Syllabus Cursus Master's Degree in Engineering, Mechanics. Sorbonne University CMI5

Fluid Mechanics: **Fundamentals and Applications** (MF2A)

List of Teaching Units

Semester 9

Core Units

- Technoscience, ethic and society
- Dynamics and Modelling of turbulence

Fluid Mechanics

- Multiscale Hydrodynamic Phenomena
- Numerical methods for fluid mechanics
- Drops, Bubbles and co
- Diffusion, advection and the dynamo effect
- Introduction to hydrodynamical instabilities
- Flows and acoustics in fluid media
- Separeted flow/ compressive Flow

Modelling and Simulation in Hydrodynamics

- Continuum mechanics for fluids
- Porous media and suspensions
- Multiphase flows
- Numerical methods for incompressible flows
- Natural Environment Flows and Transfers
- Vortices in hydrodynamics
- Digital Project

Aerodynamics and Aero-acoustics

- Airborne Acoustics
- Fundamental aerodynamics
- Numerical methods for compressible flows
- Quantification of uncertainty
- Modelling and simulation in aeroelasticity
- Options: 2 TU (3 ECTS) in the other themes
- Digital Project

Semester 10

- Certification
- Deepening Project
- End of study internship

		Title Teaching Unit - Master Cycle -	Code	Lecture	Discussion session	Lab	SSA	Hours Attendance	Work Personal	ECTS
CMI5 S9		Technoscience, ethic and society	MU5EEG03	16	8		24	24	40-60	6 *
		Fluid Mechanics, Fundamentals and Applications (MF2A)								
		Dynamics and Modelling of turbulence	MU5MEF02	14	14			28	20-30	6
	Thematic elective teachings	**Fluids Mechanics**								
		Multiscale Hydrodynamic Phenomena	MU5MEF15	15	15			30	20-30	3
		Numerical methods for fluid mechanics	MU5MEF19	15	15			30	20-30	3
		Drops, Bubbles and co	MU5MEF17	15	15			30	20-30	3
		Diffusion, advection and the dynamo effect	MU5MEF18	15	15			30	20-30	3
		Introduction to hydrodynamical instabilities	MU5MEF19	28	2			30	20-30	3
		Flows and acoustics in fluid media	MU5MEF21	30	30			60	50-60	6
		Separeted flow/ compressive Flow	MU5MEF24	15	15			30	20-30	3
		Modelling and Simulation in Hydrodynamics								
		Continuum mechanics for fluids	MU5MEF00	20		10		30	20-30	3
		Porous media and suspensions	MU5MEF23	15	15			30	20-30	3
		Multiphase flows	MU5MEF02	40	10	10		30	50-60	6
		Numerical methods for incompressible flows	MU5MEF22							
		Natural Environment Flows and Transfers	MU5MEF04	20		12		32	20-30	3
		Vortices in hydrodynamics	MU5MEF04	13,5	13,5			27	20-30	3
		Digital Project	MU5MEF06	15			10	30	20-30	3
		Continuum mechanics for fluids	MU5MEF32	4				4	80	3

Theme Aerodynamics and Aero-acoustics								
Airborne Acoustics	MU5MEF07	20	10			30	20-30	3
Fundamental aerodynamics	MU5MEF22	19,5	19,5		4	30	20-30	3
Numerical methods for compressible flows	MU5MEF08	20	12			32	20-30	3
Quantification of uncertainty	MU5MEF04	14	14	6		30	20-30	3
Modelling and simulation in aeroelasticity	MU5MEF39	12	10	8		30	20-30	3
Options: 2 TU (3 ECTS) in the other themes							60-80	6
Digital Project	MU5MEF32	4				4	80	3
Total Common Core 3 + 6* ECTS - Total Thematic 27 ECTS - Total CMI5 S3 MF2A = 30 ECTS + 6*								

Title Teaching Unit - Master Cycle -		Code	Lecture	Discussion session	Lab	SSA	Hours Attendance	Work Personal	ECTS
CMI5 S10	TOIC /TOEFL certification	MU4LVANT				30		30-40	3*
	Deepening Project	MU5EEG04				40		50-60	3*
	Graduation internship	MU5MES03					800	80-100	30
Total CMI5 - S10 30 ECTS + 6 *									

