AE 311 – Incompressible Flow

Laura Villafañe

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General Information

Instructor:
Laura Villafañe

Office Hours & Location
Monday 3-4 pm, 319n Talbot Lab

Teaching Assistants
Paul Poovakulam, Ilia Kheirkhah, Tuhin Bandopadhyay

Office Hours & Location
Thursday, 4-5:30pm, 106B3 Engineering Hall

Lectures
MWF 10:00-10:50 pm, 3031 Campus Instructional Facility.

Office Hours

Start date: 2nd week of classes (Thursday Sept 4). *No office hours during Fall break,*

You may walk-in to any office hour session that suits you. Bring to office hours any question you might have about the course material. You can also use office hours to ask clarifications about homework, or to get help with specific parts of a problem that you have doubts on how to approach. If requested by a group of people, we can dedicate specific office hours to revisit parts of the course material.

Online Course Platforms

We will use two online platforms: Canvas as the central course website for all communications, discussions, and as course material repository; Gradescope for submission of all assignments. Details below:

Canvas - course website. *You are automatically enrolled to Canvas if registered for this course*

- All course materials including handouts, lecture slides, supplemental material, problem sets and their solutions, quiz links, and any other material shared will be hosted in Canvas. Course content materials will be posted in Canvas section **Modules**. Course information, guidelines, syllabus and any document related to management and logistics as needed will be available in Canvas section S**yllabus.**
- All written communications will use Canvas, including:
  - ALL private communications with instructor/TAs will use **Canvas mail** (see **Inbox** in Canvas left panel). Course emails sent to instructor email address (outside Canvas) will not be answered.
  - Public announcements will be posted under **Announcements.**
  - Open questions/discussions regarding course material or homework will be hosted in in section **Discussions**. You are encouraged to create discussions and raise public questions about concepts, homework or any other related topic you think might be interesting for all (including cool applications or news, etc). You are also highly encouraged to answer such questions from your peers. For those that find this scary you can post anonymously. The instructor and TAs will moderate discussions and answer questions as timely as possible. Questions regarding assignments must respect certain guidelines (see Homework section below).

  Turnaround times: expect responses to Canvas questions within 24-48 hours Monday through Friday. Responses will generally be faster than that, but it is not a norm.

Gradescope – submission portal *You are automatically enrolled if registered for this course*
All homework, quizzes and projects must be submitted in Gradescope unless different instructions are given explicitly in the body of an specific assignment. Gradescope can be accessed within Canvas, but not only.

Course Description and Goals:

Synopsis. Moving fluids are present on every aspect of our lives. As aerospace engineers, an evident motivation to learn fluid dynamics is to understand how "air flows" around bodies with important engineering goals like predicting lift and drag or designing engineering systems relying on moving air. Fluid dynamics gives us the tools to solve aerodynamic problems, but not only; these tools serve to understand and model the dynamics of all fluids, including natural flows (atmospheric phenomena, river and ocean dynamics, etc), biological flows, and all those flows we rely on for our daily activities (domestic water, ventilation systems, gas and cooling loops within our car, and many more).

This course will start with the fundamentals of fluid motion, to then focus on the dynamics of a specific type of fluid, air, and on how the interaction of moving air with surfaces enables flight. We will progress through question like: What defines a fluid? What are the equations that govern the motion of a fluid and how amenable are these equations to analytical solutions? What assumptions can we make in different contexts, how do those simplifications allow approximating the flow behavior, and how good are those approximations for engineering solutions? We will address all these questions primarily for air moving relatively slow when compared to the speed of sound, this is in the incompressible regime.

Learning Goals. At the end of this course, you will be able to:

- Describe fluid motion both qualitatively and quantitatively, with a full understanding of the origin of the fluid equations of motion and the physical significance of the different terms in the equations.
- Reduce fluid problems to a set of known and unknown variables and a set of equations that provide a closed solution.
- Differentiate between exact solutions and approximations and know when certain assumptions are appropriate to the specific engineering goal.
- Make use of different problem-solving skills to solve a wide variety of engineering problems: approach complex or novel problems, iterative solving strategies, find alternative paths.
- Explain the origin of aerodynamic forces and know how to calculate their value
- Estimate the aerodynamic performance of two-dimensional and three-dimensional bodies, explain the role of viscous effects, and the reach of inviscid theories.

