NDSU Mechanical Engineering Department
ME 483/683 - Introduction to Computational Fluid Dynamics
2024 Spring Semester Syllabus
MWF 10:00am-10:50am, Dolve 202 (Lab: ENGR 222)

Instructor: Dr. Y. Bora Suzen
Office: Dolve 102C
Phone: (701) 231 8302, Email: Bora.Suzen@ndsu.edu
Office Hours: Monday, Friday 1:00pm-2:00pm or by appointment

Learning Assistants:

Omid Nazempour
Email: Omid.Nazempour@ndsu.edu
Office: Dolve 134
Assistance Hours: *TBD* and by appointment

Tariqul Islam Shazeeb
Email: Tariqul.Shazeeb@ndsu.edu
Office: Dolve 134
Assistance Hours: *TBD* and by appointment

Course Prerequisites: ME 352, basic fluid mechanics course or graduate standing

Course Catalog:
An in-depth introduction to the methods and analysis techniques used in numerical solutions of fluid flow, heat, and mass transfer problems of practical engineering interest.

Course Description and Goals:
Computational Fluid Dynamics (CFD) is a valuable resource in engineering. This course will provide the students with an introduction to CFD and its growing range of applications in analysis of engineering flow problems.

The course will start with review of governing equations of fluid flow. Numerical solution methods for these equations, such as finite differences and finite volume techniques will be introduced with emphasis on accuracy evaluation and efficiency. Convergence, numerical accuracy, verification of results, sources of errors in numerical solutions, and interplay between numerics and physics will be discussed.

A major portion of this course will involve the use of a commercial CFD software (ANSYS CFX/Fluent) to analyze flow problems of engineering interest. Simple flow problems such as flows in various pipe geometries will be studied to provide introduction to the inner workings and the usage of the commercial CFD software. These sample problems will be used to illustrate the aspects of geometry modeling including the conversion of CAD entities into CFD-ready models, proper grid generation for accuracy, identification and application of appropriate boundary conditions, solution strategy, and post-processing of results for flowfield visualization, analysis, and presentation.

Several turbulence closures are readily available in commercial CFD codes; a brief introduction will be given on basic concepts in turbulence modeling and several examples will show the impact of the modeling assumptions. Students will use the available turbulence models to simulate turbulent flowfields. The course will also include an introduction to the use of parallel computers and emerging trends in CFD.

At the end of this course students will understand and apply the process of analyzing a flow problem including developing a geometrical model of the flow system, applying the appropriate boundary conditions, specifying solution parameters, and visualizing, analyzing and presenting the results. The students will have an understanding of the factors affecting the accuracy of CFD solutions and have the knowledge and experience of industry accepted “best-practice” guidelines for using commercial CFD software.

Prerequisite Knowledge and/or Skills:

This course combines the materials learned in thermodynamics, fluid mechanics, heat and mass transfer and applies them to the analysis of engineering systems. Students will utilize their knowledge and skills in:

- Calculus: integrals, derivatives, partial derivatives, vector calculus
- Mechanics: force and momentum balances
- Thermodynamics: conservation of mass and energy; properties and equations of state
- Fluid Mechanics: conservation of momentum, control volume analysis, simple differential analysis, dimensional analysis, engineering correlations and relationships commonly used in mechanical engineering for internal and external flows, simple compressible flows
- Computer Science: introductory numerical methods including differentiation and integration and use of a computer programming language such as FORTRAN, C, MATLAB, etc.

References:

There is no single text available to cover all the materials to be presented in the course. Copies of lecture notes will be made available and handouts will be distributed as needed. For the commercial software used in the course online help and manuals will be used.

The following supplemental references are suggested:

1. Anderson, J. D., 1995, *Computational Fluid Dynamics, The Basics With Applications*, McGraw-Hill College, Blacklick, Ohio.
2. Hoffmann, K. A. and Chiang, S. T., 2004, *Computational Fluid Dynamics*, 4th ed., Engineering Education System, Wichita, Kansas.
3. Tannehill, J. C., Anderson, D. A., and Pletcher, R. H., 1997, *Computational Fluid Mechanics and Heat Transfer*, 2nd ed., Taylor and Francis, Philadelphia, Pennsylvania.
4. Versteeg, H. K. and Malalasekera, W., 2007, *An Introduction to Computational Fluid Dynamics: The Finite Volume Method*, 2nd ed., Pearson Education Limited, Essex, England.

Anticipated Course Outcomes and Affected Program Outcomes:

The anticipated course outcomes are listed below along with the affected program outcomes. A list of program objectives and outcomes are listed at the end of the syllabus.

