Climate/Space 551 - Advanced Fluid Dynamics Fall 2019

Time: MWF 10:30am - 12:30pm

Place: CSRB 2238

Textbook: There is no required textbook. I will distribute draft notes online ahead of each lecture.

Course Description:

CLIM/SPAC 551 covers the principles of fluid dynamics. The purpose of the course is to provide you with the tools and intuition you need to understand the fundamentals of fluid dynamics. Fluid dynamics is an old subject that has fascinated some of the best mathematicians, physicists and engineers for centuries. Given this history, understanding the fundamentals of fluid dynamics can be difficult, but we can understand much about the physical world using the basic tools of ordinary and partial differential equations.

We will meet for an average of 4 hours per week, broken into lectures, problem solving sets, individual meetings and (hopefully) laboratory demonstrations. Lectures will typically run from 10:30 am to 12:30 pm on Wednesdays and Fridays in 2238 SRB. Monday lecture times will often be used for make-up lectures, problem sessions, math tutorials and, when needed, additional office hours.

Accommodation for disabilities:

The University of Michigan is committed to providing equal opportunity for participation in all programs, services and activities. If you think you need an accommodation for a disability, please let us know at your earliest convenience. Some aspects of this course, such as the assignments, in-class activities, or the way we teach may be modified to facilitate your participation and progress. Request for accommodations by persons with disabilities may be made by contacting the Services for Students with Disabilities (SSD) Office located at G664 Haven Hall. The SSD phone number is 734-763-3000. As soon as you make us aware of your needs, we can work with you, the Office of Services for Students with Disabilities, or the Adaptive Technologies Computing Site to help determine appropriate accommodations. We will treat any information about your disability with the utmost discretion.

Student Mental Health and Well-being:

University of Michigan is committed to advancing the mental health and wellbeing of its students. If you or someone you know is feeling overwhelmed, depressed, and/or in need of support, services are available. For help, contact **Counseling and Psychological Services (CAPS)** at (734) 764-8312 and https://caps.umich.edu/ during and after hours, on weekends and holidays, or through its counselors physically located in schools on both North and Central Campus. You may also consult **University Health Service (UHS)** at (734) 764-8320 and https://www.uhs.umich.edu/mentalhealthsvcs, or for alcohol or drug concerns, see www.uhs.umich.edu/aodresources. For a listing of other mental health resources available on and off campus, visit: http://umich.edu/~mhealth/.

Attendance, Participation, and Universal Learning:

Attendance and participation are highly important in this class. Please notify me of absences due to religious observance or University sporting events as soon as you can. I am committed to the principle of universal learning. This means that our classroom, our virtual spaces, our practices, and our interactions will be as inclusive as possible. Mutual respect, civility, and the ability to listen and observe others carefully are crucial to universal learning. Active, thoughtful, and respectful participation in all aspects of the course will make our time together as productive and engaging as possible.

Climate and Space Sciences and Engineering Diversity Statement:

The teaching and research mission of the Department of Climate and Space Sciences and Engineering is enhanced by learning from and working with a diverse intellectual community within an environment of full inclusion – a supportive and welcoming workplace that values all individuals and their perspectives, contributions and ideas. We welcome members with diverse global experiences across all forms of dimensions and intersections, including race, ethnicity and national origins, gender and gender identity, sexuality, class and religion. We are especially committed to increasing the representation of those populations that are underrepresented in the Earth and Space Sciences. We are committed to attracting, recruiting and retaining a diverse population of faculty, undergraduate and graduate students, and staff. We work to identify and promote practices and structures that support inclusion, safety and diversity's development in our department's work through programs supported by our Diversity Ally, mentoring activities and our student organizations.

Office hours:

I will try to set aside time when most students are free to stop by my office. These meetings will be opportunities to answer questions, address problems or work personally with each of you material that is challenging. We have 20 people in the class, which is close to double what we have had in the past. This introduces some new challenges in working individually with students. In addition to meeting with each of you individually, you are free to drop by my office anytime you have a question about the course or fluids in general.

Course grades:

Course grades will consist of homework (some will be done in and some will be done out of class) and 3 exams with the following distribution:

Homework: 70%
Exam 1: 10%
Exam 2: 10%
Exam 3: 10%

Tentative learning objectives:

- Be able to apply dimensional analysis to problems to make order of magnitude estimates, simplify differential equations and determine units of quantities, including integrals of distributions functions.
- Be able to use dimensional analysis to determine geometrically and dynamically similar flow regimes and the non-dimensional numbers that govern these types of regimes. Examples considered in class will include the Reynolds and Rossby numbers, but students should be able to apply dimensional analysis to new problems and situations.
- Be able to write down and provide a physical explanation for each of the terms in the equations describing conservation of mass and linear-momentum for a fluid.
- Be able to explain the difference between Eulerian and Lagrangian reference frames and be able to write down the material derivative of scalar and vector quantities.
- Be able to linearize differential equations and use the linearized equations to obtain dispersion relations and/or growth rates of instabilities. Examples considered in class may vary, but could include sound waves, gravity waves, Rossby waves along with Rayleigh-Taylor instability, Kelvin-Helmholtz instability. Students should be able to apply the linearization procedure to new problems beyond those covered in class.
- Be able to explain, using words and equations, the difference between stable and unstable flow.
- Be able to explain, using words and equations, the difference between the phase and group speed of waves.
- Be able to write down equations describing the Coriolis and Centrifugal forces and explain the effect of these forces using mathematical and physical arguments.

Collaboration policy:

The engineering honor code is in effect. I encourage you to work together on problem sets. You are free to ask more senior students for advice or help, but the work you turn in must be your own and you are required to understand everything you turn in.