In a nutshell, you will have a clear perspective on the What, Why and How of incompressible flows: *What* are incompressible flows?, *Why* are they important to us? *How* do we solve incompressible flow problems?

Course Prerequisites, Structure, Materials, and Expectations:

Course Prerequisites: MATH 241, AE202 (or concurrent)

Course background that we will use in this course includes thermodynamics, tensor calculus and algebra, statis, basic coding.

Structure and content: This is a **3 credit hour** course, divided in the following modules.

Modules	Reference Text's section
1. Introduction	1.1 - 1.4, 1.9 - 1.11, 2.2
2. Governing Equations	2.3 - 2.6, 2.9 - 2.12, 3.2 - 3.5
3. Potential Flow Theory	2.13 – 2.16, 3.7 – 3.18, 1.5 - 1.6
4. Inviscid Incompressible Flow Over Airfoils	4.1 – 4.10
5. Inviscid Incompressible Flow Over Finite Wings	5.1 - 5.3
6. Viscous Flow	15.2 – 15.4, 16.2 – 16.3, 17.1 – 17.4, 18.2, 19.1 – 19.3

Reference Text: (Recommended, not required)

Fundamentals of Aerodynamics, 5th or 6th Edition, John D. Anderson, Jr., McGraw-Hill,2011/2016.

Certain sections of the reference text will be made available in PDF via Canvas. Hard copies are available at the University Engineering Library.

The reference text is recommended reading material but it does not substitute the course lectures. The order and context in which concepts are presented in class differs from that in the reference book.

Other useful textbooks:

General books on fluid dynamics and aerodynamics:

1. Foundations of Aerodynamics, 5th edition, A.M. Kuethe and C.-Y. Chow, Wiley, 1998.
2. Aerodynamics, Aeronautics and Flight Mechanics, 2nd edition, B.W. McCormick, Wiley, 1995.
3. Aerodynamics for Engineers, 6th edition, J.J. Bertin and R.M. Cummings, Pearson, 2014.
4. Theoretical Aerodynamics, E. Rathakrishnan, Wiley, 2013.
5. Introduction to Fluid Mechanics, 8th ed., R.W. Fox, P.J. Pritchard, and A.T. McDonald, Wiley, 2011.

With specific focus on viscous effects:

6. Viscous Fluid Flow, 3rd edition, F.M. White, McGraw Hill, 2006.

A more advanced book specific to boundary layers:

7. Boundary Layer Theory, 8th edition, H. Schlichting and K. Gersten, Springer, 2000.

The best compilation of flow images to date:

8. An Album of Fluid Motion, M. Van Dyke, Parabolic Press, 1982.- will make common references to it in class

Video Channels:

1. NSF Fluid Mechanics Series https://www.youtube.com/playlist?list=PL0EC6527BE871ABA3
2. National Committee for Fluid Mechanics Films, NCFMF http://web.mit.edu/hml/ncfmf.html
3. Gallery of Fluid Motion https://gfm.aps.org/
4. F Yeah Fluid Mechanics https://www.youtube.com/user/fyfluiddynamics

The NCFMF is a great source of knowledge by Ascher Shapiro. Videos are old in style but remain one of the best lecture series in Fluid Mechanics.

Expectations:

Student Expectations

- Be active and participate in class
- Listen and respect others
- Be comfortable asking and answering questions
- Complete all assignments
- Turn off/keep away & in silence your cell phones (unless needed for in-class activities)
- Be punctual for classes
- Discuss class concerns with TAs or instructor

Instructor/ TAs/CAs Expectations

- Be active and enthusiastic to facilitate student learning
- Listen and respect students' views
- Respond effectively to student concerns
- Grade objectively, consistently and in a timely manner
- Be prepared for class
- Accommodate differences in students' learning

Course Components, Organization and Assessment

Lectures (3/week)

The lectures will consist of in-person sessions that will use slide-based lectures and supplemental board/tablet work for example problems or as driven by student questions (please ask questions!). A pre-lecture version of the slides will be available in Canvas at the beginning of each class for you to use to make annotations if desired (not required). The post-lecture version will be uploaded after the class, and it might contain additional annotations from examples or in class questions. The post-lecture set should be used for reference of the material covered in the class, as pre- and post-slides might differ. Note these slides are used for the class delivery and are not meant as curated and narrated course notes. Related supplemental materials will also be posted to Canvas in the corresponding module. In some instances, and always with prior announcement, you will be asked to do pre-lecture reading.

