the graded work of the course is strictly prohibited. The use of such tools for graded work will be considered a serious infraction of the Georgia Tech Honor Code, subject to investigation by the Office of Student Integrity.

Health and Well-Being

Georgia Tech and the School of Aerospace Engineering understand that many students experience stress through a variety of academic, financial and personal experiences. We value you and want to make you aware of resources available to you should you need them. Your well-being and mental health are important, and we are here for you.

- Center for Assessment, Referral and Education (CARE): https://care.gatech.edu/
- Campus Police (any emergency): 404-894-2500 http://www.police.gatech.edu/
- Counseling Center: 404-894-2575 https://counseling.gatech.edu/
- Dean of Students Office: 404- 894-6367 https://studentlife.gatech.edu/
- Georgia Crisis and Access Line: 800-715-4225 Crisis Text Line: Text HOME to 741741
- National Suicide Prevention Lifeline: 800-273-TALK (8255) https://suicidepreventionlifeline.org/
- VOICE: Victims Survivor Support: (404) 385-4464 (or 4451) https://wellnesscenter.gatech.edu/voice
- Stamps Health Services: https://health.gatech.edu/contact

Topical outline

This is an outline of the material that will be covered and the appropriate chapter readings from the required textbooks (T = Turns, A = Anderson):

Topics	Reading	# Hours
I. Introduction and Overview	A1.2, 7.1; T1.1,1.2	**1.5**
A. Thermodynamics		
B. Fluids		
C. Compressible Flow		
D. Units, Significant Figures and Precision	A1.4.1; 1.6	
II. Basic Concepts		**4**
A. How to Think of Matter	A1.10.1, 2.3.3	
1. Macroscopic vs microscopic viewpoints of matter		
2. Continuum vs rarefied viewpoints of fluids		
B. Thermodynamic Concepts and Definitions	T1.3, 1.5, 2.2a	
1. Systems		
2. Energy and its Transfer by Work and Heat		
3. Equilibrium and Properties		
Example: Work as Path Function		
C. Flow Field Concepts and Definitions	A1.4, 2.3-2.3.2, 2.11	
1. Velocity		
2. Reference frames		
3. Fluid elements: Eulerian and Lagrangian approaches		
4. Visualizing velocity fields: streamlines, streaklines and pathlines		
III. Properties of Substances		**7.5**
A. Extensive and Intensive (Thermodynamic) Properties	T2.1	
1. Definitions		
2. Converting extensive to intensive property		
3. Creating new properties: enthalpy (and stagnation enthalpy)		
B. The State Postulate and State Equations	T2.3a-b, 2.5	
1. Independent TD properties: how many?		
2. Equations of state (EOS) and p-v-T examples		
3. Generalized compressibility and compressibility factor		
C. Ideal/Thermally Perfect Gas State Equations	T2.4-2.4d	
1. Ideal Gas Law		
2. Caloric equations of state		
3. Example: TPG state equations		
D. Incompressible Substances (Liquids/Solids)	T2.7-2.8	
E. Two-phase mixtures:	T2.6-2.6a	
Equilibrium Diagrams and Saturated Liquid/Vapor Systems		
1. Phase transitions, phase diagrams and supercritical fluids		
2. Mixed phases: quality and saturated liquid-vapor mixture properties		
3. Example problems and use of data tables		
F. Transport Properties	A1.4, 1.10-11, 1.8, 15.3	
1. Diffusion and diffusivities		
a. Heat conduction and thermal conductivity		
b. Shear stress and viscosity		

c. Temperature and pressure dependence
2. Introduction to boundary layers: momentum and thermal
3. Similarity parameters: Prandtl number, Reynolds number, Mach number

IV. Conservation Equations **16**

A. Mass Conservation — T 3.1-3.3; A2.4, 2.9 — **2.5**

1. Closed Systems (Control Mass Approach)
2. Open Systems (Control Volume Approach)
   a. Integral forms
   b. Differential forms and material derivatives

B. Reynolds Transport Theorem — **0.5**

C. Conservation of Linear Momentum — A2.5,1.9, 2.6, 3.2 — **4.5**

1. Derivation of differential and integral forms
   a. Control mass integral form and wing pressure example
   b. Control volume integral form
   c. Control volume differential form
2. Example applications
   a. Hydrostatics: atmospheric pressure
   b. Aerodynamic forces from velocity profiles: airfoil lift and drag (and coefficients)
   c. Propulsion: engine nozzle force
3. Bernoulli equation
   a. Derivation from streamline momentum conservation
   b. Dynamic and stagnation pressure
   c. Application examples: low speed wind tunnel; Pitot-static probes
4. Differential form for quasi-1D steady flows

