Mech 380: Fluid Dynamics

Winter, 2018-19

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Lectures: MWF 8:00, Dempster 310

Office hours: M 9:00–10:30

TAs: Ali Kheirabadi (alickubc@mail.ubc.ca) and Akhil Jayasankar (akhiljay@mail.ubc.ca)

Tutorials: Section T2A: T 2:00, MacLeod 214
Section T2B: F 9:00, MacLeod 254

Feel free to contact any of us with questions, either in person or by email. It may not be practical to answer a given question in an email; for questions which would require more than 5–10 minutes of typing to answer, we reserve the right to suggest in-person meetings instead. To make that time count, it is helpful if your question includes the following details:

- What's the problem? (image is great!)
- What confuses you?
- What do you think is relevant?
- What have you tried? (again, an image helps a lot!)

Purpose of the course. Mech 222/280 focused on basic analysis techniques and solving internal, incompressible flow problems. Mech 380 applies those same analysis techniques to solve problems in external flow (for example, planes, trains, and automobiles) and compressible flow (for example, planes, explosions, jet and rocket engines, and gas pipelines).

The overall goal of the course is for each student to develop the ability and the confidence to solve relatively challenging, open-ended problems in fluid mechanics. Reaching this goal will require you to understand the underlying physical principles of fluid mechanics and to be able to manipulate the basic equations that mathematically describe these principles. These skills are necessary, but not sufficient, for good problem solving ability. In addition, you will need to learn how to work your way from a description of a complex flow problem to determining the applicable physical principles to grinding numbers to come up with an answer. To address this issue, we will spend a significant amount of time and effort during the term specifically on problem solving techniques and exercises.

Prerequisites: Differential equations, thermodynamics, and introductory fluid mechanics. The actual list of acceptable courses is a complicated mess; if there's any doubt about your eligibility, I'll be in touch with you.

Textbook: *Fluid Mechanics: Fundamentals and Applications,* by Yunus Çengel and John Cimbala. Most of you will already have a copy of this from Mech 222/280. The bookstore may be stocking a newer edition than you have. There aren't any really significant differences between editions (a place or two where sections have merged or split, plus more problems), so it doesn't matter which edition you have.

Learning activities: Learning is not a spectator sport. Fundamentally, the responsibility to learn is yours and yours alone. For learning to happen in any course, you as students must take an active role in the process. I expect that you will come to class prepared and ready to learn, which requires you to *read* and to *study* the assigned reading before you come to class. Being prepared for class enables you to construct a knowledge base on which subsequent learning rests.

What does it mean to be prepared for class?

- Complete assigned readings. This does *not* mean simply passing your eyes over the page, but actively trying to understand the material in the readings. When there are things in the reading that you don't understand, you should try to formulate, as explicitly as possible, questions that will move you towards full understanding. Some readings will also have online reading quizzes associated with them, timed so that the quiz is due before in-class discussion of the material covered by the readings begins.
- Complete online problem sets. The course Canvas site includes weekly problem sets. The problems in these assignments are of two types: quantitative questions that require simple calculations for situations where it is reasonably clear which concepts are applicable, and conceptual questions that will require you to apply basic concepts qualitatively.

The overall goal in forcing you to actively prepare for class is to shift the learning of the simplest material outside the classroom so that class time can be spent on higher-level learning. In comparison, traditional lectures with students who haven't prepared well for class succeed mostly in getting across the simple material in class, leaving students to digest the complex stuff on their own.

Marking scheme: In addition to the reading quizzes and problem sets, the course will also include online quizzes, a midtem, and a final. The quizzes will include both quantitative and conceptual questions, which will be somewhat more complex than the problem sets. The midterm and final will have problems that are different in nature than the quizzes: they will aimed at assessing your ability to apply what you have learned about fluid mechanics to solve problems that don't follow standard textbook problem templates (the tutorial problems will give you practice with this sort of problem).