In person lectures will not be recorded. Attendance will not be tracked. Students who miss lectures are strongly advised to timely check Canvas and revise the material covered on their own (using the posted materials and corresponding ref. book sections as needed). Announcements made in class will not be posted to Canvas Announcements section, but they will be reflected on the first page of the class slides. If you miss a class, check that first page for important announcements.

Course materials in Canvas will be organized in modules. The first page on each module will contain useful information for you to overview the contents: module outline, learning goals, and class progress with corresponding ref. book sections. Students have reported finding this information useful to keep up with the course progress and gain perspective on how every part is related. (Further improvements/suggestions are welcomed!)
Students are referred to the course reference text and books indicated in other resources if further interested in the topics covered in class. Please reach out to the instructor or TAs during office hours for further knowledge or clarifications.

Post-lecture quizzes:

Short post-lecture quizzes will be available in Gradescope following many of the lectures – announced in class. They are meant to reinforce concepts and help you stay up to date with the material. They also serve to identify unclear concepts so that I can address them in following lectures. They will be posted by 5pm the day of the lecture and submission will automatically close by the end of the day of the following class. No late submission or exception will be granted for a missed pos-lecture quiz. However, up to 3 missed post-lecture quizzes will not be accounted for in the final grade computation. Each missed quiz after 3 will be assigned a grade of 0 and will count towards the average quiz grade for the course. Note: quizzes will not be announced in Canvas.

Example: for a class on Monday, quiz submission will close Wednesday at 23:59, for a class on Friday submission will close on Monday at 23:59.

Homework:

Assigned: on Fridays. About 6 homework in total are to be expected, evenly distributed during the semester. HW statements will be first made available in Canvas (in the corresponding Module, chronological order) on expected predefined dates indicated in the Course Schedule provided at the end of the syllabus. Note that those may be subject to change, therefore it is your responsibility to keep track of any pertinent announcements during lectures and to check periodically for updates. Homework will be announced in class and reflected in your Canvas Calendar and under "Course Summary" in the Canvas Syllabus section too.

Due: before the end of the day (11:59 pm) one week after assignment is posted.

Drop policy: At the end of the semester, the (one) homework with the least credit will not be included in your grade calculation. This can potentially include a non-submitted homework.

Late policy: Late homework submission will be accepted up to 48 hours after the due date/time with a 25% grade penalty if within 24 hours past the deadline, and 50% grade penalty if after 24 and before 48 hours past the deadline. *No submission will be accepted after 48-hours of deadline*.

Solutions: will be posted 48 hours after the due date in Canvas. Solutions will be provided with great detail and are meant as additional course material.

Submission guidelines. Homework must be submitted in **Gradescope** as a **single PDF file**. You can find guidelines on scanning and submitting your homework on Gradescope Student Center. Unlimited submission attempts are allowed until the deadline.

Homework and project guidelines. Submissions must include all derivations, explanations, figures, data and any code that you have used to produce your solution. Detailed guidelines, quality requirements and tips for full credit are described in the separate document "Homework Guidelines" (see ***Canvas Syllabus section***). Make sure you check it as many times as needed and ensure your submission complies for full credit. You will not get full points for an assignment that does not provide sufficient information on how the solution was obtained, that cannot be understood or that lacks the code used to generate the results, even if the final answer is correct.

Each assignment turned in must be your own individual work. You are encouraged to discuss problem sets with peers, but each student should prepare and submit their own work, code, and plots. Assignments will be checked for plagiarism. If your work closely matches someone else's, it will be flagged and investigated. Submitting the work of another (person or machine) as one's own, or facilitating such a submission: 1) goes against your best interest and is a lost opportunity to learn, 2) is considered an infraction of academic integrity as outlined the Student Code of the University of Illinois at Urbana-Champaign and may be reported via the FAIR system, in addition to not given any credit.

Mini-Projects

Instead of exams, we will have two projects in this course, each with two deliverables: 1) individual work, 2) group work. Each project will take more effort and critical thinking than homework. Projects will have a component that is open-ended by design and will offer you an opportunity to dive in and extend your knowledge beyond the course material.

Each group will be formed by 4-5 students and will only upload one submission per group. Note that it need not be the case that all group members earn the same grade for the group portion of the project. In situations where it is clear that a group member (members) is (are) not contributing adequately, their grade for the group portion of the project may be less than the nominal group grade. Make sure that you are prompt in responding to meeting requests, contributing to the technical evolution and writeup/presentation of the project, etc., to ensure that you and your team all receive the same grade on the group portion.