*Units not included in the calculation of the semester average (appear in the diploma supplement

Semester 9

Technosciences, Ethic and Society

Level CMI5 - **Semester** S9 - **Credits** 6 ECTS - **Code** MU5EEG03 - Master's **mention**

Pedagogical presentation.
The objective of this course is to bring students to reflect on the social and ethical dimensions of the engineering profession. It focuses on the complex relations between society and technology, and in particular on the role of technology as a value carrier. Based on these analyses, the course then explores the ethical questions and dilemmas that engineers may encounter in the course of their work. Particular attention is paid to examining classic cases in engineering ethics, such as Three Mile Island and the Quebec Bridge. By the end of this course, students will be able to identify ethical issues raised by professional practices. They will also be reflective on their future profession. The course is taught in English.

Content of the Teaching Unit.

- Introduction
- Technical determinism and social construction. Read: T. Pinch and W. Bijker, The Social Construction of Facts and Artifacts? Presentation : (also) Robert Heilbroner, Do Machines Make History?
- Devices, systems, and their power of action on society. Read: B. Latour, Where are the Missing Masses? The Sociology of a Few Mundane Artifacts. Presentation: (also) T. Hughes, Technological Momentum.
- Techniques et valeurs. Lire : J. Wetmore, A. Technology : Reinforcing Values, Building Community. Exposé : (aussi) LangdonWinner, Do Artifacts Have Politics ? et R. Weber, Manufacturing Gender in Commercial and Military Cockpit Design.
- Complexity and uncertainty. Bring: Proposal for a dissertation Read: D. Vinck, Engineers in everyday life. Lecture : (also) JamesonWetmore, Engineering Uncertainty.
- Engineering and experimentation. Read, lecture: M. Martin and R. Schinzinger, Introduction to Engineering Ethics, pp. 77-103.
- Technical disasters. Reading and presentation : S.K.A. Pfaitteicher, Lessons amid the Rubble, pp. 36-61.
- Engineering and security. Reading and presentation : Mike Martin and Roland Schinzinger, Ethics in Engineering, pp. 117-145.
- Engineering and environment. Reading, presentation: Mike Martin and Roland Schinzinger, Ethics in Engineering, pp. 219-242.
- Nanotechnologies, génétique et robotique. Lire: Bill Joy, Why the Future Doesn't Need Us. Exposé : Interagency Working Group on Nanoscience, Engineering, and Technology, Nanotechnology : Shaping theWorld Atom by Atom.

Prerequisite. The corpus of societal and cultural opening lessons of the LECTUREI course followed since the 1st year.

Références bibliographiques. Bowen R. 2012. Engineering Innovation in Health Care : Technology, Ethics and Persons. HRGE, pp. 204-221. Collins, Harry & Trevor Pinch. 2002. The Golem at Large : What You Should Know about Technology. Cambridge University Press. Didier. Ch. 2008. Penser l'éthique des ingénieurs. Paris, PUF. Didier, C.. 2008. Les ingénieurs et l'éthique : pour un regard sociologique. Hermes Science publications. Heilbroner, Robert. 1967. Do Machines Make History? Technology and Culture, pp. 335-345. Hughes, T. 1994. Technological Momentum, in Marx, Leo & Merritt Roe Smith, Does Technology Drive History? The Dilemma of Technological Determinism. Cambridge: MIT Press, pp. 101-113. Interagency Working Group on Nanoscience, Engineering, and Technology, Nanotechnology: Shaping the World Atom by Atom, in Johnson, Deborah et Jameson Wetmore. Technology and Society: Building Our Sociotechnical Future. MIT Press Johnson, D. & Jameson W.. 2008. STS and Ethics: Implications for Engineering Ethics, in Hackett, Edward, Olga Amsterdamska, M. Lynch et J. WajLecturean, The Handbook of Science and Technology Studies. Cambridge, MIT Press, pp. 567-582. Joy, Bill. Avril 2000. Why the Future Doesn't Need Us,Wired, pp. 238-262. Latour, B. 1992. Where Are the Missing Masses? The Sociology of a Few Mundane Artifacts in Wiebe Bijker et John Law, Shaping Technology/Building Society: Studies in Socio-technical Change. Cambridge, MIT Press, pp. 225-258. Martin, Mike & Roland Schinzinger. 2005. Ethics in Engineering. McGraw-Hill. Martin, M. & Roland S.. 2010. Introduction to Engineering Ethics. New York : McGraw- Hill. Pfattaicher, S. K. A. 2010. Lessons Amid the Rubble. Johns Hopkins University Press. Pinch, Trevor & Wiebe Bijker. 1987. The Social Construction of Facts and Artifacts in Wiebe Bijker, Thomas H.,Trevor P., The Social Construction of Technological Systems.

