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Course Outline
A&AE 613 Viscous Flow Theory
Prof. S. Schneider, Spring 2023

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I spend most of my time at my lab office.

Meets MWF from 11:30-12:20 in ARMS 1021. Course was last offered in Fall 2018. Makeup lectures are to be scheduled at times to be arranged.

General Information: The course will assume a general familiarity with fluid mechanics, on the level of a first graduate fluids course, such as A&AE511. F. M. White's book, *Viscous Fluid Flow*, 3rd edition, 2006, is a recommended reference. A 4th edition came out in 2022 with a co-author, but this is not yet available in bound paper form. Course content will vary depending on student background and interest. A copy of my notes is available on the course website, at https://engineering.purdue.edu/~aae613/, along with selected handouts.

Homework will be graded on a 0-5 scale. Final grades will be assigned based on homework (30%), a project (40%), and an exam (30%). The homework and exam will cover section 1 through the first part of section 3, and the project will cover the second part of section 3, and sections 4 and 5. Project topics are best student-initiated and usually involve some kind of computer modeling, but they can also be literature studies. The exam will take 3 hours, to be scheduled at a later date. Three classes must be cancelled in exchange for this evening exam. These cancellations are to be at times when I expect to be on travel. I am likely to be on travel quite a bit for various hypersonic meetings. Already I expect to cancel classes for 23-27 January, since I am to attend the AIAA SciTech meeting then. There will be no class on Friday 10 March as I'm to be out for medical reasons. Other classes will be cancelled or rescheduled for dates when I am to be at hypersonics meetings.

Sections 1-3 will be primarily delivered through blackboard lectures. Sections 4-5 will primarily be delivered through discussions of slides.

Outline:

1. **Derivation of the Equations of Motion:** Review of Cartesian tensor notation. Review of thermodynamics. Heat transfer. Derivation of the full compressible viscous Newtonian equations (conservation of mass, momentum, energy). Vorticity and entropy equations. Kelvin's theorem. About 12 lectures.

2. **Laminar Incompressible Viscous Flow:** Exact solutions: stagnation point flow, Jeffrey-Hamel flow, Stokes problems. Low Reynolds number flow. Introduction to perturbation theory. Boundary layer theory. Effects of pressure gradient and curvature. Boundary layer integral equations, Thwaites method. Laminar separation, separation bubbles. About 12 lectures.

3. **Laminar Compressible Viscous Flow:** Exact solutions: compressible Couette flow, flow through a shock wave. Compressible boundary layers. Introduction to shock-boundary layer interaction and hypersonic effects (dissociation, heating, and non-equilibrium thermodynamics). About 10 lectures.

4. **Transition to Turbulence:** Linear transition theory. Introduction to nonlinear theory and numerical methods. Introduction to experimental results in bounded and free shear flows, both incompressible and compressible. Effects of roughness, turbulence, vibration, noise, curvature, etc. Transition-separation interactions in boundary layers. About 6 lectures.

5. **Introduction to Turbulent Flow:** Reynolds averaged equations of motion. Introduction to statistics and correlations. The Kolmogorov scale. The 5/3 law for inertial range self-similarity. Law of the wall in the turbulent boundary layer. Introduction to experimental results for various fundamental turbulent flows - bluff bodies, internal flows, free shear flows. Introduction to far field self-similarity theories. Limitations of computational approaches. Perhaps 5 lectures.

Some References:
Abramowitz and Stegun, *Handbook of Mathematical Functions*
Anderson, *Hypersonic and High Temperature Gasdynamics*
Aris, R., *Vectors, Tensors, and the Basic Equations of Fluid Mechanics*, Dover, 1989.
Batchelor, *An Introduction to Fluid Mechanics*
Babinsky and Harvey, *Shock Wave-Boundary Layer Interactions*
Bender and Orszag, *Advanced Mathematical Methods for Scientists and Engineers*
Bolz and Tuve, *Handbook of Tables for Applied Engineering Science*
Butkov, *Mathematical Physics*
Courant and Friedrichs, *Supersonic Flow and Shock Waves*
Drazin and Reid, *Hydrodynamic Stability*
Goldstein, *Modern Developments in Fluid Dynamics*
Gradshteyn and Ryzhik, *Tables of Integrals, Series, and Products*
Jeffreys and Jeffreys, *Methods of Mathematical Physics*
Lamb, *Hydrodynamics*
Lagerstrom, P.A., *Laminar Flow Theory*, Princeton Univ. Press, 1996
Landau and Lifshitz, *Fluid Mechanics*
Liepmann and Roshko, *Elements of Gasdynamics*
Milne-Thomson, *Theoretical Hydrodynamics*
Rosenhead, *Laminar Boundary Layers*
Schlichting & Gersten, *Boundary-Layer Theory*
Shapiro, *The Dynamics and Thermodynamics of Compressible Fluid Flow*
Thompson, *Compressible-Fluid Dynamics*
Thwaites, *Incompressible Aerodynamics*
Tritton, *Physical Fluid Dynamics*
Van Dyke, *Perturbation Methods in Fluid Mechanics*