D. 1st Law - Conservation of Energy — T5.1-5.2a, 5.3 — **4**

1. Control mass (integral and differential forms)
2. Examples
   a. Constant volume heat addition
   b. Constant pressure heating
   c. Impact of friction on constant pressure process
   d. Latent heat of vaporization
   e. Shaft work
3. Control volume analysis (integral form)
4. Examples
   a. High speed nozzle and stagnation temperature
   b. Adiabatic mixing
   c. Compressor
5. Cycles and cycle efficiency
6. Differential form for quasi-1D steady flows

E. 2nd Law - “Conservation” of Entropy — T6.1-2;6.3a,d;6.5-6 — **4.5**

1. Entropy basics and 2nd Law for an isolated system
   a. Limitations of the 1st Law, work and molecular chaos
   b. Characteristics of entropy
   c. Entropy production and the 2nd Law for isolated systems
   d. Reversible and irreversible processes
   e. Entropy transfer through heat transfer
2. Development of 2nd Law for a control mass (modern approach)
3. Analysis of 2nd Law for CM
   a. Entropy change and isentropic processes

            b. Maximum/minimum work conditions
            c. Carnot cycle and limiting cycle efficiency
        4. Entropy state relations
            a. The Gibbs equation
            b. General substances, saturated mixtures, incompressible substances
            c. Ideal (thermally perfect) gases and mixtures
            d. Stagnation pressure, relation to Bernoulli equation
        5. 2nd Law for control volumes and examples

V. Compressible Flows **21**

- A. Fundamentals **2**
    - 1. Wave Propagation in Compressible Substances
        - a. Speed of Sound A8.3
        - b. Mach Angle and Mach Number A9.1 (pp. 604-606)
    - 2. Stagnation Properties and Mach Number A7.5 (pp. 535-537)
    - 3. Steady, Quasi-1D Flow Equations A10.2 (pp. 672-677)
- B. Isentropic Compressible Flows **3**
    - 1. Steady Isentropic Flow with Area Change A10.2-3 (pp. 678-682)
        - a. Conservations Equations - Mach Relations
        - b. Sonic Throat Condition and Choking
    - 2. Isentropic Nozzle Analysis and Back Pressure A10.3 (pp. 683-686)
        - a. Converging Nozzle Analysis
        - b. Converging-Diverging Nozzle Analysis
- C. Shock Waves A8.1 **7.5**
    - 1. Formation of Shock Waves - Compression
    - 2. Normal Shock Waves
        - a. Mach Number Relations A8.2, 8.6
        - b. Moving Normal Shocks
        - c. Reflected Normal Shocks
        - d. Normal Shocks in Converging-Diverging Nozzles A10.3 (pp.687-688)
        - e. Starting Problem - Supersonic Windtunnels A10.5
    - 3. Oblique Shock Waves A9.1-2
        - a. Mach Number Relations
        - b. Strong, Weak and Detached Shocks
        - c. Application to Supersonic Inlets (Diffusers)
- D. Prandtl Meyer Expansions and Compressions A9.6 **1.5**
    - 1. Flow Equations - Mach Relations
    - 2. Maximum Turning Angle
    - 3. Continuous Expansions and Compressions
- E. Reflected Waves A9.4 **2**
    - 1. Reflections of Compression and Expansion Waves
    - 2. Application to Under & Overexpanded Supersonic Nozzles
    - 3. Plug and Aerospike Nozzles
- F. Lift and Drag on Simple Supersonic Airfoil Geometries A9.7 **2**
    - 1. Thin flat plate
    - 2. Diamond airfoil
- G. Flows with Friction and Heat Transfer **3**
    - 1. Generalized (1-D) Mach Relations
    - 2. Fanno Flow - Adiabatic Constant Area Flow with Friction
        - a. Overview - Thermodynamics Analysis

    b. Flow Equations - Mach Relations and Property Changes
    c. Example - Supersonic Nozzle with Constant Area Duct
3. Rayleigh Flow - Constant Area Flow with Heat Transfer
    a. Overview - Thermodynamics Analysis
    b. Flow Equations - Mach Relations and Property Changes
    c. Examples - Heated Duct and Combustor/Afterburners