Cambridge, MIT Press, pp. 17-50. Vinck, D. 1999. Ingénieurs au quotidien : ethnographie de l'activité de conception et d'innovation. Presses universitaires de Grenoble. Weber R.. 1997. Manufacturing Gender in Commercial and Military Cockpit Design, Science, Technology, & Human Values, pp. 235-253. Jameson. 2008. Engineering with Uncertainty: Monitoring Air Bag Performance, Science and Engineering Ethics, pp. 201-218. Jameson. 2009. Amish Technology: Reinforcing Values, Building Community in Johnson, D. et Jameson W.. Technology and Society: Building Our Sociotechnical Future. Cambridge: MIT Press. -Winner, Langdon. 1986. Do Artifacts Have Politics? The Whale and the Reactor: a Search for Limits in an Age of High Technology. University of Chicago Press, pp. 19-39.

Resources available to students. Lecture materials. List of books.

Scientific knowledge developed in the unit.

- Knowledge of the social and ethical dimensions of the engineering profession.

Skills developed in the unit.

- Improvement of the knowledge of English. Improvement of written expression.
- Forms of reasoning practiced in the social sciences.

Hourly volumes in and out of the classroom.

Total attendance hours: 24 hours divided into 16 hours of class, 8 hours of DISCUSSION SESSIONS. Personal work 40-60 hours.

Evaluation. Attendance at sessions: 20%, Presentation: 20%, Essay: 40%, Essay defence: 20%.

Teacher. C. Lecuyer

SCIENCES
SORBONNE
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Turbulence: dynamics and modelling

Level CMI5 - **Semester** S9 - **Credits** 6 ECTS - **Code** MU5MEF02 Master of Mechanics - Fluid Mechanics and Applications.

Pedagogical presentation.
The aim of this EU is to give students the necessary basis for understanding the turbulent phenomena that appear in many applications in the sectors of activity covered by the Master's speciality (part I), as well as a review of techniques for modelling turbulent flows with a view to predicting their dynamics by means of numerical simulation (part II).

Content of the Teaching Unit.
Part I: Introduction to Turbulence: Definition and Associated Equations. Statistical description of turbulent flows. Reynolds mean and averaged equations. Isotropic turbulence: definition, Kolmogorov theory, theories and self-similar solutions. Sheared turbulence. Confined flows. Turbulent boundary layer: dynamics, turbulent drag generation.

Part II: Simulation and modelling of turbulent flows: direct simulation (DNS), statistical modelling (RANS) and large scale simulation (LES). Notion of closure and classification, presentation of the usual models of order one (from 0 to 2 equations) and order two (RSM). Treatment of walls and boundary conditions. Essential notions on the construction of meshes adapted to the different models and to the different numerical constraints.

Prerequisites. Basics of fluid mechanics

Bibliographical references.
- Pope, S.B., Turbulent flows, Cambridge University Press, 2000
- Tennekes-Lumley A first introduction to turbulence The MIT press 1972

Resources available to students. Course notes

Scientific knowledge developed in the unit.
- Turbulence Modelling.

Skills developed in the unit.
- Understanding turbulence.
- To know how to set up a numerical Modelling of turbulence (choice of meshes, models).

Hourly volumes in and out of the classroom.
Total attendance hours: 28 hours divided into 14 hours LECTURE, 14 hours DISCUSSION SESSIONS. Expected personal work: 20 - 30 hrs.

Evaluation. Exams (distributed): written E1 (50%) + E2 (50%).

Teacher. Arnaud Antkowiak

Thematic

Fluids Mechanics

Multiscale Hydrodynamic Phenomena

Level CMI5 - **Semester** S9 - **Credits** 3 ECTS - **Code** MU5MEF15 Master de Mécanique - Mécanique des fluides et applications.

