EMEM 550-01: Transport Phenomena

Winter 2006-2007

Instructor: Dr. Amitabha **Ghosh**, Department of Mechanical Engineering, Rochester Institute of Technology

Introduction

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This is the second course in fluid mechanics in your curriculum. By now you must have had a course in Fluid Mechanics and Matrices and Boundary Value Problems. Transport Phenomena deals with transport of fluid properties and heat. You will learn the dynamic behavior of fluids in potential flows, and inside the boundary layers for laminar and turbulent flows. The methodology in this course will review some control volume applications, but primarily focus on the applications of differential approach. Understanding this material is crucial to making sense of computational fluid dynamics, an essential tool used in the industry.

Prerequisite: 0307-415: Fluid Mechanics

Co-requisite: 0307-514

1016-318: Matrices and Boundary Value Problems

Course Objectives: On successful completion of the course, students will be able to

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Formulate the governing fluid flow equations and initial/boundary conditions

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Solve applied problems of fluid dynamics with an understanding of the underlying assumptions

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Solve analytically some basic equations by the differential approach

Course Content: The following subjects will be covered

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Review of Fundamentals – Newton's Laws of Motion, Systematic Problem Solving, control volume and differential approaches of fluid flow solutions

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Fundamentals of Fluid Flow Analysis

Definition of a fluid, Fluid properties (physical & dynamical)
Control volume approach to solve flow problems
Differential approach to solve flow problems
Boundary Conditions in Inviscid and Viscous Flows
Velocity, Concentration and Temperature Profiles in Laminar and Turbulent Flows

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Applications and Extensions

Conservation Laws of Fluid Flows – Mass, Momentum and Energy
Pitot and Pitot-Static Tubes, Static and Stagnation Pressures
Potential Flows, Superposition Principle, Introduction to Aerodynamics
Internal Flows, Plane Poiseuille, Couette, and Pipe Flows, Head Loss
External Flows at low and high speeds, Boundary Layers in Velocity, Concentration and Temperature

Preparation: This course will become a foundation for many elective courses. Fluid flow theory involves various levels of mathematics. To prepare you for the subject, you should thoroughly review differentiation, integration, and algebraic and trigonometric identities. A complete set of lecture notes is available on the Internet at the address: http://www.rit.edu/angeme/550cd. You may begin at "Introduction.doc" and navigate your way through. It is advisable to read these notes before the class so that you may absorb the class material better. You should also add your own notes with it for better understanding. Make a habit of reviewing your own lecture notes right after each lecture. If you are not able to follow the development in class or have difficulty in connecting physics to appropriate mathematics, address these issues immediately because later lectures may use understanding developed in the earlier ones. If you are unable to resolve your questions, please stop by my office with your work during my office hours given below. You may already have copies of the following books from prior classes (note the editions).

Textbook: Introduction to Fluid Mechanics - by Fox, McDonald & Pritchard (Prentice Hall, 6th Edition)

Fundamentals of Heat and Mass Transfer – by Incropera, et. al. (John Wiley, 6th

Edition)
Syllabus: Chapters 5, 6, 8, 9 of F&M & Chapter 6 of Incropera

Detailed Topics Covered:

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Basic Concepts Review: Reynolds Transport Theorem; Extensive, intensive and specific properties; Control Volume and Differential Analysis of Fluid Motion.

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Flow Kinematics: Dilation, Acceleration, Rotation and Shear; Vorticity and Circulation

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Ideal Flow Analysis: Streamlines and Stream Function; Velocity Potential; Continuity and Momentum Equations; Euler and Bernoulli Equations; Laplace Equation and Principle of Superposition; Singular Flows: Sources/Sinks, Free and Forced Vortices, Doublet; Stagnation Streamline; Rankine Half-body and Oval; Flow over a Circular Cylinder; D'Alembert's Paradox; Helmholtz and Kelvin Theorems; Crocco's Theorem; Static, Stagnation and Dynamic Pressures; Aerodynamics of the Airfoils, Airplanes and, Wind Tunnels.

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Incompressible Internal Flows: Fully developed and Parallel Flows; Entrance Lengths in Laminar and Turbulent Flows; Velocity Profiles in Fully Developed Flows; Plane Poiseuille, Couette and Pipe Flows; Boundary Conditions; Electrical Analogy of Fluid Flows; Head Loss and Interpretations; Kinetic Energy Flux Coefficient; Darcy Weisbach Formula; Moody Diagram; Pipe Flow Calculations; Major and Minor Head losses; Iterative Solutions.

