AME 60635–Intermediate Fluid Mechanics
Fall 2019

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Listserver address: fa19-ame-60635-01-group@nd.edu. When e-mail is sent to this address, the entire class will be receive a copy of the mail.

Course time and location: MWF 9:25 AM-10:15 AM, B036 Geddes

Prerequisites: Formally, none. Undergraduate level fluid mechanics, differential equations

Catalog description: "Derivation of governing equations of mass, momentum, and energy for a viscous, compressible fluid; general survey of vortex dynamics, potential flow, viscous flow, and compressible flow (Every fall)"

Comments: This course is intended to give the student a broad understanding of nineteenth- and early twentieth-century fluid mechanics. The lectures first focus on a rigorous formulation of the governing equations and subsequently survey a series of classical problems in vortex dynamics, potential flow, compressible flow, and viscous flow. In so doing, topics in traditional analysis and modern numerical analysis are introduced. The successful student will leave with an appreciation of how the interplay of mass, momentum, energy, and state equations determine velocity, pressure, density, and temperature fields and how such knowledge can be used in simple engineering applications.

Required Text

R. Panton, 2013, *Incompressible Flow*, 4th edition, John Wiley (required).

Recommended Supplemental Texts

C.-S. Yih, 1988, *Fluid Mechanics*, West River Press.
M. Van Dyke, 1982, *An Album of Fluid Motion*, Parabolic.
R. Aris, 1990, *Vectors, Tensors, and the Basic Equations of Fluid Mechanics*, Dover.
L. Prandtl and O. G. Tietjens, 1957, *Fundamentals of Hydro- and Aeromechanics*, Dover.
G. Batchelor, 2000, *An Introduction to Fluid Mechanics*, Cambridge.
L. D. Landau and E. M. Lifshitz, 1995, *Fluid Mechanics*, Butterworth-Heinemann.
H. W. Liepmann and A. Roshko, 2002, *Elements of Gasdynamics*, Dover.
H. Schlichting, 2000 *Boundary Layer Theory*, Springer.
S. Whitaker, 1992, *Introduction to Fluid Mechanics*, Krieger.

Required Work and Grading

Exams will be closed book, closed notes, no calculator, and held in class. The final exam will be comprehensive.

Homework will be assigned for essentially every class period. All homework will be graded and returned. Homework must be done on *one side only* of 8 1/2" by 11" *engineering* paper with no frayed edges. Multiple pages must be stapled. You should briefly restate the problem, give a sketch if helpful, give all necessary analysis, and place a box around your final answer. All plots must be computer generated, trimmed, and taped to engineering paper. Label all axes. Raw Mathematica or Maple output will not be graded. Neatness and effective communication are considered in grading as well as the final answer itself.

Two short (one page maximum) critical reviews of works from the literature will be required. The first review must consider an article on fluid mechanics which has stood the test of time. It must be over fifty years old, written by a well-known fluid mechanician, and should have a proven lasting value. The second will consider a topic of current interest in fluid mechanics from the *Journal of Fluid Mechanics*. The articles you choose should *not* fall into the category of review, historical discussion, biography, or other version of "fluids lite;" rather, it should be a substantive, original contribution. Your reviews should 1) summarize the article's major findings and 2) offer an argument why this paper is deserving of its recognition. The reviews are required to be written in a LaTeX format and will be checked primarily for style, format, grammar, and content.

Grades will be assigned based on students' performance on examinations, homework, and papers. Pertinent information is as follows:

Exam I	20	Friday, 11 October 2019
Exam II	25	Friday, 6 December 2019
Final Exam	40	Tuesday, 17 December 2019, 8:00 AM-10:00 AM, B036 Geddes
Homework	13	
Reviews	2	Friday, 20 September 2019; Friday, 8 November 2019
Total	**100**	

Honesty Policy

Academic honesty is expected. When confronted with an apparent violation, I will enforce the appropriate University regulations to the best of my ability. I will also try to make my expectations clear. By and large, though, these issues are out of my control and as such I do not seek out violations. Instead, I depend upon your basic integrity to prevent any problems.

In brief my expectations are as follows. I encourage you to freely discuss the homework amongst one another as you formulate your solutions *individually*. *Your* written work should represent *your* understanding of the problem. In practice this means copying (in whole or in part) another student's homework, exam, computer program, or paper is *not* permitted. If you choose to discuss your work with a colleague, it should be a discussion in which one teaches another or both work to a mutual understanding. As a counter-example, it is not acceptable to give a friend your homework five minutes before class so that friend can copy your work. I also consider it unacceptable to copy work from a student who was in the class in a previous year. In your written reports, be careful to correctly use quotation marks for words that did not originate with you. Paraphrasing should be held to a minimum, but if used, the paraphrased section should be specifically identified and unambiguously cited. It is not sufficient to simply list a reference but not indicate where a specific quotation or paraphrase was employed. In addition all sources used should be fully cited. As is done in the scientific literature, you should *briefly* acknowledge in writing any significant discussions or interactions you had regarding the work you submit. As a general principle, I do not accept the justification that you were not sure of my intentions. If you feel you may be in an ethical grey area, then you should consult with me *before* acting.

Detailed Topical Outline

- Philosophy of continuum mechanics
- Some necessary mathematics
  - Vectors and Cartesian tensors
  - Solution of linear algebra equations
  - Eigenvalues and eigenvectors
  - Div, grad, and curl
- Kinematics
  - Lagrangian description
  - Eulerian description
  - Material derivatives
  - Streamlines, pathlines, and streaklines
  - Kinematic decomposition of motion: translation, rotation, deformation
  - Expansion rate
  - Invariants of the strain rate and velocity gradient tensors
  - Two-dimensional kinematics
  - Three-dimensional kinematics
  - Kinematics as a dynamical system
- Conservation axioms
  - Mass
  - Linear momenta (Newton's second law of motion)
  - Angular momenta
  - Energy (first law of thermodynamics)
  - Entropy inequality (second law of thermodynamics)
  - Integral forms
- Constitutive relations
  - Frame and material indifference
  - Second law restrictions
  - Fourier's law
  - Stress-strain rate relationship for isotropic, compressible, Newtonian fluids
  - Equations of state
- Full equation system and special cases
  - Boundary and interface conditions
  - Complete set of compressible Navier-Stokes equations
  - Incompressible Navier-Stokes equations
  - Euler equations
  - Dimensionless compressible Navier-Stokes equations
  - First integrals of linear momenta equations

- Vortex dynamics
  - Cylindrical coordinates
  - Ideal rotational and irrotational vortices
  - Helmholtz vorticity transport equation
  - Kelvin's circulation theorem
  - Potential flow of ideal point vortices
  - Influence of walls
- One-dimensional compressible flow
  - Formulation of generalized one-dimensional flow equations
  - Flow with area change
  - Normal shocks: ideal and non-ideal gas
  - Rarefactions and the method of characteristics
- Potential flow
  - Stream functions and velocity potentials
  - Mathematics of complex variables
  - Elementary complex potentials
  - Pressure distribution
- Viscous, laminar flow
  - Fully developed, one dimensional solutions
  - Similarity solutions (Stokes' first problem and Blasius boundary layer)