Pedagogical presentation.
To master the analytical tools to solve problems, mainly arising in fluid mechanics, in which widely different scales are present. To provide an advanced knowledge in incompressible fluid mechanics, through the study of analytic solutions and classical asym.

Content of the teaching unit
The method of matched asymptotic expansions is introduced, in which the ratio of scales appears as a small parameter in the equations. Examples: simple ordinary differential equations, and fluid flows with boundary layers . Low Reynolds numbers, Stokes equations, dissipation theorems, dynamics of falling bodies, Oseen approximation. HIgh Reynolds numbers: special solutions, self similar jet and wake solutions.

Pre-requisite. Basic notions of fluid mechanics

References.
Radyadour K Zeytounian, Modélisation asymptotique en mécanique des fluides newtoniens, Berlin ; Heidelberg ; Paris : Springer-Verlag, cop. 1994.

Resources available to students. Handout and course materials.

Scientific knowledge developed in the unit.
- Analytical method of resolution.
- Asymptotiques methods

Skill developped in the unit
- Master the analytical tools to solve problems.
- Applying asymptotic developments to simple cases

Hourly volumes in and out of the classroom.
Heures présentielles totales : 30 h (15 h CM et 15 h TD).
Travail personnel attendu : 30-40 h.

Evaluation. Examen écrit final.

Teacher. S. Zaleski & P.Y. Lagrée

SCIENCES
SORBONNE
UNIVERSITÉ

Numerical methods for fluid mechanics

Level CMI5 - **Semester** S9 - **Credits** 3 ECTS - **Code** MU5MEF16 Master of Mechanics - Fluid Mechanics and Applications.

Pedagogical presentation.
The objective of the course is to bring the audience to a high level of understanding of numerical fluid dynamics with unstructured meshes adjusted to the body. The course will focus mainly on finite volume and finite element methods for Navier-Stokes equations, incompressible and compressible with or without turbulence models. Mesh generation will also be discussed. The content of well-known software such as Fluent will also be analyzed. Illustrations and numerical exercises will be made with our internal open source software freefem++.

Content of the Teaching Unit.
Stokes' equations and difficulties explained on a uniform grid of finite differences. Variational formulations for the incompressible Navier-Stokes equations. Mesh generation and adaptation. A finite element approximation solver for convection-diffusion and pressure projection. A finite volume method for compressible Navier-Stokes equations. Difficulties and solutions for the k-epsilon turbulence model; wall laws and weak shape of boundary conditions.

Prerequisite. Basic knowledge of EDP, knowledge of a popular programming language.

Bibliographical references.

- https://freefem.org/

Resources available to students. Handout and course materials.

Scientific knowledge developed in the unit.

- Variational approach to the Stokes equations
- Finite volumes and finite differences.
- Weak form of boundary conditions.

Skills developed in the unit.

- Programming on FreeFem++ of the Navier Stokes equations in the studied case.
- Write the different equations and boundary conditions.

Hourly volumes in and out of the classroom.
Total attendance hours: 30 hours (15 h lectures and 15 h discussion sessions). Expected personal work: 20 - 30 hrs.

Evaluation. Final written exam.

Teacher. F. Hecht & O. Pironneau

Drops, bubbles

Level CMI5 - **Semester** S9 - **Credits** 3 ECTS - **Code** MU5MEF17 Master of Mechanics - Fluid Mechanics and Applications.

Pedagogical presentation.
The objectives of the course are as follows:

- to become familiar with surface tension phenomena that play a role in many situations of practical interest, such as detergency, coating, drop impacts, microfluidics, etc.
- manipulate simple but often subtle laws of scale to address complex problems.

Content of the Teaching Unit.
It consists of :

- or an experimental research project on soft matter physics or mobile interfaces,
- or a course on soft matter phenomena (traditional lectures and short project).

The themes of the course are as follows:

- Drops and bubbles
- Wetting: ideal wetting, complex wetting Coating process, impacts
- Interfacial instability
- Liquid sheets and bells
- Surfactants and other additives

Prerequisite. None required.

Bibliographical references.