At the conclusion of ME 483/683, students will be able to:

1. Derive the finite difference formulations for the one-dimensional heat equation and perform computational experiments with sample codes that implement these methods.
2. Interpret exact and numerical solutions to the one-dimensional convection-diffusion equation and explain the pros and cons of upwind difference scheme and the central difference scheme.
3. Starting from a rough sketch of a flow problem, develop a geometrical model of the flow system, identify all physical data and boundary conditions necessary to set up and solve the velocity, pressure, and temperature fields using CFD software.
4. Use CFD software to solve three-dimensional laminar and turbulent flow problems.
5. Post-process the results of a CFD simulation and describe the key features of a three-dimensional flowfield represented by a vector plot of the velocities and a contour plot of the pressure field and be able to compute required quantities from the solutions such as skin friction coefficient, pressure coefficient, forces, and moments.
6. Prepare their work as a technical paper and present their findings effectively in a poster session.

Communication:

- The primary method by which course-related information will be communicated is during class. Reminders, notification of any assignments or schedule changes will be communicated through NDSU email and posted on Blackboard announcements page. You will need to login and check https:/blackboard.ndus.edu for announcements and assignments.
- Your NDSU email address is the official route for information.
- You may meet with me or the Learning Assistant during help hours or by appointment.

Copyright of Course Materials:

In accordance with NDSU Policy 190 on Intellectual Property in this course recording the lectures is prohibited with your own personal devices (without prior approval from the instructor).

Assessment:

- Your level of success in attaining the anticipated course outcomes will be assessed during the semester by homework assignments, quizzes, an independent project, midterm and final examinations. ***The format of your solutions in homework assignments, quizzes, project, and the exams should be in acceptable engineering form.***
- In this course Blackboard will be used for assignment submission (and grading) for all students.

(a) Homework Assignments and Quizzes:

Homework assignments may consist of both "hand-solution" of problems using various numerical methods, and computer assignments requiring the development and implementation of numerical algorithms. Assignments will typically be collected on a weekly basis. Short quizzes may be given without prior notice on the topics covered in previous classes and study/reading assignments. Quiz grades will count as homework grades. Graduate students will have additional in depth homework problems assigned.

(b) Simulation and Computer Homework:

There will be simulation and additional computing assignments. Simulation assignments will cover a wide range of flow problems and will be covered in lab in detail to illustrate the different aspects of CFD simulations. Students then finalize the computations and submit a report for each of the assignments detailing computation setup, solution, results and discussion. Additional computing assignments will require programming using Matlab, etc. to solve problems. Graduate students will have additional in-depth computational problems assigned.

(c) Project:

There will be an independent project during the semester corresponding to 20% of the overall grade for the course. The projects will include detailed computation and analysis of specific flow problems using the commercial CFD software. A list of project topics will be provided by the instructor, however other topics can be proposed by each student based on their interests with instructor approval. The project topics will cover diverse areas of application of computational fluid dynamics such as manufacturing, energy systems, cooling of electronic equipment, power cycles, engines, heat exchangers and HVAC, hydraulics and pneumatics, fire and explosion protection systems, biomedical applications, aerodynamics, etc. All students will conduct a detailed literature survey on their project topics. At the end of the semester, each student will submit a report, prepare and present a poster in the course poster session. The final report will be prepared according to the conference paper format of American Institute of Aeronautics and Astronautics (AIAA) which will be provided by the instructor. All project related computer files (project directories) will be turned in at the end of the semester in the project group folder provided by the instructor in the common server drive including the final project report. During the semester detailed guidelines will be provided to the students about projects. The complexity of the projects and expected depth of analysis will be different for graduate and undergraduate students.

(i) Undergraduate Students:
The undergraduate students taking the class may work on steady state flow problems. The computations must include grid independence studies, convergence histories, and validation of results against available experimental or analytical data. The final report should be six to eight pages long.

(ii) Graduate Students:
The graduate students taking the class are expected to work on more complex projects and perform further detailed analysis of the flow problems compared to the undergraduate students. The graduate student projects may involve computation and analysis of unsteady, turbulent flow problems, design improvement of a given flow system based on parametric studies. The computations must include grid independence studies, convergence histories, and validation of results against available experimental or analytical data. The final report should be between ten to twelve pages long.

(d) Examinations:
There will be a midterm and a final exam. The midterm and the final exam each will be 20% of the overall grade for the course. Final examination will be comprehensive. Students who fall ill, or who know they will be missing the exam for a valid reason (e.g. family emergency) are encouraged to notify the instructor by phone or e-mail *prior to the exam*, if at all possible. Students missing the exam without a valid excuse will receive a grade of zero for that exam.

Grading Policy:

The grade distribution is:

Homework/Quizzes	10%
CFD/Computer Homework	30%
Project	20%
Midterm	20%
Final	20%
Total	100%

Final course grades will be assigned according to the following scale:

A	90-100
B	80-89
C	70-79
D	60-69
F	below 60

The final grades will NOT be curved

Additional Information:

- Unless specifically stated otherwise, **all assigned work is assumed to be performed individually.**
- You are expected to work on all assignments.
- You are expected to read, study, and work on the study materials before class.