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Incompressible Boundary Layer Theory: Non-Dimensional Forms of Flow Equations; Thermal Analogy of Boundary Layer Concepts; Prandtl's Order Analysis; Velocity Profiles and Boundary Conditions in Laminar and Turbulent flows; Boundary Layer Thicknesses and their uses; Exact and Approximate Solutions of Prandtl's Boundary Layer Equations; Viscous and Pressure Drags at low and high speeds; Pressure Coefficient, Local and overall skin friction coefficient; Lift and Drag Coefficients; Flow Transition and Critical Reynolds Number; Flow Separation and Controls; Lift and Drag Controls; Streamlining; Low Reynolds Number Flows; Terminal Speed Calculations; Steady and unsteady flows.

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Convective Heat and Mass Transfer: Thermal and Concentration Boundary Layer Equations; Fully developed vs. developing flows; Local and average Heat and Mass Transfer Coefficients; Non-Dimensional numbers in heat and mass transfer, their interpretations and uses; Heat Transfer Correlation Relations in Laminar and Turbulent Flows; Heat and Mass Transfer Analogies; Applications of Forced Convection.

Organization: Every week there are 2 lectures of 2 hours duration in which theory and examples will be presented. You should take a good set of your own notes and add to your previous knowledge incrementally. To facilitate your understanding of the course material, I shall divide your class in groups of 4 and assign some homework problems from your text every week. A few of these will be collected as homework for grading. It is your responsibility to attempt and understand all assigned problems for the purpose of tests and quizzes. The group participants will teach and learn from each other, as well as from other groups to master these topics. Although homework will be graded on group efforts the quizzes and tests will be graded on individual performance.

Homework: Every week you will have some problems from the textbook as homework (underlined ones on the schedule page) and some for practice. I suggest that you do these problems in groups so that you can learn from each other. Only one homework paper per group will be collected and graded. **The submission time for homework problems is 8 am on Tuesdays.** After collection, your textbook's solutions of the assigned problems will be posted on Wednesdays at the site: www.rit.edu/angeme/**emem550**. Please do as many of the practice problems as you can, for tests and quiz questions will be very similar to these.

Quizzes: Every week you will have a pop quiz of 10 to 15 min. duration to test your understanding of the assignments and topics discussed in class. A missed quiz will not be repeated saving reasons stated below (*see* Tests). Best 7 out of the 9 quizzes will be counted toward your final grade.

Tests: You will have two midterm tests (Dates: 1-11-07 & 2-8-07) and a comprehensive final examination given during the eleventh week of the quarter. There will be no make up examinations given for a missed test or a quiz, unless you have a physician's certificate for illness. If you know of a conflict with an examination date due to a business schedule, you must discuss with me at least one week before that examination date. Then only a make-up

may be given after a missed test or quiz.
All the quizzes and tests will be closed book, closed notes type.
Grading: The breakdown of your final grade will be as follows:

Component
% of final grade
% breakdown
Home Assignments
10%
7 Quizzes (of 9)
35%
2 Midterm Tests
30%
15% each
Final Examination
25%
Grade Distribution:
Your numerical grade score will be converted to a letter grade at the end of the course using the following cut-offs:
A
(90 - 100%)
B
(80 - 89%)
C
(70 - 79%)
D
(60 - 69%)
F
(< 60%)
Course Policies: Attendance in classes is necessary but not mandatory. Due to a systematic development of the subject matter and pop quizzes, it is in your best interest to attend all classes. We will be working out many examples in class. Please bring your textbook, a notebook and a calculator to the class. I am available for help during my office hours given below, and also over the phone. In seeking my help, please bring your textbook and the work you completed so far in solving the problem.
The Mechanical Engineering Department strongly enforces the academic honesty policy. Although I strongly encourage frequent discussions and your working in groups for better learning purposes, homework, examinations and quizzes are expected to be your own individual effort without any assistance from other sources. Any academic dishonesty will result in a failing grade in the course.
I welcome your feedback as often as possible. It is very helpful to have a frequent dialogue on your expectations and progress. If necessary, please review with me your grades after each midterm examination to monitor your progress. I hope you will have an enjoyable and productive learning experience with calculus.
Contact Information: Room No: 09-2179; Office Phone: 475-2191; Fax: 475-7710; Email: angeme@rit.edu
Office Hours: 12 – 2 pm on Tuesdays and Thursdays. These hours are reserved for student consultation. If you need to see me outside these hours, please call me and schedule an appointment ahead of time.