- Zaleski S. 2001, Science and Fluid Dynamics should have more open sources , direct publication on the web.
- Gilou Agbaglah, Sébastien Delaux, Daniel Fuster, Jérome Hoepffner, Christophe Josserand, Stéphane Popinet, Pascal Ray, Ruben Scardovelli and Stéphane Zaleski 2011: Parallel simulation of multiphase flows using octree adaptivity and the volume-of-fluid method, C. R. Acad. Sci. Paris, online, doi: 10.1016/j.crme.2010.12.006. PDF of preliminary version.

Resources available to students. Handout and course materials.

Scientific knowledge developed in the unit.

- Physical phenomena in bubble mechanics
- Approaches by laws of scale

Skills developed in the unit.

- Manipulating laws of scale.
- Understanding surface phenomena.
- Performing experiments and interpreting them.

Hourly volumes in and out of the classroom.
Total attendance hours: 30 hours (15 h lectures and 15 h discussion sessions). Expected personal work: 20 - 30 hrs.

Evaluation. Final written exam.

Teacher. D. Queré & C. Baroud

Diffusion, advection and the dynamo effect

Level CMI5 - **Semester** S9 - **Credits** 3 ECTS - **Code** MU5MEF18 Master of Mechanics - Fluid Mechanics and Applications.

Pedagogical presentation.
The course has two objectives:
- on the one hand, we study at the macroscopic level the transport properties in fluids. We start with diffusion processes and continue with problems of increasing complexity: advection-diffusion of a passive scalar and then of a passive vector by a laminar or turbulent flow.
- on the other hand, we will study magnetohydrodynamics and magnetic field generation by the flow of an electrically conductive liquid (the so-called dynamo effect) and will study in particular saturation regimes where the magnetic field is no longer a passive vector. Some effects of turbulent fluctuations on the dynamics of the magnetic field will be presented (intermittence on-off and reversals of the magnetic field).

Content of the Teaching Unit.

- Diffusion equation. Self-similar solutions.
- Advection of a passive scalar. Effect of flow geometry. Taylor diffusivity.
- Advection of a passive vector. Approximation of magnetohydrodynamics.
- Feedback of the field on the flow. Alfven waves. Génération of the magnetic field by the flow of an electrically conductive fluid. Mean field effects in MHD
- Magnetic and kinetic energy, Joules power and viscous dissipation.
- Magnetic field of astrophysical objects.
- Effects of turbulent fluctuations on dynamo instability: intermittent on-off and magnetic field reversals.

Prerequisite. Basics of fluid mechanics. Introduction to hydrodynamic instabilities.

Bibliographical references.

- G I Barenblatt, “Scaling, Self similarity and Intermediate Asymptotics”, Cambridge Text in Applied Math. H.K. Moffat “Magnetic field generation in electrically conducting fluid”

Resources available to students. Handout and course materials.

Scientific knowledge developed in the unit.

- Knowledge associated with the different phenomena (advection, magneto-hydro-dynamics) and the associated modelling.
- Dissipation phenomena.

Skills developed in the unit.

- Choosing Modelling for transport phenomena.
- Analysis of the effects of turbulence.

Hourly volumes in and out of the classroom.
Total attendance hours: 30 hours (15 h lectures and 15 h discussion sessions). Expected personal work: 20 - 30 hrs.

Evaluation. Final written exam.

Teacher. F. Petrelis

Introduction to hydrodynamic instabilities

Level CMI5 - **Semester** S9 - **Credits** 3 ECTS - **Code** MU5MEF15 Master of Mechanics - Fluid Mechanics and Applications.

Pedagogical presentation.
Master the analytical tools to solve problems, mainly in fluid mechanics, in which very different scales are present. To provide advanced knowledge in incompressible fluid mechanics, through the study of analytical solutions and classical asymmetry.

Content of the Teaching Unit.
The method of asymptotic paired developments is introduced, in which the ratio of scales appears as a small parameter in the equations. Examples: simple ordinary differential equations, and fluid flows with boundary layers. Low Reynolds numbers, Stokes equations, dissipation theorems, falling-body dynamics, Oseen approximation. High Reynolds numbers: special solutions, self-similar jet and wake solutions.

Prerequisites. Basics of fluid mechanics.

Bibliographical references.

- Radyadour K Zeytounian, Asymptotic Modelling in Newtonian Fluid Mechanics, Berlin; Heidelberg; Paris: Springer-Verlag, cop. 1994.

Resources available to students. Handout and course materials.

Scientific knowledge developed in the unit.
- Asymmetrical development method.

Skills developed in the unit.
- Master the analytical tools to solve problems.
- Application to simple cases of asymptotic developments.

Hourly volumes in and out of the classroom.
Total attendance hours: 30 hours (15 h lectures and 15 h discussion sessions). Expected personal work: 20 - 30 hrs.

Evaluation. Final written exam.

Teacher. S. Zaleski & P.Y. Lagrée

SCIENCES SORBONNE UNIVERSITÉ

Flow and acoustics in fluid media

Level CMI5 - **Semester** S9 - **Credits** 6 ECTS - **Code** MU5MEF21 Master of Mechanics - Fluid Mechanics and Applications.

Pedagogical presentation.
Course Description (15 hrs): The physical principles of acoustics in fluid media are presented with emphasis on plane and guided waves, sound radiation, resonators and self-sustained oscillations. Theoretical concepts are illustrated with examples of various musical instruments and duct acoustics. A lecture is devoted to the measurement and analysis of acoustic signals.

Content of the Teaching Unit.

1. Basic equations of acoustics. Guided flat waves. Sound sources.
2. Resonators and self-sustained oscillations
3. Measurement and analysis of acoustic signals
4. Application to musical instruments and duct acoustics

Prerequisites. Mechanics of continuous media (CMI3, CMI4).

Bibliographical references.

- Antoine Chaigne, Acoustics of Musical Instruments, 2nd revised and expanded edition, October 2013.

Resources available to students. Handout and course materials, DISCUSSION SESSIONS topics,

Scientific knowledge developed in the unit.

- Wave propagation, sound radiation.

Skills developed in the unit.

- Analysis of sound signals generated by musical instruments.

Hourly volumes in and out of the classroom.
Total attendance hours: 60 hours. Expected personal work: 50-60 h.

Evaluation. Written exam.

Teacher. A. Chaigne

Separate flows: Wakes and Cavities

Level CMI5 - **Semester** S9 - **Credits** 1.5 ECTS - **Code** MU5MEF ? Master of Mechanics - Fluid Mechanics and Applications.

Pedagogical presentation.
Theoretical and experimental concepts on flows around bodies in boundary layer situations décollements massifs. These notions apply directly to single-phase flows around land vehicles (cars, trains, etc.) or two-phase flows around all hydrodynamic vehicles in supercavitation regimes (torpedoes, foils, etc.). Understanding the origin of aerodynamic forces est à the basis of strategies for flow control and is part of the context actuel de reducing energy costs in transport.

Content of the Teaching Unit.
The course begins by recalling the phenomenon of separation. It is defined and discussed in terms of Reynolds number; we will see that separation is not unique to inertial effects. We then move on to the physics of large Reynolds number flows, for which the notion of boundary layer is central. In this framework where Navier Stokes' equations are simplified, the dynamics of the boundary layer developing on a body is studied, showing the major role of the pressure gradient. However, this classical approach leads to a singularity in the solution, which makes it totally ineffective in describing the disbonding. The complete description in the vicinity of a disbond will be given by the so-called triple bridge theory. After this theoretical basis, we will discover the complexity of real flows around cylinders of various cross-sections. The mean flow and wake dynamics will be commented as a function of Reynolds number. We will understand the major role of the turbulent or laminar nature of the boundary layer downstream of the disbond and how it can affect the mean stresses and wake dynamics. Theoretical treatment of the separated flow around a plate is then discussed after first presenting the theory of potential free surface flows. Disagreement with the experiment reveals the theoretical problem of the finite size of the recirculation zone. Despite this size problem, the theory is even better adapted to cavitating flows, for which a laboratory session is planned around the cavitation tunnel of the Mechanics Unit of ENSTA.

Prerequisites. Elementary bases of the potential flow theory. Notions on shear instability. Prandtl's boundary layer.

Bibliographical references.

- http://wwwy.ensta.fr/~cadot/separated%20flow%20for%20internet/separated_flows.html

Resources available to students. Course notes

Scientific knowledge developed in the unit.

