ME 451C: COMPRESSIBLE TURBULENCE

Spring 2017

Course Syllabus

Course Description: Conservation equations. Thermodynamics of ideal gases. Isentropic flows. Crocco-Vazsonyi's equation, creation and destruction of vorticity by compressibility effects. Acoustics and generation of sound by turbulence. Shock waves. Kovasznay's modal decomposition of compressible flow, linear and nonlinear modal interactions, interaction of turbulence with shock waves. Turbulent Mach number. Shocklets. Energetics of compressible turbulence, effects of compressibility on homogeneous turbulence, free-shear flows and turbulent boundary layers. Van Driest transformation, recovery temperature, and shock/boundary layer interaction. Strong Reynolds analogy. Subgrid-scale modeling for compressible turbulence.

Prerequisite*:* Familiarity with compressible laminar flows (ME 355) and incompressible turbulence (ME 361), or consent of the instructor.

Instructor: Javier Urzay, Ph.D.
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Office: 206 CTR, Phone: 650 723 9601
Office Hours: Mondays 4:00 PM-6:00 PM.

Lectures: Tuesdays and Thursdays, 1:30 PM-2:50 PM at room 380-381T.

Reference Texts (not required):

- H.W. Liepmann & A. Roshko, *"Elements of Gas Dynamics"*, Dover, 1957.
- Y.B. Zel'dovich & Y.P. Raizer, "*Physics of Shock Waves and High-Temperature Hydrodynamic Phenomena"*, Dover, 2002.
- E. Garnier, N. Adams, P. Sagaut: "Large Eddy Simulations of Compressible Flows", Springer, 2009.

Supplementary material shall be provided in class.

Homeworks: There will be 3-4 homework assignments. No late homeworks will be accepted.

Exams: Midterm Exam: Tuesday, May 9, in class.

Final Exam: TBA.

Both exams will consist of two parts: i) Short Questions (closed books, closed notes, no calculator), and ii) Problems (open book and open notes, calculator allowed).

Grading Scheme: 30% Homeworks + 30% Midterm Exam + 40% Final Exam.

Academic Integrity: The Stanford Honor Code will be followed:
https://communitystandards.stanford.edu/student-conduct-process/honor-code-and-fundamental-standard

Website: http://www.stanford.edu/~jurzay/ME_451C

TENTATIVE OUTLINE

1. Introduction

Engineering applications. Historical developments.

2. Fundamental Aspects of Compressible Flows

Continuum limit. Entropy. Ideal gas. Conservation equations of compressible flows. Molecular transport. Compressibility and kinetic/thermal energy exchanges. Low-Mach limit. Speed of sound and Mach cone. From subsonic to supersonic flows around slender bodies. Isentropic flows. Bernoulli equation. Stagnation and static quantities. Crocco's equation and vorticity production by compressibility effects.

3. Shock Waves

Inviscid description of tangential and normal discontinuities. Mass, momentum and energy conservation. Rankine-Hugoniot equations. Oblique shocks. Moving Shocks.

4. Acoustics

Linear and non-linear acoustics. Generation of sound by turbulence. Lighthill's equation. Kirchoff integral. Ffwocs-Williams-Hawkings method.

5. Fluctuation Dynamics in Compressible Turbulence

Linearized disturbance equations. Kovasznay's modal decomposition: Vorticity, acoustic and entropy modes. The inviscid limit in uniform mean flow. Non-uniform mean flow. Utility of modal decompositions. Non-linear fluctuations. Modal interactions. Mass sources. Force sources. Turbulent Mach number. Shocklets.

6. The Interaction of Shock Waves with Plane Disturbances

Stability of curved shocks. Plane and evanescent waves behind the shock. Ribner's analysis. Statistics behind the shock wave. Direct numerical simulations. Shock holes.

7. Compressible turbulent boundary layers.

Conservation equations. Crocco's solution. Solutions for non-unity Prandtl numbers. The mean velocity. Van Driest transform. Viscous sublayer. Reynolds analogies. Strong Reynolds analogy. Morkovin's Hypothesis. Gaviglio's Reynolds analogy. Some remarks on transition at high Mach numbers.

8. Subgrid-scale modeling for compressibile turbulence.

Favre filtered/averaged conservation equations. Turbulent kinetic energy. Energy pathways. Solenoidal and dilatational dissipations. First and second-order closures.