Activity	How many?	Weight (passed exams)	Weight (failed exams)
Reading Quizzes	≈ 5	4%	—
Problem Sets	≈ 10	4%	—
Quizzes	≈ 5	7%	—
Midterm		35%	35 / 85
Final		50%	50 / 85

Note that you must pass the midterm and final combined (last column of the table) for other parts of the course assessment to count towards your course mark. Also, in each of the three online assessment categories, your mark will be based on the best $N-1$ out of N (that is, the lowest mark will be dropped).

Course Outline

1. Review of second-year fluids concepts
2. The Navier-Stokes Equations
   (a) From control volume analysis to differential equations for fluid flow
   (b) Relating the math in the Navier-Stokes equations to flow physics
   (c) Simple laminar flows
3. Viscous effects in external flows without pressure gradients
   (a) Why boundary layers (BL's) are thin (Rayleigh's problem)
   (b) Physical reasoning and scaling for BL's
   (c) Solving the Navier-Stokes equations for the case of a boundary layer
   (d) Laminar BL velocity profile, thickness, and skin friction
   (e) Turbulent BL velocity profile, thickness, and skin friction
4. Realistic external flows and separation
   (a) Why do streamlines look the way they do?
   (b) Inviscid flow and lift
   (c) What is flow separation, and why does it occur?
   (d) Velocity profiles near separation

(e) Predicting separation

(f) Drag of non-streamlined objects

5. Compressible flow

   (a) Sound speed, Mach number, and isentropic variations of thermodynamic properties

   (b) Isentropic nozzle flow

   (c) Nozzle flow with normal shock waves

   (d) Compressible flow in long pipes with heating or friction

6. Review of Mech 380

Learning Objectives

The low-level objectives are annotated with the relevant section of the outline.

After completing Mech 380, students will be able to:

- Correctly simplify the Navier-Stokes equations on the basis of assumptions about flow physics.
  - Explain the physical meaning of each term in the incompressible Navier-Stokes equations. (2b)
  - Explain the mathematical implications of common physical flow assumptions, including incompressible flow, inviscid flow, and fully-developed flow. (2b)
  - Determine when it is appropriate to neglect the velocity or the variation in one or more variables in a coordinate direction. (2b, 2c)
- Solve simple laminar flow problems analytically.
  - Remove appropriate terms from the Navier-Stokes equations and solve the resulting simplified equations. (2c)
  - Interpret the physical results of solving the Navier-Stokes equations, in terms of the velocity and pressure distributions, and quantities like skin friction and drag. (2c)
- Understand mechanisms for growth of laminar and turbulent boundary layers, and be able to relate boundary layer properties to drag
  - Describe why viscous effects are normally limited to a thin region near an object. (3a)
  - State the order of magnitude of velocity components and derivatives in a boundary layer, and use this information to eliminate negligible terms in the Navier-Stokes equations. (3b)
  - Sketch approximate laminar and turbulent boundary layer velocity profiles. (3c, 3d, 3e)

  - Compute boundary layer thickness, skin friction, and drag for both laminar and turbulent cases. (3d, 3e)
  - Explain why drag is higher for streamlined bodies when the boundary layer is turbulent rather than laminar. (3d, 3e)

- Have some intuitive understanding of how the pressure and velocity fields around an object depend on its shape for inviscid flow.
  - Describe the relationship between pressure and streamline curvature. (4a)
  - Use Bernoulli's equation to find pressure from velocity in inviscid flow solutions.
  - Use lift coefficient data to determine body forces. (4b)

- Understand why boundary layer separation occurs, and the effect separation has on drag for non-streamlined bodies.
  - Define flow separation. (4c)
  - Identify flow and geometric features that influence separation. (4c)
  - Relate body shape and/or pressure distribution to boundary layer separation. (4c)
  - Describe why a laminar boundary layer is more prone to separate than a turbulent BL. (4c, 4d)
  - Explain why drag is higher for blunt bodies when the boundary layer is laminar rather than turbulent. (4c, 4d)
  - Use drag coefficient data to compute body forces and moments. (4f)