The total project grade for each of the two projects will be a 50/50 split of the individual and group grades.

Project expected timelines:
The dates indicated below and in the Course Schedule are subject to change depending on the class evolution. If they do change it will not be by more than a week from those indicated below. Any change will be announced in class, Canvas and reflected in Gradescope.
-**Project 1** is expected to be released on **September 26.** Individual component **due date October 3**, and group component due date **October 10**.
-**Project 2** is expected to be released on **November 14** with individual component **due date on November 21,** and group component **December 5.**.

Group members: You are encouraged to start choosing your team members. The group sign-up sheets for Projects 1 and 2 are already live, can be accessed here (link is also available in *Canvas Syllabus section)*. Note the group members do not need to be the same for both projects but can if you choose to. (Note: you need to be signed in Google apps@Illinois account to access the link). You must enter the names and surnames of your group members using your full name as reflected in Banner. The spreadsheet contains two different tabs for P1 and P2. Deadlines to choose group members: **September 26** for P1, and **November 14** for P2. Past those dates, we will randomly assign students to groups. Note that if you created a group with 3-4 people it is possible that we assign 2-1 additional members.

Grading

Grading Scheme:

Homework	40 %
Post-lecture quizzes	8 %
Project 1	24 %
Project 2	28 %

All assignments will be graded on a scale 0-100. While each individual assignment might have assigned a different number of points the final score of a given assignment will be considered in percent of the total points. (Example: HW X has a total of 85 points. A student gets 80/85 points. The student will be getting a score of 94.1/100 points.) This way each HW counts equally towards the final HW grade.

Grades of 90, 80, 70, and 60 guarantee at least an A-, B-, C- and D-. The cutoffs might be lowered to account for challenging assignments, but they will not be raised.

Participation: Please contribute to the class environment by asking questions and participating in discussions! Your interaction (in class and/or Canvas) will be considered when assigning borderline grades, as it will improving performance throughout the course of the semester.

Grading assignments: Most questions on homework and project assignments will be graded for correctness of approach and final answer, with partial credit given for explaining your reasoning and your problem-solving process. Open-ended questions will be graded on effort rather than on complete correctness. To get full credit review the HW guidelines doc. Neatness and clarity of presentation will affect the grade; confusing or illegible content will be considered wrong.

Regrading Policy: Regrade of homework or project will follow this process:

- You must wait 24 hours after receiving your returned item before requesting a regrade. During this time, review the posted solutions and carefully consider what the dispute is and why you believe an error has been made. While we all are humans and make errors, unjustified regrade requests might result in lower scores after scrutiny.
- Requests should be made in Gradescope, with rationale, and within one week of returned items. After one week no dispute will be considered.
- If you and the TAs/CAs do not reach agreement, we will meet and resolve the matter.

Justified absences

Attendance will not be tracked in this course, but missing classes might correlate with justified absences that affect your ability to meet class deadlines. Read the separate document "AE 311 absences and exceptions", available in Canvas Syllabus section with guidelines on what to do to stay up to date with the course materials.

Important notes

Academic Integrity. The University of Illinois at Urbana-Champaign Student Code should also be considered as a part of this syllabus. Students should pay particular attention to Article 1, Part 4: Academic Integrity. Read the Code at the following URL: http://studentcode.illinois.edu/

Academic dishonesty may result in a failing grade. Ignorance is not an excuse for any academic dishonesty. It is your responsibility to read this policy to avoid putting yourself in a position that may result in you failing this course. Do not hesitate to ask the instructor(s) if you are ever in doubt of what constitutes plagiarism, cheating, or any other breach of academic integrity in the context of this course.

Use of Generative AI Technology Generative AI, such as OpenAI ChatGPT, Microsoft Copilot/Bing Chat, Google Gemini, and others, can answer questions and generate text, images, and code. The appropriate use of generative AI will vary from course to course. Guidelines for using generative AI in this course are as follows:

1. Do not ask AI to solve assignments or parts of them.
2. If you use AI (see permitted uses belo), document and attribute all AI contributions to your assignment, and assume full responsibility for AI contributions, ensuring the accuracy of facts and sources.