Homework:

Homework should show all steps in calculations. You are allowed to upload solutions to Canvas as a pdf, but please make sure work is legible. If you use Maple/Mathematica/Matlab/Python etc, please indicate this. All code, including Maple/Mathematica should be included as an appendix to the assignment or included online as an accessible Jupyter notebook. All work should be legibly written using ample space and exposition to allow myself and the grader to follow your train of thought. You are encouraged, but not required to use LaTex or other software to help prepare homework. Penalty points will be assessed on these issues:

◦ Illegible work will be penalized based on how much we can decipher

◦ Late homework will be penalized one letter grade per day late until the assignment is returned. After the assignment is returned we will not accept late assignments. If an emergency compels you to turn in an assignment late or miss significant class time please let me know as soon as possible and we can work together to come up with a plan.

◦ Grading of each homework or exam problem will be converted to a numerical 10-point nominal scale.

Draft rubric giving the meanings of the points:

8-10: Student solved the problem with no conceptual or quantitative errors. Written solutions included exposition explaining physical reasoning and stepping through mathematical and physical steps. Here the student has mastered both the problem and the exposition. This corresponds to the range of A to A+.

7: A complete and correct treatment of the problem, but steps or logic connecting steps is missing in some places. Here the student is beginning to demonstrate that they can solve the problem, but more work is needed to establish a narrative explaining to readers how all of the steps necessary for the solution fit together. A score of 7 will be an A- in the final grading.

5-6: Nearly correct work deficient in various minor details. This can include some algebraic mishaps or conceptual misunderstandings. Here the student has demonstrated that they grasp the fundamental concepts, but still need more work in applying the concepts all the way through. This will correspond to a B+ grade.

3-4: Work that is on the right path, but has one or more major errors or conceptual misunderstandings. This could be work that successfully identifies and applies the correct formulae and *some* of the concepts, but fails to accomplish all of the necessary mathematical or conceptual reasoning. Here the student has demonstrated that they grasp *some* of the fundamental concepts, but there is still some confusion about one or more concepts. This will correspond to a B grade.

2: Work that shows the ability to identify relevant formulae or concepts, but not to apply them to problems or work that fails to adequately set up and define the problem. Here the student has not demonstrated that they fully grasp the fundamental concepts or cannot translate the concepts to the problem being assessed. More practice is needed to ensure students can both appreciate the concepts and apply the concepts. This will correspond to a B- or lower grade in the final grading.

1: Work that shows an absence of understanding of relevant concepts. Here the student has some serious misconceptions or gaps in knowledge that are preventing them from successful completing problems. This might indicate gaps in prior preparation that we need to urgently address so that the student can be successful. This will correspond to a C+

0: No work or plagiarized work. This indicates that the student has made little or no effort to solve the problems. Suspicion of plagiarism will be reported to academic integrity council.

Grades are meant to provide you with an assessment of how well you understand the problem and to point out weaknesses or deficiencies. Don't be alarmed if your grade on one or more homework assignments or exams is lower than you expected or hoped. Instead, setup an appointment to meet with me so that we can discuss ways to improve any weaknesses.

The rough outline of the class is:
Part 1: Fundamentals

A. Mechanics of particles and conservation laws
- Lagrangian and Newtonian mechanics of particles and conservation laws
- Introduction to the mechanics of continuous materials: Lagrangian and Eulerian coordinates, labels and mass conservation
- Equations of motion for ideal and perfect fluids

B. - Connection between statistical mechanics of particles and fluid mechanics (review of distribution functions)
- The equations of ideal and perfect fluids derived by averaging the behavior of many particles
- A brief review of equilibrium and non-equilibrium statistical mechanics
- Viscosity for an ideal gas computed using a simple thought experiment

C. Scalars, Vectors and Tensors
- Geometric interpretation of scalars, vectors and tensors
- How to think about (and transform) vectors and tensors
- Equations of motion deduced a third time, this time just using integrals over volume

Part 2: Dimensional Analysis and Similarity

A. How to apply dimensional analysis and why it is useful
- Dimensional analysis and the fine art of not solving differential equations
- How to estimate the magnitude of terms in an equation
- How to make systematic approximations by discarding small terms

B. Application of dimensional analysis to the equations of fluid motion
- Reynolds number and Prandlt Number

- Linearization, perturbation and asymptotic approximations
- Linearization and perturbation analysis sometimes fails: hints about singular perturbation theory
- Some solutions for high viscosity (laminar) flows
- Some solutions for flow around objects at different Reynolds number
- Mach number: when is a fluid really incompressible?

Part 3: Rotating flow on a sphere
- Coriolis force and centrifugal force
- Dimensional analysis and a new dimensionless number: the Rossby number
- Vorticity and potential vorticity
- Taylor columns and Taylor-Proudman theory
- Conservation of angular momentum in a rotating fluid re-revisited
- Basics of atmospheric and oceanic circulation

Part 4: Waves
- Linearization of equations reviewed
- Example 1: Sound waves
- Example 2: Gravity waves
- Example 3: Internal waves
- Dispersion relations: what is the difference between a group speed and phase speed
- Example 4: Rossby waves
- Example 5: Kelvin waves
- Example 6: Alfven waves
- General solutions of waves

Part 5: Instabilities
- Example 1: Rayleigh-Taylor Instability and spiral galaxies
- Example 2: Kelvin-Helmholtz instability and waves
- Linearization and expansion in normal modes
- Example 3: Thermal convection--Is Europa really an icy shell that convects?
- Example 4: Hints about the onset of turbulence

Part 6: Turbulence
- Simple route to turbulence using Landau period doubling theory
- Some experimental results
- Kolmogorov spectrum of turbulence
- Eddy viscosity revisited
- General (lack of) theory for closure relationships and why turbulence is such a thorny problem

Part 7: Special topics

TBD given enough time