Western Engineering

Department of Chemical & Biochemical Engineering

CBE 9155 – Advanced Fluid Dynamics

Course Description

A survey of concepts in fluid mechanics for chemical engineering graduate students. Topics include conservation laws, global control volume analysis, governing equations of fluid flow, analytical solutions for viscous flows, irrotational flow, boundary layer theory, turbulence, numerical solution of the Navier-Stokes equations, and micro/nanoscale fluid flows.

Prerequisites

CBE 2221 (Fluid Flow) or equivalent

Contact hours

3 lecture hours per week.

Instructor

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Graduate coordinator

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Reference textbooks

Fluid Mechanics (6th edition). P. K. Kundu, I. M. Cohen, D. R. Dowling. Academic Press, 2015.

Viscous Fluid Flow (3rd edition). F. M. White. McGraw-Hill, 2005.

Evaluation

The final mark will be calculated as follows:

Assignments	10%
Term project	20%
Midterm	35%
Final exam (during exam period)	35%

The midterm and final exams are both 3 hours and open book / open notes. No credit will be given for late assignment or project report submissions.

There will be no make-up midterm exam. If you are unable to write the midterm for medical or compassionate reasons, you must provide the appropriate documentation. Your final exam will be reweighted to absorb the value of the midterm in your final grade. Failure to provide adequate documentation will result in a mark of zero.

Course content

1. Review of undergraduate fluid mechanics
   - Fluid properties, fluid kinematics, forces in fluids, Bernoulli equation, conservation laws
2. Control volume analysis
   - Application of conservation laws to fixed and deforming, inertial and non-inertial global control volumes
3. Governing equations of fluid motion
   - Derivation of Navier-Stokes and continuity equations, Eulerian and Lagrangian viewpoints, analytical solutions for viscous flows, lubrication approximation, vorticity theorems
4. Inviscid fluid flow
   - Irrotational flow, potential flow solutions, numerical solution of Laplace equation, Bernoulli equation normal to a streamline
5. Boundary layer theory
   - Boundary layer equations, similarity solutions, momentum integral formulation,* numerical solutions
6. Stability, transition, and turbulence
   - Linear stability theory for laminar shear flows, Rayleigh and Orr-Sommerfeld equations, characteristics of transitioning and turbulent flows
7. Micro/nanofluidics
   - Surface tension, creeping flow electrokinetic phenomena,* slip flow, Knudsen number, free molecular flow, molecular dynamics simulation,* Boltzmann transport equation*
8. Introduction to computational fluid dynamics
   - Finite volume methods, convection schemes, turbulence models*

* these sections will be covered if time permits.

Learning Outcomes

At the end of this course, students should be able to:

- Apply control volume analysis to calculate flow fields, flow rates, and fluid forces.
- Predict qualitative characteristics of a variety of flows based on experience with the behavior of flows in simpler geometries.
- Identify appropriate approximations based on physical intuition and order of magnitude estimates to develop tractable models for fluid flow systems.
- Employ separation of variables, similarity, superposition, and numerical solution methods to solve PDEs for laminar flows.
- Explain the physical and mathematical basis of boundary layer theory, irrotational flow theory, and linear stability theory, and apply these concepts to understand flow development.
- Recognize when micro and nanoscale fluid flow models are needed and choose the appropriate tools to predict flow rates in these cases.
- Discuss basic numerical techniques used to solve the Navier-Stokes equations.

Course Notes

Lecture slides will be posted on the OWL website, but most of the lecture notes will be written on the board in class and will not be posted. Students are responsible for all material covered in lectures, tutorials, labs, and the corresponding chapters of the textbook.

Units

SI units will be the primary units used in lectures. Students are expected to be able to solve problems formulated in English/British units by first converting all parameters into SI units.

Repeating All Components of the Course

In accordance with Senate and Faculty Policy, students who have failed an Engineering course (i.e. <50%) must repeat all components of the course. No special permissions will be granted enabling a student to retain laboratory, assignment, or test marks from previous years. Previously completed assignments, projects, and laboratories cannot be resubmitted by the student for grading in subsequent years.

Use of English

In accordance with Senate and Faculty Policy, students may be penalized up to 10% of the marks on all assignments, tests, and examinations for the improper use of English. Additionally, poorly written work with the exception of the final examination may be returned without grading. If resubmission of the work is permitted, it may be graded with marks deducted for poor English and/or late submission.

Attendance

Attendance in all lectures is mandatory and will be monitored. Any student who, in the opinion of the instructor, is absent too frequently from class or tutorial periods will be granted a mark of zero for course participation and will be reported to the Dean (after due warning has been given). On the recommendation of the Department concerned, and with the permission of the Dean, the student will be debarred from taking the final exam in the course.

Graded Work

All marked materials (except for the final examination) will be returned during lectures. Students are required to pick up and archive their marked materials. It is not the responsibility of the instructor nor that of the teaching assistants to archive or store unclaimed marked exams, assignments, or reports.

Cheating

University policy states that cheating is a scholastic offence. The commission of a scholastic offence is attended by academic penalties, which might include expulsion from the program. If you are caught cheating, there will be no second warning (see Scholastic Offence Policy in the Western Academic Calendar).

Plagiarism

Students must write their essays and assignments in their own words. Whenever students take an idea, or a passage from another author, they must acknowledge their debt both by using quotation marks where appropriate and by proper referencing such as footnotes or citations. Plagiarism is a major academic offence (see Scholastic Offence Policy in the Western Academic Calendar).

The University of Western Ontario has software for plagiarism checking. Students may be required to submit their work in electronic form for plagiarism checking.

Sickness and Other Problems

Students should immediately consult with the instructor or Associate Chair (graduate) if they have problems that could affect their performance in the course. The student should seek advice from the Instructor or Associate Chair (graduate) regarding how best to deal with the problem. Failure to notify the Instructor or the Associate Chair (graduate) immediately (or as soon as possible thereafter) will have a negative effect on any appeal.

SSD

Please contact the course instructor if you require material in an alternative format or if any other arrangements can make this course more accessible to you. You may also wish to contact Services for Students with Disabilities (SSD) at 661-2111 x 82147 for any specific question regarding an accommodation.

Notices

Students are responsible for regularly checking their Western email and notices posted on the OWL course site.

Consultation

Students are encouraged to ask questions during lectures. Office hours will be arranged for students to see the instructor. Other individual consultation can be arranged by appointment with the instructor.

Email policy

Students wishing to communicate with the instructor by email should include “CBE9155” at the start of the subject line. Email responses should not be expected in less than 2 business days.