Permitted uses of generative AI in this course include:

- Shortening your own text and revising it for spelling and grammar.
- Testing and practicing your knowledge of course topics.
- Conducting basic research on course materials.
- Getting support for coding or formatting.

When using generative AI, keep a journal documenting prompts, AI responses, and your usage, or, if possible, share a link to your chat history. Your instructor may ask you to provide this documentation. Refer to the APA style guide for citing generative AI, including the text of your prompt to the AI. Remember, a generative AI conversation in and of itself is not a valid source for facts. Always work to find, verify, and cite the original source of ideas, rather than citing the AI directly. Review the University of Illinois System's Generative AI Guidance for Students. You are responsible for verifying sources and facts and attributing ideas generated by the AI. Generative AI tools sometimes invent facts and sources.

Failure to abide by these guidelines is a violation of academic integrity.

Inclusivity, respect among peers. The effectiveness of this course is dependent upon each of us to create a safe and encouraging learning environment that allows for the open exchange of ideas while also ensuring equitable opportunities and respect for all of us. Everyone is expected to help establish and maintain an environment where students, staff, and faculty can contribute without fear of personal ridicule, or intolerant or offensive language. If you witness or experience racism, discrimination, micro-aggressions, or other offensive behavior, you are encouraged to bring this to the attention of the course director if you feel comfortable. You can report these behaviors to the Bias Assessment and Response Team (BART). Based on your report, BART members will follow up and reach out to students to make sure they have the support they need to be healthy and safe. If the reported behavior also violates university policy, staff in the Office for Student Conflict Resolution may respond as well and will take appropriate action. Read the separate document "Guidelines for classroom interactions", available in Canvas in Syllabus section with expectations for our class.

Disability-Related Accommodations: To obtain disability-related academic adjustments and/or auxiliary aids, students with disabilities must contact the course instructor and the Disability Resources and Educational Services (DRES) as soon as possible. To contact DRES, you may visit 1207 S. Oak St., Champaign, call 333-4603, e-mail disability@illinois.edu or go to https://www.disability.illinois.edu. If you are concerned you have a disability-related condition that is impacting your academic progress, there are academic screening appointments available that can help diagnosis a previously undiagnosed disability. You may access these by visiting the DRES website and selecting "Request an Academic Screening".

Religious Observances: Illinois law requires the University to reasonably accommodate its students' religious beliefs, observances, and practices in regard to admissions, class attendance, and the scheduling of examinations and work requirements. You should examine this syllabus at the beginning of the semester for potential conflicts between course deadlines and any of your religious observances. If a conflict exists, you should notify your instructor of the conflict and follow the procedure at https://odos.illinois.edu/community-of-care/resources/students/religious-observances/ to request appropriate accommodations. This should be done in the first two weeks of classes.

Family Educational Rights and Privacy Act (FERPA): Any student who has suppressed their directory information pursuant to Family Educational Rights and Privacy Act (FERPA) should self-identify to the instructor to ensure protection of the privacy of their attendance in this course. See https://registrar.illinois.edu/academic-records/ferpa/ for more information on FERPA.

Extra Resources to Succeed

Counseling Center. Counseling Center services are designed to help students address many of the academic, relational, social, and emotional concerns they face. The Counseling Center provides a same-day appointment system. To schedule a same-day, confidential appointment please call 217-333-3704 any time after 7:50 a.m., Monday through Friday or go to the Counseling Center website.

Health Center. The McKinley Health Center provides medical services to students University of Illinois at Urbana-Champaign. The Health Service Fee, which is paid as part of your enrollment, provides the funds to prepay many of your health care needs. To schedule appointments please call 217-333-2700, Monday through Friday, 8 a.m. to 5 p.m. or go to the McKinley website. For ambulance or emergency situations dial: 911 (from a campus phone: 9-911).

Office of the Dean of Students. The Office of the Dean of Students implements a variety of programs and services to assist and support students in achieving academic and personal success. The Office provides important educational and developmental opportunities, serves as student advocates, empowers students to be successful, and promotes students' rights and responsibilities. For more information, please visit the Office of the Dean of Students website.

Center for Academic Resources in Engineering. The Center for Academic Resources in Engineering (CARE) enhances the learning experience for all undergraduate engineering students through academic support, enhancing collaborative learning opportunities, and providing positive influence through peer mentoring. For more information, please visit the CARE website.