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Course Schedule, Homework Problems & Tests

Week
Text Sections
Course Content: Topics Covered
Home Work & Practice Problems

Test/Quiz Coverage
12/04/06
through
12/08/06
5.1 – 5.5
Review of Fluid Mechanics and Calculus, Control Volume and Differential Approaches (through Navier.doc on the Internet)
5-28, 5-37, **5-41**, 5-43, 5-52, **5-62**, 5-64, **5-70**, 5-73, **5-79**, 5-81, **5-83**
No quiz this week
12/11/06
through
12/15/06
6.1 – 6.5
Movie in class
6.7 (CD-ROM)
Applications of Euler's and Bernoulli Equations
Movie: Vorticity (I & II)
Elementary Plane Flows
6-2, 6-4, **6-8**, 6-9, **6-39**, 6-42, **6-49**, **6-66,** 6-85, 6-90, 6-94
Read Movie Notes online (http://www.rit.edu/angeme/emem550/movie/)
Quiz No. 1 will cover Chapter 5
12/18/06
through
12/22/06
6.7 (see CD-ROM with the Textbook)
Superposition Principle
Introduction to Aerodynamics and Wind Tunnels
6-97, **6-99**, **6-101**, 6-105, **6-106**, 6-107
Quiz No. 2 will cover Movie Concepts, 6.1
1/08/07
through
1/12/07
8.1 – 8.5
Internal Flows: Introduction, Boundary conditions, Velocity Profiles
Review for Test No. 1
Test No. 1 (in class)
8-4, **8-7**, 8-9, **8-10**, 8-20, **8-21**, 8-28, **8-32**, 8-34, **8-41**
Quiz No. 3 will cover 6.7
Test No. 1 will cover

Chapts. 5,6, +movie
1/15/07
through
1/19/07
8.6 – 8.8
Pipe Flows, Review Head Loss + Laminar & Turbulent Velocity Profiles
8-60, **8-62,** 8-64, **8-77**, 8-117, **8-105,** 8-106, **8-133**, 8-143, 8-145, 8-149
Quiz No. 4 will cover
8.1 – 8.5
1/22/07
through
1/26/07
9.1 – 9.3
Prandtl's Boundary Layer Concepts, Boundary Layer Thicknesses
9-2, 9-6, **9-7**, 9-8, **9-11, 9-15**, 9-17, **9-18**, 9-20, 9-51, 9-61
Quiz No. 5 will cover
8.6 – 8.8
1/29/07
through
2/2/07
9.4 – 9.8
Momentum Integral Solutions, Separation Process, B.L. Controls, Creeping Flows, Terminal Velocity
9-32, 9-38, **9-41**, 9-45, 9-59, **9-71**, **9-75**, 9-107, **9-112**, 9-111, 9-132, 9-138
Quiz No. 6 will cover
9.1 – 9.3
2/5/07
through
2/9/07
6.1 – 6.4
(Incropera)
Synthesis of approaches, energy and mass transport
Review for Test No. 2
Test No. 2 (in class)
6-1, **6-2**, **6-15, 6-17**, 6.25
(Incropera)
Quiz No. 7 will cover
9.4 – 9.8
Test No. 2 will cover
Chapters 8 - 9 parts
2/12/07
through
2/15/07
6.5 – 6.7.1
6.7.3 – 6.9

(Incropera)
Synthesis of approaches;
Similarity in Differential
Equations, Velocity and
Temperature Profiles
6-7, 6-11, **6-19**, 6-29, **6-35**, 6-39
(Incropera)
Quiz No. 8 will cover
6.1 – 6.4 (Incropera)
2/19/07
through
2/23/07
No new topics
Course Review for the Final
Examination
Last home work will be collected
Quiz No. 9
(mystery quiz !)
Details in class
Week 11
Final
Examinations
Week
Examination Schedule will be
posted by the department
Final Examination
will test coverage of
Chapters 5 – 8 + 6.1
– 6.10 (Incroper