AE 6009 Viscous Fluid Flow

Course objectives:

This is a first graduate course intended to cover the fundamentals of fluid mechanics from an advanced point of view, with emphasis on the mathematical treatment of viscosity effects in laminar flows of a Newtonian fluid. We begin with the Navier-Stokes equations and some of its exact solutions available in simplfied configurations. Attention is given to the Stokes-flow regime of very low Reynolds numbers, flows with wall and free-shear boundaries, and the effects of pressure gradients, heat transfer and compressibility. We also provide an introduction to the phenomena of instability and transition to turbulence. (Turbulent flows are to be studied in detail in AE 6012.)

Course Outline

The numbers in square brackets give rough estimates of the number of weeks to be devoted to each topic.

1. Fundamental concepts and conservation laws [2]
   - (a) Viscosity, continuum, streamlines, pathlines
   - (b) Derivation of the Navier-Stokes equations
   - (c) Cartesian tensor notation
   - (d) Stress-strain relationships and shear deformation
   - (e) Introduction to vorticity dynamics
   - (f) Dimensional analysis and similarity
2. Some exact solutions of N-S equations [1.5]
   - (a) Steady and unsteady parallel flows:
     — Couette-Poiseulle flow, parallel plates, concentric cylinders
   - (b) Concept of similarity transformations: 2D stagnation point flow
3. Flow at very low Reynolds number [1]
   - (a) Stokes flow equations
   - (b) Applications: lubrication theory, flow past a small sphere
4. Wall-bounded flows [2]
   - (a) Boundary layer approximation and parameters
   - (b) Transformations for BLs over thin wedges and flat plates

   (c) Approximate methods, momentum-integral relations
   (d) Effects of pressure gradients, wall suction and blowing

5. Free shear flows [1.5]
   (a) Jets, wakes and mixing/shear layers
   (b) Similarity solutions for plane jets and plane wakes

6. Heat transfer and compressibility effects [2]
   (a) Energy balance equations for viscous and inviscid fluids
   (b) Thermal boundary layers, adiabatic and isothermal walls
   (c) Aerodynamic heating, effects of Prandtl and Mach numbers
   (d) Transformations for compressible boundary layers

7. Flow separation [0.5]
   (a) Shape of velocity profile
   (b) Separation in relation to, but without, transition to turbulence

8. Introduction to hydrodynamic stability [2]
   (a) Linearized small-disturbance theory, application to simple flows
   (b) Physical mechanisms: Kelvin-Hemholtz, Rayleigh-Taylor, Gortler...
   (c) Parametric effects: heat transfer, Mach number...

9. Turbulence: introductory concepts [1]

   Disorder, mixing, intermittency; averaging

10. Introduction to transition to turbulence [1]
   (a) Experimental observations
   (b) Modern research developments

Textbook and references

Viscous Fluid Flow by F.M. White (McGraw-Hill, 2nd ed., 1991) is listed at the textbook for this course. It is a good reference, and contains useful descriptions of many viscous flow topics. Hwoever the class material will not be following the text very tightly. It is important that you keep a good and complete set of class notes from the lectures.

As graduate students, if you want to become *really* good in a certain subject, it is very important for you to take your own initiative. This includes independent learning on your own, and looking up other references relevant to the course. It would be useful for you to consult, *among others*:

1. *Boundary Layer Theory* by H. Schlichting (7th ed., 1979).
2. *Incompressible Flow* by R.L. Panton (2nd ed., 1996).
3. *Hydrodynamic Stability* by Drazin & Reid (1981)
4. *A First Course in Turbulence* by Tennekes & Lumley (1972).

(I will be making an effort, soon, to put the first two of these on reserve in the library.)

A note on prerequisites and mathematical tools

A quick survey of your background knowledge is to be conducted in the first week of class. In general, you are expected to have had at least one good introductory course (or equivalent) covering viscous flows at the undergraduate level. In writing the general equations some elementary vector and tensor notation will be used. (The latter is also very important in the study of turbulent flows—the subject of AE 6012.) The computer assignment will involve some numerical methods for ordinary differential equations, and you will be expected to be able to write your own programs (preferably in Fortran or C) for that purpose.

A thought

From my perpsective, your basic objective in graduate school should be

"*to learn something new*"