Instructor: Professor Foluso Ladeinde  
224 Heavy Engineering Building  
foluso.ladeinde@sunysb.edu

Lecture: Thursdays, 3:50 – 6:40 p.m. in Old Chemistry 138

Recitation: TBD

Office Hours: Thursdays 9:30 – 11:00 a.m., 1:00 – 2:30 p.m., and as available

Co-requisites: Graduate standing; an advanced course in continuum mechanics, heat transfer, or fluid mechanics; some FORTRAN, C++ or other programming experience.

Synopsis: Introduction to finite difference, finite element, and finite volume methods for incompressible flows and heat transfer. Topics include explicit and implicit schemes, accuracy, stability, and convergence, derived and primitive-variable formulation, orthogonal and non-orthogonal coordinate systems. Selected computer assignments from heat conduction, incompressible flows, and forced and free convection.


Organization: Two Prelims + Three Computer Problems  
(40%)  
(60%)

Homework: Irregular, not collected. Students may work cooperatively.

Computer: Problems will be collected and graded on a letter basis. Unless indicated otherwise, computer work is to be done independently and not as cooperative projects.

† This course is patterned after a similar course at Cornell University, MAE 737: Computational Fluid Mechanics and Heat Transfer. The course outline, lecture notes, and the required text are similar. The course at Cornell was developed by Professor Kenneth E. Torrance.
Tentative Course Outline

I. General Background
   A. Conservation Laws
   B. Classification
   C. Boundary and Initial Conditions
   D. Characteristic Solution Forms – Dissipation and Dispersion
   E. Numerical Errors

II. Discretization Procedures
   A. Differential Equation Approach
      1. Finite Difference Approximations
      2. Taylor Series Approach and Truncation Errors
      3. Consistency
      4. Implicit and Explicit Methods
   B. Control Volume (Finite Volume) Approach
   C. Finite Element Approach
   D. Miscellaneous Methods

III. Time-Dependent Problems (Parabolic PDE’s)
   A. Stability
      1. Basic Concepts
      2. Lax Equivalence Theorem
      3. Review of Vector and Matrix Norms
      4. Stability Analyses for 1D Transient Diffusion
         a. Matrix Formulation
         b. Von Neumann Stability (Computer Problem #1)
   B. Other Differencing Methods (1D, Multi-D, Explicit, Implicit, ADI, LOD)

IV. Steady Problems (Elliptic PDE’s)
   A. Iterative Methods
      1. Jacobi, Gauss-Seidel, Over-relaxation
      2. Alternating-Direction-Implicit Methods
      3. Multi-grid Methods
   B. Direct Methods
      1. Direct Elimination
      2. Fourier Methods
      3. Cyclic Reduction (Computer Problem #2)

V. Application to Convection-Diffusive Problems
   A. Inviscid Flows
   B. Boundary Layers
   C. Linear Viscous Flows
   D. Convective-Diffusive Flows
   E. Basic Computational Schemes (Computer Problem #3)
      1. FTCS, Leapfrog, ADI, Time-Splitting/LOD, Upwind Methods
      2. Primitive Variable Methods (SIMPLE)
      3. Galerkin, Spectral and Semi-Analytic Methods
F. Benchmarking and Grand Applications

Notes on readings in the textbook: Computational Heat Transfer:

We will cover much of the material in Chapters 1-3, 5 and 6. We will not cover Chapters 4, 7, and 8. Please adjust your readings in the text to follow the course material.

Our coverage will extend rather than repeat the text. We will select examples and model equations that simulate convective/diffusive processes, whereas the text may use examples involving only diffusion in order to simplify the presentation.

We will cover the theory of stability, convergence, and consistency in greater detail than the text, and our coverage of numerical methods for flow problems will be more comprehensive and detailed.

We will omit the material on finite elements (Chapter 4), and the various sections in Chapters 5 and 6 that deal with finite elements.

We will assign homework problems from the book.
**Reference Texts**

<table>
<thead>
<tr>
<th>Call Number</th>
<th>Author</th>
<th>Title</th>
</tr>
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<tbody>
<tr>
<td>QA 377 S64</td>
<td>G. D. Smith**</td>
<td>Numerical Solution of Partial Differential Equations, 2nd ed. (1978)</td>
</tr>
<tr>
<td>TA 357 H75</td>
<td>P. J. Roache**</td>
<td>Computational Fluid Dynamics (1976)</td>
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<tr>
<td>QA 911 C75</td>
<td>C.-Y. Chow</td>
<td>An Introduction to Computational Fluid Mechanics (1979)</td>
</tr>
<tr>
<td>TA 347 F5 H88</td>
<td>K. H. Huebner*</td>
<td>The Finite Element Method for Engineers (1975)</td>
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***Required  
**Highly recommended  
*Recommended
References for Applications Section

Basic Differencing Methods (mostly incompressible, $\omega - \phi - T$ variables):

1. **Leapfrog Methods** (central time; central space; Dufort-Frankel diffusion difference; explicit)


2. **ADI Methods** (two-step, midpoint time; central space; alternating-direction (Peaceman-Rachford) line implicit)


3. **Upwind Methods** (two-point time; upwind, exponential, or power-law space; explicit or implicit)


4. **Time-Splitting/LOD Schemes** (multistep time; locally one-dimensional space; explicit or line implicit)


Extended Differencing Methods ($\rho - P - u - T$ variables; compressible flows; etc.)

5. **Primitive Variable Methods** (density, pressure, velocity, temperature)


6. **Steady-State, Boundary Layer, and Turbulent Flows**


7. Strongly-Compressible Flows


Basic Finite Element Methods ($\omega - \varphi - T$ and $\rho - P - u - T$ variables; incompressible and compressible flows):

8. Galerkin – FE Method


Semianalytical (grid-free) Methods (mostly incompressible):

9. Vortex Methods


10. Galerkin-Fourier Spectral Methods


A Spectrum of Applications:

11. Molecular Motions
12. Meterology


References on the Finite Element Method

General:


Application to fluid flow/heat transfer:


Methods of weighted residuals:


Calculus of variations and the Euler theorem: