EN1200
Fluid Mechanics

Professor: Thierry Schuller (S7) Franck Richecoeur (S6-S8)

Language of instruction: French – **Number of hours**: 36 – **ECTS**: 3

Prerequisites: Calculus and vector analysis, continuum mechanics

Period:	S6	Elective 01	February to March	IN16DE1, SEP6DE1
	S7	Elective 03	September to November	IN27DE3, FEP7DE3
	S8	Elective 08	February to March	IN28IE1, SEP8IE1

Course Objectives

Fluid mechanics is a central subject in many technological applications. It intervenes in energy conversion, oil exploration, ocean engineering, materials processing, propulsion, aeronautics and space, process engineering, biomechanics and biotechnologies, environment, meteorology, climate change, microfluidics. Its recent developments have been substantial. A number of theoretical problems have been resolved, new experimental methods have provided unique data on many flow processes, novel simulation tools have allowed considerable insights in fundamental and more applied scientific or engineering problems. In this context, a basic understanding of fluid mechanics is essential to engineers and scientists. This course provides the fundamental elements allowing an operational **understanding of central issues in this field**.

The focus is on:

- Physical understanding,
- Training in problem solving,
- Sharing our knowledge and passion for fluid mechanics and its applications.

The course includes detailed presentations of essential aspects in combination with simple experiments, computer demonstrations, fluid mechanics film projections. Problem solving workshops (PSW) are organized after each lecture to train students in tackling real life engineering problems. The midterm and final exams consist in solving practical fluid mechanics problems.

On completion of the course, students should be able to

Understand the physics of fluid flows, manipulate the balance equations of fluid dynamics, estimate forces and moments induced by fluid motion, evaluate head losses and analyze fluid flows in channels and ducts, use dimensional analysis to estimate orders of magnitude of different flow processes, understand the fundamentals of boundary layer theory, determine the characteristic scales of turbulent flows, use the Reynolds average Navier-Stokes equations to study turbulent flow problems, analyze adiabatic and isentropic flows with area change, understand the physics of shock waves, relate variables across a normal shock, examine flows in nozzles, diffusers and wind-tunnels.

Course Contents

- (1) **Introduction**. The role of fluid mechanics in current technologies. Program, objectives, organisation, staff and methods. Introduction to the study of fluid flow. Continuum concept. Various types of flows. General solution methods of fluid mechanics problems. Description of motion, material derivative, acceleration. Streamlines, trajectories and streaklines. Control volumes and transport theorems. Balance of mass. Description of multispecies mixtures.
- (2) **Balance of species and momentum**. Diffusion velocity and balance of species. General motion of a fluid particle. Rate of rotation, vorticity, rate of strain. Stresses in fluids. Relation between stress and strain rate tensors. Momentum balance equation. Euler and Navier-Stokes equations. Bernoulli's theorem.

- (3) **Balance of energy**. Balance of kinetic energy. Balance of total and internal energies. Applications of Bernoulli's theorem. Balance of mechanical energy. Incompressible flows in ducts, hydraulic machines. Practical methods for head loss estimation. Moody's diagram. Losses at singularities.
- (4) **Macroscopic balance equations**. The momentum and angular momentum theorems. Application to the determination of hydrodynamic forces and moments. Propulsion applications (jet engines an rockets).
- (5) **Dimensional analysis**. A priori estimates, fundamental dimensionless groups. The Pi-theorem and its application to the analysis of drag. Model scale testing, similarity conditions. Examples of application of similarity concepts.
- (6) **Physics of boundary layers**. Various types of shear flows. Boundary layers. A priori estimates of the laminar boundary layer thickness. Characteristic scales and the Karman integral equation. Separation and transition. The boundary layer equations for a laminar flow over a flat plate.
- (7) **Boundary layer analysis**. Boundary layer equations. Synthesis of the boundary layer equations. Solution of the Blasius problem using shooting methods. Numerical solution of the boundary layer equations (computer demonstrations). Effects of pressure gradients. Adverse gradients and flow separation.
- (8) **The physics of turbulence**. Importance of turbulence in practical applications. The nature of turbulence. Estimation of characteristic time and length scales. The Kolmogorov cascade. Statistical analysis of turbulent flows. Reynolds decomposition and Reynolds average balance equations. Introduction to the closure problem and to turbulence modeling.
- (9) **Compressible flows**. Adiabatic flows of compressible fluids. Isentropic flows of real gases. Effects of area changes. Isentropic flows of perfect gases. Isentropic flow tables.
- (10) **Shock waves**. Physics of shock waves. Visualization methods, experimental observations, formation of shock waves. Normal shock wave equations. Determination of the flow properties across a normal shock. Shock tables. Weak shock waves.
- (11) **Nozzles, diffusers, wind tunnels**. Synthesis on one-dimensional compressible flows. Flow regimes in convergent-divergent nozzles. Application to flow acceleration and wind-tunnels.
- (12) **Final exam** (3hr). Application of the balance equations to the solution of an incompressible or compressible flow problem.

Course Organization

Lectures and problem-solving workshops: 33 hr, Final exam: 3 hr

Teaching Material and Textbooks

- S. Candel (2001) Mécanique des fluides, Dunod Paris.
- S. Candel, (under the direction of) (1995) Mécanique des fluides, problèmes résolus. Dunod, Paris
- Lecture notes and problem notes

Evaluation

- Mandatory 2-hr written midterm exam, under the supervision of the course assistant, all documents allowed ; only calculators without communication medium are permitted as electronic device
- Mandatory 3-hr written final exam with all documents allowed ; only calculators without communication medium are permitted as electronic device.

Final mark = MAX(0.4xmidterm+0.6xfinal, final).