# Mech 511

## Computational Methods in Transport Phenomena II

Spring, 2013

**Instructor:** Carl Ollivier-Gooch

**Office:** CEME 2064. Phone: 822-1854. Email: cfog@mech.ubc.ca

**Class meetings:** T 12:30-2, Room TBA. Starting January 15.

**Office hours:** MTWF 2:15-3 (joint with Mech 2).

Mech 510 was aimed solely at building proficiency in both analysis and programming to reach the goal of solving the laminar, incompressible Navier-Stokes equations numerically. Mech 511 is quite different in approach, being a collection of advanced topics which are (more or less) independent of each other. The goal of the course is to give you at least a passing familiarity with many of the leading-edge topics in modern CFD. It's unrealistic to expect that you'll master all of these topics to the extent that you would be able to jump right in to an industrial development team and implement them, but it *is* realistic to expect that you'll master one or more topics that well, and that you'll have enough knowledge of the others to at least understand what people are talking about at conferences or in journal articles.

This is also a significant practical difference between 510 and 511: 510 was a lecture course, while 511 is a reading course. ***I will introduce material and answer questions, but not lecture in the traditional sense.*** The expectation for this course is that you will read and make a solid effort to understand the assigned readings, so that our relatively brief weekly meetings can focus on clearing up remaining questions, not on initial coverage of material.

# Topics to be Covered

**Multigrid methods.** Solving Poisson's equation for large meshes requires large amounts of CPU time using conventional iterative methods. Multigrid methods take advantage of the excellent smoothing properties of point iterative methods to remove high-frequency errors, and then solve the resulting smooth problem on a coarser mesh.

**Unstructured mesh computation.** For complex geometries, structured meshes become awkward to use and difficult to generate. For these case, unstructured meshes are essential. We will discuss application of finite volume methods to triangular meshes.

**Krylov subspace methods.** As discussed in 510, we need to use some approach that's more efficient than direct inversion when solving the large linear systems of equations that arise in implicit time discretizations. Approximate factorization is a powerful tool for this, but not always applicable. Krylov subspace methods address this problem by approximating the solution of the linear system as a linear combination of a very small number of vectors (20-40 for a linear system with a size in the millions). We will discuss one particular Krylov method, GMRES, which is widely used in CFD.

**Turbulence modeling.** Another dramatic simplification that we insisted on in Mech 510 was laminar flow. Most flows of engineering interest are turbulent; we will discuss how this is handled numerically. We will review the Reynolds-averaged form of the Navier-Stokes equations, then examine some of the most commonly-used one- and two-equation models for turbulent closure. We will discuss computational issues in turbulence modeling, and why all turbulence models should be viewed with suspicion.

**Compressible flow calculation.** Physically, compressible flows (especially supersonic ones) behave in a qualitatively different way than compressible flows. Not surprisingly, this leads to significant differences in how compressible flow calculations are done. After a brief review of the physics of compressible flow, we will discuss upwinding for compressible flow using flux vector splitting and flux difference splitting. Also, we will discuss application of boundary conditions for compressible CFD.

**Adjoint methods.** For many applications — including error estimation, mesh adaptation, and shape optimization — solving an auxiliary PDE, called the *adjoint problem*, related to the original PDE is very helpful. We'll focus on adjoint methods as applied to error estimation.

# Schedule

| Topic | Intro | Discussion | Assignments | Analysis Due | Program Due |
|---|---|---|---|---|---|
| Multigrid | Jan 15 | January 22 | January 22 | February 5 | March 5 |
| Unstructured FV | Jan 22 | Jan 29, Feb 5 | January 29 | February 26 | March 19 |
| Krylov methods | Feb 5 | Feb 12 | February 12 | — | March 26 |
| Turbulence modeling | Feb 12 | Feb 26, Mar 5 (?) (Student pres.) | February 12 | February 26 | — |
| Compressible flow | Mar 5 | March 12, 19 | March 19 | April 2 | April 9 |
| Adjoint methods | Mar 19 | March 26, April 2 | March 26 | — | April 16 |

## Marking Scheme

| Activity | Date Out | Date In | | Marks |
|---|---|---|---|---|
| Homework | | | | 40 |
| Multigrid | Jan 22 | Feb 5 | 8 | |
| Unstructured meshes | Feb 5 | Feb 26 | 7 | |
| Turbulence modeling | Feb 12 | Feb 26 | 15 | |
| Compressible flow | Mar 19 | Apr 2 | 10 | |
| Programming (3 out of 5) | | | | 60 |
| Multigrid | Jan 22 | Mar 5 | 20 | |
| Unstructured meshes | Feb 5 | Mar 19 | 20 | |
| Krylov methods | Feb 12 | Mar 30 | 20 | |
| Compressible flow | Mar 19 | Apr 16 | 20 | |
| Adjoint error estimation | Mar 26 | Apr 23 | 20 | |

The assignment due dates are firm. You'll want to start on the programming assignments early, especially since you don't have the option to wait until you've seen the details on all of them before you begin. Early submissions are encouraged.