- Modelling turbulent flows (isotropic or not).
- Boundary layer in turbulence.

Skills developed in the unit.

- Manipulate the different equations of turbulence.

Hourly volumes in and out of the classroom.
Total attendance hours: 15 hours divided into 10 hours LECTURE, 5 hours DISCUSSION SESSIONS. Expected personal work: 10 - 15 hrs.

Evaluation. Oral Examination

Teacher. S. Chibbaro

SCIENCES
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Thematic

Modelling and Simulation in Hydrodynamics

SCIENCES SORBONNE UNIVERSITÉ

Modelling of continuous fluid media

Level CMI5 - **Semester** S9 - **Credits** 3 ECTS - **Code** MU5MEF00 Master of Mechanics - Fluid Mechanics and Applications.

Pedagogical presentation.

The aim of this teaching is to give students a solid foundation for tackling a wide variety of research topics, both fundamental and applied, both during their Master's course and in their post-Master's orientation. This course gives a general presentation of the laws of balance and methods for constructing laws of behaviour. It is illustrated by numerous examples and allows students to acquire fundamental knowledge for the modelling of continuous fluid media.

Content of the Teaching Unit.

Kinematic description of continuous media, convective transport, deformations; General formulation of balance laws. Classical continuous media, mixtures, media with micro-structures; Clausius-Duhem inequality; Closing of the balance laws using behavioural laws and determination of evolution equations. General methods for constructing behavioural laws; Hypothesis of the associated local state. Generalized forces and flows. Thermodynamics of irreversible processes; Notion of objectivity. Examples: fluid media, granular media, polymers, ...

Prerequisite. CMI4 "Fluids and Solids" Mechanics course or equivalent Continuous Media Mechanics course

Bibliographical references.

- P. Germain and P. Muller, Introduction à la mécanique des milieux continus, Masson, Paris, 1994.
- J. Coirier, Mécanique des milieux continus - concepts de base, Dunod, Paris, 1997
- S.R. de Groot et P. Mazur, Non equilibrium thermodynamics, Dover Publications, 1984

Resources available to students. Handout and course materials.

Scientific knowledge developed in the unit.

- Description of the kinematics and internal forces of a fluid.
- Laws of state and evolution.
- Thermodynamics of irreversible processes.

Skills developed in the unit.

- Write a complete behavioural model applied to an evolving fluid.

Hourly volumes in and out of the classroom.

Total attendance hours: 30 hours divided into 20 hours of Lecture and 10 hours of Lab. Expected personal work: 20-30 hrs.

Evaluation. Examination in two parts (/50) and (/50)

Teacher.

SCIENCES SORBONNE UNIVERSITÉ

Porous media and suspensions

Level CMI5 - **Semester** S9 - **Credits** 3 ECTS - **Code** MU5MEF23 Master of Mechanics - Fluid Mechanics and Applications.

Pedagogical presentation.

Heterogeneous media are physical media composed of two or more constituents (materials, fluids), such as a fractured rock mass, a pile of sand, a ceramic material (porous media), a suspension of pigments in a paint... Such media are characterized by two scales: the microscopic scale of heterogeneities (fracture, sand grain, suspended particle) and the macroscopic scale on which the medium is to be studied. The objective of the course is to describe the techniques allowing to take into account the microscopic characteristics in the global macroscopic Modelling of the environment, in order to build the behaviour laws of complex multi-scale environments.

Content of the Teaching Unit.

The course is structured in two parts:

- Porous media: Examples, geometrical characteristics. Macroscopic Modelling techniques: statistiques averaging methods, homogenization method with multi-scale developments for periodic media. Single-phase flows: filtration laws (Darcy, Brinkman, Forcheimer); permeability models. Non-miscible two-phase flows, application to oil-bearing rocks. Miscible two-phase flows, application to pollutants (Taylor dispersion, effective diffusion coefficients). Flow at a porous interface (Beavers & Joseph experiment).
- Suspension Dynamics: Basics in microhydrodynamics (Stokes flow, sphere motion, Stokeslet, Rotlet, Stresslet, hydrodynamic interactions, sphere doublet interactions, lubrication interactions, inter-particle forces, Brownian motion). Macroscopic modelling of suspensions (statistical techniques, balance laws, stress tensor). Sedimentation of suspensions (sedimentation rate of a sphere, of a doublet of spheres, mean sedimentation rate of a diluted suspension, approximation for non-diluted suspensions, effect of Brownian motion, attractive forces, non-Newtonian carrier fluid). Rheology of suspensions (diluted suspension of rigid spheres: Einstein viscosity, approximation for undiluted suspensions, rod suspensions, suspensions of deformable particles)

Prerequisites. Continuous media mechanics, fluid mechanics, tensor calculus

Bibliographical references.