- Have an intuitive understanding of the differences between incompressible and compressible flow physics, and be able to apply this to solve problems in compressible flow.
  - Understand why pressure, density, and temperature all vary with velocity for compressible flow. (5a)
  - State the assumptions for compressible, isentropic flow. (5a)
  - Relate pressure, density, and temperature to Mach number for isentropic flow. (5a)
  - Understand the basic differences between compressible and incompressible flow through a converging-diverging nozzle. (5b)
  - Solve isentropic converging-diverging nozzle flow problems. (5b)
  - Explain how and why shocks might form in a supersonic nozzle. (5c)
  - Solve converging-diverging nozzle flow problems involving shocks. (5c)

Frequently Asked Questions and Other General Comments

1. *Your notes should have more explanatory text in them!* No, they shouldn't. They're meant as a framework for you to organize your notes around, so they don't contain the entire soundtrack of the lectures. They're notes, not a textbook.

2. *The homework/quiz questions should be more like the midterm and final exam questions.* What I'm trying to assess with the homeworks/quizzes and exams are two fundamentally different things. The homeworks and quizzes are intended to assess whether you can manipulate the basic equations and concepts in contexts that are pretty tightly defined, so that it's relatively easy to identify which equations / concepts are relevant. That's an important skill, obviously, but not the only important skill that I try to assess. The midterm and final are designed with the goal of assessing whether you can apply the basic equations and concepts in new contexts and to problems where thought is often required to decide which ones apply. The tutorial questions are much more similar in flavor to exam questions than the homework/quiz questions are; in fact, many of the tutorial questions are old exam questions. Accordingly, it's to your advantage to try to work through the tutorial questions yourself (alone or with a study group) before going to the tutorial, as you're much more likely to learn something from the question if you grapple with it some on your own before seeing someone demonstrate how to solve it.

3. *Why don't you put solutions for all the tutorial questions on Connect?* Some of the tutorial questions I deliberately don't post solutions for because there is, in my opinion, more than one reasonable approach, and no clear best choice. If I provide a single solution, students who have taken some other reasonable approach will conclude (incorrectly) that their approach was wrong, regardless of what disclaimers I put on the solutions.

4. *What advice would students from previous years pass on about the course?* I have actually asked this on end-of-term evaluations in the past. Answers that appeared frequently were:

   (a) Start on the online assignments early.

   (b) Attend class. [Really, they said that, not me...]

   (c) Do the assigned readings in advance.

   (d) Consider joining / forming a study group.

UBC Policy on Academic Honesty

UBC's policy on Academic Honesty and Standards says, in part:

> Academic honesty is essential to the continued functioning of the University of British Columbia as an institution of higher learning and research. All UBC students are expected to behave as honest and responsible members of an academic community. Breach of those expectations or failure to follow the appropriate policies, principles, rules, and guidelines of the University with respect to academic honesty may result in disciplinary action.

In the context of this course, I expect that your work on reading quizzes, post-quizzes and exams will be completely your own. For the homework assignments, I encourage you to work together with classmates, with the understanding that you are responsible for learning the content covered by those assignments.

For your reference, here are links to this policy and the procedures in place to administer it.

Generally Useful Information

Accommodation for Students with Disabilities

Students with disabilities that may affect their learning, or my assessment of their learning, should contact the Centre for Accessibility as soon as possible. Also, see the relevant section of the Calendar.

UBC Policy on Sexual Assault and Other Sexual Misconduct

A reminder of the obvious: UBC does not, nor should it, tolerate sexual assault or other sexual misconduct, as described in detail in UBC Policy 131. Also, UBC provides resources for the prevention of sexu

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Mental Health Resources

University can be a stressful time for students, especially when life circumstances outside the university complicate matters further. Should you have need of their assistance, UBC Counselling Services provides a variety of resources to help students cope with mental health issues.

Other Relevant UBC Policies

- Policy on Academic Freedom
- Freedom from Harassment and Discrimination
- Religious Observances