North Dakota State University
Department of Mechanical Engineering
ME 754 - Boundary Layer Theory (3 credits)

2024 Spring Semester
MWF 12:00pm -12:50pm, Dolve 118

Instructor: Dr. Y. Bora Suzen
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Office Hours: Monday, Friday 1:00pm-2:00pm or by appointment

Prerequisites:
Students attending this course are assumed to have taken a course in Fluid Dynamics similar to ME 352.

Suggested References:
1. "Boundary Layer Analysis," Joseph A. Schetz, Prentice Hall, 1993
2. "Viscous Fluid Flow," 3rd Ed., Frank M. White, McGraw Hill, 2006
3. "Boundary-Layer Theory," 8th Ed., H. Schlichting, K. Gersten, Springer Verlag, 2003
4. *American Institute of Aeronautics and Astronautics Journal*
5. *Journal of Fluid Mechanics*

Course Description:
Fundamental laws of motion of a viscous fluid used in the consideration of laminar boundary layers, transition phenomena, and turbulent boundary layer flows.

Course Goals and Anticipated Course Outcomes:
In this course the governing equations of viscous fluid flows, the Navier-Stokes equations, their simplified forms and the associated boundary conditions will be examined in detail. The objective is to have the students gain the necessary understanding of the underlying physics in Navier-Stokes equations, acquire the skills to simplify them in different viscous flow cases and learn to apply the proper boundary conditions and solution techniques. Laminar, transitional, and turbulent flows, transition and turbulence modeling techniques and recent developments in these areas will be discussed in detail. The course is best suited for students interested in aerodynamics, hydrodynamics, gas dynamics, biofluids, and energy engineering.

Assessment:
Your level of success in attaining the anticipated course outcomes will be assessed during the semester by homework/computer assignments, examinations, and computer projects. ***The format of your solutions in homework, projects, and the exams should be in acceptable engineering form.***

(a) Homework Assignments: Homework assignments will include problems based on both analytical and computer solutions. Assignments will typically be collected on a weekly basis. Additionally, there will be assignments to be completed during class which will count towards homework grade.

(b) Examinations: There will be a midterm and a final exam. Students who fall ill, or who know they will be missing an 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 an exam without a valid excuse will receive a grade of zero for that exam.

(c) Computational Projects: During the semester in depth viscous flow problems will be assigned that will be solved using computational tools. For each project students are required to prepare a report including the details of theoretical background of the problem, solution method used, analysis of results and conclusions reached from the study. Format of the project reports will be provided in class.

Grading Policy:

The grade distribution is:

Homework:	25%
Computational Projects:	25%
Two Exams (25% each):	50%
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, **all assigned work is assumed to be performed individually.**
- Course assignments, calendar, announcements etc. will be posted on Blackboard on regular basis, you will need to login and check https:/blackboard.ndus.edu for announcements and assignments.

Attendance Statement:

- According to NDSU Policy 333 (www.ndsu.edu/fileadmin/policy/333.pdf), attendance in classes is expected.
- If you are unable to attend class at the regularly scheduled time as a result of a COVID-19 diagnosis or quarantine, please contact the instructor for alternate arrangements for accommodations (synchronous online attendance or recording of the classes) and extensions as needed.
- Do not come to class if you are sick. Please protect your health and the health of others by staying home. For information on COVID-19, symptoms, testing, and steps to stay healthy see https://www.ndsu.edu/studenthealthservice/covid_19/.
- Do not come to class if you have been exposed to individuals who tested positive for COVID-19 and/or you have been notified to self-quarantine due to exposure.
- 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.

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.

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.

Tentative Course Topics:

1. Basic Principles of Viscous Fluid Flow
    a. Continuum approach
    b. Properties of a fluid
    c. Boundary conditions for viscous flow problems
2. Fundamental Equations of Compressible Viscous Flow
    a. Conservation of mass
    b. Conservation of momentum
    c. Conservation of energy
    d. Orthogonal coordinate systems
    e. Mathematical character of fundamental equations
    f. Dimensionless parameters in viscous flows
    g. Nondimensionalization of fundamental equations
3. Solutions of the Newtonian Viscous Flow Equations
    a. Classification of solutions
    b. Couette flows
    c. Poiseuille flows
    d. Unsteady duct flows
    e. Similarity solutions
    f. Creeping flows
    g. Computational fluid dynamics
4. Laminar Boundary Layers
    a. Boundary Layer assumptions and equations
    b. Similarity solutions for steady, 2-D flow
    c. Free shear flows
    d. Other analytic 2-D solutions
    e. Approximate integral methods
    f. Computational solutions
5. Stability of Laminar Flows-Transition
    a. Transition process
    b. Engineering prediction of transition
        i. Transition modeling approaches
        ii. Current transition models
6. Incompressible Turbulent Flows
    a. Physical and mathematical description of turbulence
    b. Reynolds averaged equations
    c. The 2-D turbulent boundary layer equations
    d. Turbulent velocity profiles: Inner, outer, and overlap layers
    e. Turbulent boundary layer on a flat plate
    f. Turbulence modeling – Basics and recent developments
    g. Turbulent boundary layers with a pressure gradient
7. Compressible Boundary Layer Flow
    a. Compressible boundary layer equations
    b. Similarity solutions for compressible laminar flow
    c. Compressible laminar boundary layers under arbitrary conditions
    d. Compressible turbulent boundary layer equations
    e. Law and wake law for turbulent compressible flow
    f. Compressible turbulent flow past a flat plate
    g. Compressible turbulent boundary layer calculations with a pressure gradient