# AERO 4970/7970 – Computational Fluid Dynamics (CFD) :: Fall 2022

**Class** MWF, 1:00 - 1:50 pm, 201 Ramsay Hall

**Instructor** Dr. Nek Sharan, nsharan@auburn.edu

**Office Hours** Wednesday, 3:00 - 4:30 pm, 332 Davis Hall
https://auburn.zoom.us/j/3302840089

## Course Description

This course will discuss finite-difference and finite-volume methods for solving partial differential equations of interest in fluid dynamics. Simplified (model) equations will be used to explain concepts before application to inviscid and viscous flows. Emphasis will be placed on developing scientific programming skills and analyzing numerical methods applicable to practical fluid flow problems. Some topics that will be covered include:

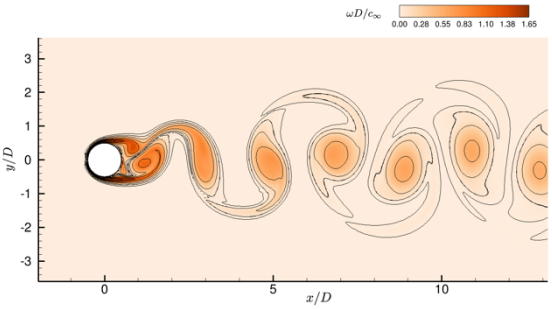

*Figure 1 CFD simulation of the flow over a cylinder.*

- Fluid flow conservation laws and model equations
- Finite-difference methods
  - Order of accuracy: Taylor Series Expansion
  - Discretization errors: Numerical dispersion and dissipation
  - Numerical stability: Fourier Analysis
  - Boundary treatment: Method of characteristics
- Unsteady flow computations
  - Time-marching methods: Runge-Kutta schemes
  - Time-space stability and convergence of ODEs
- Finite-volume methods
  - Riemann problem for the Euler Equations
  - Approximation of surface and volume integrals
  - Boundary condition implementation and solution of linear systems
- Numerical methods for incompressible flow calculation
- Turbulent flow computation and modeling

Additional topics based on students' interest may be included.

## Prerequisites

Undergraduate-level fluid mechanics, Basic calculus and differential equations, Introductory linear algebra, Some programming skills in a language of your choice

## Grading

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|---|---|
| Homework | 40% |
| Midterm | 25% |
| Final exam or project | 35% |

## Suggested Texts

B1: Lomax, Pulliam, & Zingg, *Fundamentals of Computational Fluid Dynamics*
B2: Moin, *Fundamentals of Engineering Numerical Analysis*
B3: Hirsch, *Numerical Computation of Internal and External Flows*
B4: Wendt, *Computational Fluid Dynamics: An Introduction*
B5: LeVeque, *Finite Volume Methods for Hyperbolic Problems*
B6: Toro, *Riemann Solvers and Numerical Methods for Fluid Dynamics*
B7: Ferziger & Peric, *Computational Methods for Fluid Dynamics*

## Homework Policy

- Typeset your homework or write neatly.
- Provide a main document with answers/figures/tables. Include all source code at the end of the document and reference programs/modules/functions as necessary.
- You may work together in study groups but you must provide comments/conclusions/code independently.
- Late homework policy: 20% off per day.

## Honor code

It is assumed that the Auburn Academic Honesty Code will be followed at all times, including during completion of homework and during exams. For more details visit:

https://www.auburn.edu/academic/provost/academic-honesty/_assets/pdf/academic-honesty-code-20201028.pdf

**Course Schedule:** Tentative breakdown of the course schedule is provided below.

| Class # | Date | Topics | Relevant Book Sections | HW/Exam Assignment | HW/Exam Due Dates |
|---|---|---|---|---|---|
| 1 | 17-Aug | Introduction & Syllabus | | | |
| 2 | 19-Aug | Fluid flow conservation laws and model equations | B1: Sections 2.1 – 2.5 | | |
| 3 | 22-Aug | | | HW1 | |
| 4 | 24-Aug | Steps in a CFD calculation | B1: Section 1.2 | | |
| 5 | 26-Aug | Finite-difference (FD) schemes | B1: Section 3.1 | | |
| 6 | 29-Aug | Properties of a FD scheme: Consistency and Accuracy | B1: Sections 3.2 – 3.4 | | |
| 7 | 31-Aug | | | | **HW1 Due** |
| 8 | 2-Sep | Properties of a FD scheme: Conservation | | HW2 | |
| | 5-Sep | **Labor Day – No Classes** | | | |
| 9 | 7-Sep | Properties of a FD scheme: Stability and convergence | B2: Sections 4.1 - 4.3 | | |
| 10 | 9-Sep | | | | |
| 11 | 12-Sep | Stability with different time integration methods | B2: Sections 4.4, 4.8-4.9 | | **HW2 Due** |
| 12 | 14-Sep | | | HW3 | |
| 13 | 16-Sep | Von Neumann Stability Analysis | B2: Sections 5.2 & B3: Section 7.2 | | |
| 14 | 19-Sep | | | | |
| 15 | 21-Sep | Inviscid Flow: The Euler equations | | | |
| 16 | 23-Sep | Classification of PDEs | B4: Chapter 4 | | **HW3 Due** |
| 17 | 26-Sep | Solving the Euler equations: Riemann Problem | B5: Section 3.8 | HW4 | |
| 18 | 28-Sep | | | | |
| 19 | 30-Sep | Finite-volume (FV) schemes | B5: Section 4.1 | | |
| 20 | 3-Oct | Godunov's method | B5: Sections 4.9-4.10 & B6: Section 5.4.2 | | |
| 21 | 5-Oct | | | | **HW4 Due** |
| | 7-Oct | **Fall Break** | | | |

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| 22 | 10-Oct | Roe's method | B6: Sections 11.1-11.3 | Mid-term (take home) | |
| 23 | 12-Oct | High-resolution methods | B5: Sections 6.4 - 6.11 | | |
| 24 | 14-Oct | | | | **Mid-term Due** |
| 25 | 17-Oct | | | | |
| 26 | 19-Oct | Incompressible flow equations | B7: Section 1.7.1 | HW5 | |
| 27 | 21-Oct | Solutions to the incompressible eqns. | | | |
| 28 | 24-Oct | | | | |
| 29 | 26-Oct | Numerical solutions to the incompressible flow equations | B7: Sections 7.1-7.3 | | |
| 30 | 28-Oct | | | | **HW5 Due** |
| 31 | 31-Oct | | | | |
| 32 | 2-Nov | Linear algebraic systems: Iterative methods | B3: Chapter 10 | Final exam/project | |
| 33 | 4-Nov | | | | |
| 34 | 7-Nov | | | | |
| 35 | 9-Nov | Pressure calculation | B7: Section 7.3 | | |
| 36 | 11-Nov | Fractional-step methods | B7: Section 7.4.1 | | |
| 37 | 14-Nov | | | | |
| 38 | 16-Nov | SIMPLE algorithm for incompressible flows | B7: Section 7.5 | | |
| 39 | 18-Nov | | | | |
| | 21-Nov | **Thanksgiving Break** | | | |
| | 23-Nov | | | | |
| | 25-Nov | | | | |
| 40 | 28-Nov | Turbulent flow simulations | B7: Chapter 9 | | |
| 41 | 30-Nov | | | | |
| 42 | 2-Dec | | | | **Final exam due** |