Tentative Course Schedule[1]

Week #	Mon	Wed	Fri
1	Aug-25 Instruction Begins	Aug-27	Aug-29 **HW 1 Assigned**
2	Sep-01 Labor Day – No Class	Sep-03	Sep-05 **HW 1 Due**
3	Sep-08	Sep-10	Sep-12 **HW 2 Assigned**
4	Sep-15	Sep-17	Sep-19 **HW 2 Due/ HW 3 Assigned**
5	Sep-22	Sep-24	Sep-26 **HW3 Due/ P1 Individual + Group Assigned**
6	Sep-29	Oct-01	Oct-03 **P1 Individual Due**
7	Oct-06	Oct-08	Oct-10 **P1 group Due**
8	Oct-13	Oct-15	Oct-17
9	Oct-20	Oct-22	**Oct-24** **HW 4 Assigned**
10	Oct-27	Oct-29	Oct-31 **HW 4 Due/ HW 5 Assigned**
11	Nov-03	Nov-05	Nov-07 **HW 5 Due/ HW 6 Assigned**
12	Nov-10	Nov-12	Nov-14 **HW6 Due/ P2 Individual + Group Assigned**
13	Nov-17	Nov-19	Nov-21 **P1 Individual Due**
14	Nov-24 Break	Nov-26 Break	Nov-28 Holiday
15	Dec-01	Dec-03	Dec-05 **P2 Group Due**
16	Dec-08	Dec-10 Last day of instruction	

[1]Consider this a tentative schedule that will be updated during the course.

Detailed Course Outline/ learning goals

I. Introduction (Anderson, Secs. 1.1 – 1.4, 1.7 – 1.11, 2.2) (Weeks 1-2)

A. Fluid Flow Categories, Aerodynamics and flow definitions
B. Fluid-continuum approximation
C. Gas Properties and Typical Units
D. Review: Scalar and Vector Fields
E. Hydrostatic Equation, US Standard Atmosphere

Learning goals:
- Learn fundamental concepts and vocabulary in fluid dynamics
- Understand the properties that describe the motion of fluids and their units
- Develop skills to derive conservation equations, using as practical example deriving the governing equation for static problems ($\vec{V} = 0$) from an infinitesimal volume of fluid description, and use it to solve static fluid problems

II. Governing Equations (2.3 – 2.6, 2.9 – 2.12, 3.2 – 3.5) (Weeks 3-7)

A. Conservation Laws, Approaches for Formulating Equations
B. Governing Equations for a Finite Control Volume
   1. Reynolds' Transport Theorem
   2. Continuity Equation
   3. Momentum Equation
C. Governing Equations in Differential Form - Navier-Stokes Equations
   1. Continuity Equation
   2. Momentum Equation
   3. Substantial Derivative
D. Pathlines, Streaklines, Streamlines
E. Fluid Kinematics, Rotation (Vorticity), Angular deformation (Shear)
F. Bernoulli's Equation: Along a Streamline; Static, Stagnation, Dynamic Pressures; For Irrotational Flow; Pressure Coefficient

Learning goals:
- Be familiar with the origin of the fluid equations of motion, i.e. fundamental conservation laws.
- Learn to formulate equations and solve fluid problems in terms of average (bulk) and integral quantities (relate flow rates, obtain forces on an object immersed in a flow, etc) by using mass and momentum balances.
- Develop problem solving skills for a wide variety of fluid flow applications using control volume formulations
- Learn how to solve fluid properties in all points in space by understanding the governing equations that they must satisfy.
- Know how to evaluate the time variation of a given flow property as seen by a system as it travels through a flowfield. (material derivative).
- Familiarize with flow visualization concepts and be able to describe flow patterns
- Develop a robust understanding of how fluids move at a fundamental unit level, and how their deformation is related to the velocity field and the implications of fluid jargon previously introduced such as incompressible and irrotational flow (Section I.)
- Develop and practice skills to solve fluid problems where data available is mixed: some properties can be defined in space, limited info can be given at specific locations, and inputs or desired outputs might be in terms of pressure instead of velocities.