Attendance/Participation Policy:

- According to NDSU Policy 333 (www.ndsu.edu/fileadmin/policy/333.pdf), attendance and participation in classes are required.
- Please do not come to class if
    - you are feeling ill, particularly if you are experiencing COVID-19 symptoms, or
    - you are infected during your five-day isolation period.
    - You will still need to complete the assignments, exams, reading, etc. necessary to meet class learning objectives. You can complete missed work by contacting the instructor for alternate arrangements for accommodations (synchronous online attendance or recording of the classes) and extensions as needed.
- Veterans and student service members with special circumstances or who are activated are encouraged to notify the instructor as soon as possible and are encouraged to provide Activation Orders.

Academic Honesty Statement
The academic community is operated on the basis of honesty, integrity, and fair play. All work in this course must be completed in a manner consistent with Code of Academic Responsibility and Conduct, NDSU Policy 335: Code of Academic Responsibility and Conduct applies to cases in which cheating, plagiarism, or other academic misconduct have occurred in an instructional context. Students found guilty of academic misconduct are subject to penalties, up to and possibly including suspension and/or expulsion. Student academic misconduct records are maintained by the Office of Registration and Records. Informational resources about academic honesty for students and instructional staff members can be found at www.ndsu.edu/academichonesty.

Americans with Disabilities Act for Students with Special Needs
Any students with disabilities or other special needs, who need special accommodations in this course, are invited to share these concerns or requests with the instructor and contact the Disability Services Office (www.ndsu.edu/disabilityservices) as soon as possible.

Tentative Course Topics and Schedule *(subject to change)*:

1. Overview of Computational Fluid Dynamics (CFD) and application areas
2. Background: Fluid Dynamics
    a. Governing equations
    b. Basic flow physics and concepts
3. Background: Numerical Methods
    a. Basics of discretization methods
    b. Truncation and round-off errors
    c. Stability and convergence
4. Applications of numerical methods to model equations
    a. Heat equation (undergraduate and graduate students)
    b. Advection-diffusion equations (graduate students)
    c. Diffusion equation (graduate students)
5. Incompressible Navier-Stokes equations
6. ***Midterm Exam***
7. Introduction to commercial CFD code (ANSYS-CFX/Fluent) using various examples
    a. Geometry modeling
    b. Grid generation and control of mesh resolution
    c. Selection of fluid properties, boundary conditions, solution control parameters
    d. Running a simulation using the CFD-Solver, convergence, number of iterations
    e. Post-processing of results using CFD-Post and TecPlot: velocity vectors, pressure contours, exporting subsets of pressure and velocity fields, skin friction and pressure coefficient calculations.
8. Basic concepts in turbulence and transition modeling
    a. Algebraic, one, and two-equation turbulence models
    b. Intermittency transport equation approach for transition modeling
    c. Computation of turbulent flows, selection of turbulence model and model parameters.
9. Introduction to parallel computers and emerging trends in CFD
10. ***Project presentations (poster session) Friday April 26, 2024***
11. ***Final Exam Tuesday May 7, 2024, 8:00-10:00am***

Department of Mechanical Engineering
North Dakota State University

Vision

To become nationally recognized and respected for excellence in engineering education, research, and service to local and regional industries.

Mission

The Department of Mechanical Engineering at NDSU will contribute to the aspirations of a land-grant university in the three primary components of education, research, and service. In support of these endeavors, the mission of the department is to:

- Educate undergraduate and graduate students in the fundamentals of the discipline, prepare graduates (BS, MS, or PhD) to effectively function in society in the field of their choice, and provide the learning skills to adapt to evolving personal and professional goals.
- Develop and maintain high quality research programs in traditional and emerging areas that build on the diverse strengths of the faculty, foster interdisciplinary collaborations, and address national and global needs.
- Serve the needs of the profession, the state of North Dakota, and regional industries to promote and enhance economic development opportunities.

Educational Objectives

In support of the mission of the ME Department, the educational objectives of the program are to produce engineering graduates who:

1) Are well educated in the fundamentals of the discipline, and possess the ability and willingness to adapt to emerging technologies through continued professional development.
2) Will contribute in a competent manner to the engineering profession in the field of their choice.
3) Demonstrate a commitment to uphold high ethical and professional standards in the practice of engineering.
4) Can effectively function in a team environment and interact with people of diverse backgrounds.
5) Understand the context in which their designs will be implemented and the corresponding impact of their activities on society.

Program Outcomes

To foster attainment of the program educational objectives, the ME Department has developed a curriculum that insures students will achieve the following outcomes (1) through (7). Attainment of these outcomes prepares graduates to enter the professional practice of engineering.

1. an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
2. an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
3. an ability to communicate effectively with a range of audiences
4. an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts
5. an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives
6. an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions
7. an ability to acquire and apply new knowledge as needed, using appropriate learning strategies.