

APL361 : ADVANCED FLUID DYNAMICS (3-0-0, E-SLOT)

Department of Applied Mechanics, 2025-2026, Semester-I

Instructor:	Prof. Prateek Gupta	Time:	TWF 10-11 AM
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Course Page: <https://web.iitd.ac.in/~prgupta/teaching/AFM.html>

Office Hours: Tuesday 5 pm - 6 pm. Flexible hours by appointment only (based on availability)

References: Course content may be covered in several texts with emphasis on different topics. Primary texts for this course are,

- Panton, R L. Incompressible flows
- Kundu, K P., Cohen, I M. Fluid Mechanics
- White, F M., Viscous fluid flows
- Aris, R., Vectors, tensors and the basic equations of fluid mechanics

Other texts that maybe useful for some specific topics (an incomplete list)

- Batchelor, G K., An introduction to fluid dynamics
- Saffman, P., Vortex Dynamics

Objectives: This is an intermediate level course in fluid dynamics (incompressible flows to be specific). An advanced course of fluid dynamics (in the true sense) would essentially be a course in mathematics. Through this course, we will learn basics of analytical solution techniques of Navier-Stokes equations (advanced compared to APL106) and also some numerical techniques. Primary take-aways of this course are exposure to advanced concepts in fluid dynamics and aerodynamics as well mathematical techniques for finding approximate solutions.

Prerequisites: An undergraduate-level understanding of conservation laws, fluid mechanics, Fourier series and transforms and vector calculus. Following texts maybe referred for a review of engineering mathematics

- Advanced Engineering Mathematics - E. Kreyzig
- Partial Differential Equations - Walter Strauss

Course content as per courses of study: Derivation of Navier-Stokes (NS) equations; Boundary-conditions and Exact/Similarity solutions. General Boundary-Layer assumption; Free-shear flows; Separation and drag crisis. Low Reynolds Number flows: Stokes Flow; Oseen's Correction; Lubrication Theory. Hydrodynamic Stability Theory: Capillary Instability; Orr-Sommerfeld Equation; Squire's Theorem; Turbulence: Nature of turbulence; Averaging and scales; Reynolds decomposition and the closure problem; Kolmogorov hypotheses and microscales; Reynolds stress; eddy viscosity vs. molecular viscosity. Dynamics of turbulence; balance of kinetic energy, vorticity dynamics, scalar dispersion. Statistics; convergence of averages; correlations and probability density functions. Turbulent shear flows.

Course Outline:

Module 1 - Derivation of governing equations 3 lectures

Recap of APL106, conservation laws, mass equation, stress tensor and Newtonian fluids, incompressible flow assumption, derivation of the Navier-Stokes equations, short overview of thermodynamics, energy conservation equation

Chapters 1, 2, 3, 4, 5, and 6 in Incompressible Flow, R.L. Panton

Module 2 - Mathematics of fluid kinematics and dynamics 6 lectures

no-slip, interface, surface-tension effects, inflow, outflow boundary conditions, unsteady analytical solutions, solution methods for relevant linear PDEs, vorticity dynamics, non-dimensionalization of governing equations, Reynolds number (Re)

Chapters 6, 7, 8, 10, and 11 in Incompressible Flow, R.L. Panton

Module 3 - Low Reynolds number limit ($Re \rightarrow 0$) 4 lectures

Stokes flow, approximate governing equations, Stokes flow past a sphere, asymptotic solutions, Oseen's correction, Lubrication theory for bearing, Reynolds equation, Hele-Shaw cell

Chapters 21 and 22 in Incompressible Flow, R.L. Panton

Module 4 - High Reynolds number limit : Potential flows 3 lectures

Matched asymptotic expansion, Potential flow as outer solution of flow past a body, inviscid governing equations, Potential flow, drag and lift due to potential flows, fixing the $Re \rightarrow \infty$ substitution to account for boundary layers

Chapters 15, 16, and 18 in Incompressible Flow, R.L. Panton

Module 5 - Boundary layer theory and approximation 6 lectures

Boundary layer approximation using asymptotics, incompressible flat plate boundary layer (Blasius equation), numerical solution of Blasius equation, Falkner-Skan boundary layers, mixing layer and wakes of planar and axisymmetric bodies

Chapter 20 in Incompressible Flow, R.L. Panton

Module 6 - Hydrodynamic stability theory 8 lectures

Linearization of governing equations, Rayleigh-Plateau instability, Parallel shear-flow instability (Orr-Sommerfeld equation), numerical solution of Orr-Sommerfeld equation for simple flows, inflection point analysis and boundary layer instability, Boussinesq approximation and Rayleigh-Taylor instability, Kelvin-Helmholtz instability, Squire's theorem and transition to turbulence

Chapter 25 in Incompressible Flow, R.L. Panton

Module 7 - Hydrodynamic turbulence 10 lectures

Multiscale nature of turbulence, Reynolds averaging, Reynolds stress and turbulent diffusivity, turbulent kinetic energy equation, turbulent statistics, turbulent shear flows

Chapter 26 in Incompressible Flow, R.L. Panton

Assessment:

- Mid-term exam (30%)
- Major exam (30 %)
- Best 5 out of 7 quizzes (40 % combined weightage of best 5 quizzes).

There will be one make-up mid-term exam (in the final 1-2 weeks of the semester). There will be no make-up quizzes. No student will be allowed to sit in the make-up exam without submission of a valid medical certificate.

Course Policy:

- Please sign up for APL361, only then you will receive regular updates and announcements via moodle and emails.
- Tentative audit-pass criterion - 30%

Class Policy:

- 75% attendance in lectures is mandatory as per institute norms. Grade penalty will be awarded for short-attendance.

Academic Honesty: Lack of knowledge of the academic honesty policy is not a reasonable explanation for its violation. Each student must go through the honour code of IIT-Delhi and adhere to it.