III. Potential Flow Theory (2.13 – 2.16, 3.7 – 3.18, 1.5 – 1.6) (Weeks 8-10)

A. Stream Function for 2-D Incompressible Flow
B. Velocity Potential Function for Irrotational Flow
C. Solution Strategy: Superposition
D. Elementary Flows
    1. Uniform Flow
    2. Source or Sink Flow
    3. Doublet Flow
    4. Vortex Flow
E. Integrating C_p to get C_l and C_d
F. Kutta-Joukowski Theorem
G. Viscous Flow Over a Cylinder
H. Method of Images

Learning goals:

- Learn alternative (easier) ways to solve the complete flow field in problems where viscosity and fluid vorticity are negligible. Applicable to many aerodynamic but also atmospheric problems.
- Understand the potential of the stream function and velocity potential functions to define the flow field and obtain the full flow characteristics in real applications.
- Define the four basic elementary flow solutions from which one can model every problem in potential aerodynamics
- Familiarize with the use of superposition to represent different flows, including flows over solid closed bodies.
- Practice recreating typical "every day" flows with engineering interest
- Apply the relation between pressure and velocity to derive the pressure distribution around solid bodies immersed in a uniform flow
- Learn how to obtain the forces on a body immersed in a flow due to the pressure distribution along the surface of the body
- Create connections between flow concepts such as circulation and pressure imbalance- lift: origin and applicability of one of the main theorems in aerodynamics at high Reynolds number, the Kutta Joukowski theorem
- Learn to solve potential flow problems near surfaces and use skills to estimate, among other things, FAA safety regulations for take-off and landing!
- Understand the limitations and applicability of potential flow theory and the role of viscous effects near the surface of bodies.

IV. Inviscid Incompressible Flow Over Airfoils (4.1 – 4.10) (Weeks 11-12)

A. Geometry/Nomenclature
B. Vortex Sheet
C. Kutta Condition
D. Kelvin's Circulation Theorem and the Starting Vortex
E. Thin Airfoil Theory
    1. Symmetric Airfoils
    2. Cambered Airfoils
F. Vortex Panel Method

Learning goals:

- Master aerodynamics vocabulary: airfoil nomenclature, aerodynamic characteristics and NACA designation.
- Understand the viscous mechanisms that explain the generation of circulation, and therefore lift, on a lifting body such as an airfoil: Kutta condition and Kelvin Circulation theorem.
- Assimilate and feel comfortable explaining some of the paradoxes of aerodynamics

- Understand the philosophy of using potential flow theory to estimate/predict airfoil aerodynamic performance by using vortex sheets to mimic the vorticity generated around the airfoil
- Use thin airfoil theory to simulate the flow around airfoils and derive the aerodynamic characteristics for a given airfoil geometry
- Familiarize with the applicability of thin airfoil theory to estimate airfoil performances.
- Develop skills to optimize airfoil design for specific applications and understand the benefits and drawbacks of different designs

V. Inviscid Incompressible Flow Over Finite Wings (5.1 – 5.3) (Week 13-14)

A. Introduction
B. Biot-Savart Law and Helmholtz's Vortex Theorems
C. Prandtl Lifting Line Theory
D. Elliptical Lift Distribution
E. General Lift Distribution
F. Lift Slope

Learning goals:

- Familiarize with wing nomenclature and with 3D wing aerodynamic characteristics.
- Understand the origin of 3D effects on finite wings and the differences between infinite and finite wings.
- Familiarize with the mechanisms by which 3D effects alter the aerodynamic characteristics of 3D wings, understand how they differ from the aerodynamic characteristics of 2D airfoils, and build intuition for the consequence of geometric wing modifications.
- Understand the philosophy and tools used to extrapolate the 2D potential flow analysis so that they can be extended to 3D wings within the framework of the Liftling Line Theory.
- Develop skills to predict the aerodynamic performance of 3D wings.

The depth of this last section depends on time available in the course- primer for future flow courses in the curriculum- some of this content will be advanced in Module 2)

VI. Viscous Flow (Week 14)

A. Introduction
B. Navier-Stokes Equations with exact solution: Couette Flow and Poiseuille Flow
D. Intro to Boundary Layers
E. Effects of Pressure Gradient; Flow Separation
F. Blasius Flat Plate Solution and friction coefficients

Learning goals:

- Solidify connections between prior module contents, understand the applicability and validity of the assumption that were made in the different sections and what are their implications, what is missing and how to account for it.
- Learn how simplify the equations of flow motion near surfaces when possible while keeping the important flow physics.
- Familiarize with boundary layer concepts and solutions, flow separation and how to avoid it, and laminar to turbulent transition.
- Be able to make design decisions that present compromises between laminar/turbulent based on drag minimization.
- Be able to estimate drag on common geometries using analytical solutions, empirical relations and tabulated data.