MAE 561/471

Computational Fluid Dynamics

Tue/Thu 1:30-2:45 GWC 535

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Office hours: Tue/Thu 3:00-5:00, or by appointment
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This course emphasizes the computational aspect of fluid dynamics.

The governing equations of fluid dynamics are partial differential equations (PDEs). Therefore, this course is essentially concerned with the numerical solutions for a special class of PDEs

MAE561/471 CFD :focuses on finite difference methods
MAE598 Advanced CFD: focuses on spectral methods

The governing equations of fluid dynamics, the Navier-Stokes equations, are nonlinear and very complicated

Momentum equations (Newton's 2nd law for a continuum)

$$\frac{\partial u}{\partial t} = -\frac{1}{\rho}\frac{\partial p}{\partial x} - u\frac{\partial u}{\partial x} - v\frac{\partial u}{\partial y} - w\frac{\partial u}{\partial z} + \frac{\mu}{\rho}\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right)$$

$$\frac{\partial v}{\partial t} = -\frac{1}{\rho}\frac{\partial p}{\partial y} - u\frac{\partial v}{\partial x} - v\frac{\partial v}{\partial y} - w\frac{\partial v}{\partial z} + \frac{\mu}{\rho}\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2}\right)$$

$$\frac{\partial w}{\partial t} = -\frac{1}{\rho}\frac{\partial p}{\partial z} - u\frac{\partial w}{\partial x} - v\frac{\partial w}{\partial y} - w\frac{\partial w}{\partial z} + \frac{\mu}{\rho}\left(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2}\right) + [\textit{gravity force}]$$

Continuity equation (conservation of mass)

$$\frac{\partial \rho}{\partial t} = -\frac{\partial (u\rho)}{\partial x} - \frac{\partial (v\rho)}{\partial y} - \frac{\partial (w\rho)}{\partial z}$$

+ *Thermodynamic energy equation* (1st & 2nd law of thermodynamics)
Equation of state (that relate p to ρ, T, etc.)
Equation(s) for tracer transport
Equation(s) for chemical reaction, phase change (e.g., for combustion)
And more ...

The development of numerical models (= computer codes) for such a complicated system is an epic fifty years in the making. In a first course of CFD, we obviously can only explore a small part of this development.

Our plan:

(1) Many key concepts in CFD can be explained using relatively simple prototypical PDEs. The simple equations are ideal for exercises in "model building" (design of finite difference scheme and grid, coding, processing and interpretation of output). This activity will constitutes ~ 50% of our effort.

(2) Equipped with the basic knowledge on CFD, we will attempt to build a numerical model for the 2-D incompressible Navier-Stokes equations. This system is simple enough that it is feasible for one to build a model of it <u>from scratch</u> within the semester. This will be the focus of our final project.

The task in the final project will be a variation of the problem in Sec. 8.12. (You will be asked to do more than what's asked in that problem.)
For those who want to get ahead, the relevant material is in Chapter 8.

(3) Professional-grade CFD solvers for full-3D Navier-Stokes equations are now widely available. We will use one of them, ANSYS-Fluent, for computer lab exercises. At least two homework assignments (or one HW and the final project) will be related to ANSYS-Fluent.

Access to computer lab at GWC 481 will be provided for all who registered for this class. More detail to follow.

Textbook: *Computational Fluid Dynamics, vol 1, 4th Ed*., Hoffmann & Chiang, **Required**

Almost all homework assignments (and definitely the final project) involve coding. You may use:

Matlab (ASU has free resource)
Fortran
C/C++

Matlab has excellent graphic functions that will be extremely useful for homework and project.

Grading:

Nominally 65% homework, 35% final project

No exams.

Independent, unique, original work will be rewarded.

Collaboration is allowed in most cases as long as the solution is accompanied by proper acknowledgments of the extent of collaboration ("give credit where credit is due"). No freeloaders.

Course website:

http://www.public.asu.edu/~hhuang38/MAE561.html

Why CFD?

To answer the question, it's perhaps useful to look at the alternatives.

(a scaled-down model of an
aircraft in a wind tunnel)

Source: Wikimedia Commons, http://en.wikipedia.org/wiki/Image:Windkanal.jpg