- Bear J. Dynamics of fluids in porous media, Elsevier,1972.
- E. Sanchez-Palencia, Non homogeneous media and vibration theory, Lecture Notes in Physics 127, Springer, Berlin,1980
- Guyon E., Hulin, J.-P. & Petit L., Hydrodynamique physique, EDP/CNRS, 2001
- D. Barthes-Biesel, Microhydrodynamics and complex fluids, Ellipses, Ed.Ecole Polytechnique, 2011
- E. Guazzelli and J.F.Morris, A Physical Introduction to Suspension Dynamics, Cambridge, University Press, 2011

Resources available to students. Handout and course materials.

Scientific knowledge developed in the unit.

- Micro-macro passage methods (averaging, homogenization...).
- Models for hydro-dynamics.

Skills developed in the unit.

- Perform micro macro runs to calculate effective properties.
- Apply suspension dynamics models.

Hourly volumes in and out of the classroom.

Total attendance hours: 30 hours divided into 15 hours of lecture and 15 hours of lab. Expected personal work: 20-30 hrs.

Evaluation. Examination in two parts (/50) and (/50)

Teacher.

Multiphase flows: bubble and drop dynamics

Level CMI5 - **Semester** S9 - **Credits** 6 ECTS - **Code** MU5MEF02 Master of Mechanics - Fluid Mechanics and Applications.

Pedagogical presentation.

In nature and in industry there are many open surface flows: on a large scale the surface of the sea subject to the action of the wind and underwater currents, the cataracts of mountain rivers, and on a smaller scale the water flowing from the tap, the raindrops... For these small objects (especially uides), the force of surface tension plays a decisive role in sculpting the interfaces and giving, for example, raindrops and small bubbles their spherical shape.
In order to study and understand these flows, in addition to classical uide mechanics, we need the conceptual and technical tools that will allow us to describe the movement of the surface, and describe the forces that apply to it. The objective of this course is to acquire the tools to understand and characterize two-phase flows, as well as to become familiar with several paradigms of this type of flow.
The course will also be based on practical sessions: demonstrations and experimental manipulations, numerical resolution of typical flow equations with interfaces, and use of open-source software for solving Navier-Stokes equations with Gerris and Basilisk interfaces, which will allow to compute and visualize the dynamics and morphologies of free surface flows. The student can thus immediately put his knowledge into practice and manipulate the tools that are those of researchers in the field.

Content of the Teaching Unit.

General overview of phenomena related to free surfaces. Mathematical description of the movement of a line/area. Microscopic origin of surface tension. Pressure jump at the interface related to curvature and surface tension. Contact angle / wetting phenomena. Hydrostatics and interfaces: the meniscus, balance between surface tension and gravity. Hydrodynamics and interfaces: jets and liquid sheets. Disintegration of 3lms of liquid. Oscillations of drops and bubbles. Interfaces and instabilities: Rayleigh-Plateau and Rayleigh-Taylor instabilities. Phenomena of singularities related to surface tension: self-similar solution of drop detachment and post-cracking dynamics. Numerical methods for interface processing: marker methods, level set, volume of fuid. Methods for solving 1D equations with curvature. Use of Gerris and Basilisk software. Notions on boiling.

Prerequisites. Solid bases in mechanics of fuids and mechanics of continuous media are essential. An elementary knowledge of the microscopic properties of matter is welcome.

Bibliographical references.

On the general mechanics of fuides:

- `An Introduction to Fluid Dynamics' de G.K. Batchelor (Cambridge University Press)
- `Hydrodynamique Physique' by Guyon, Hulin & Petit (CNRS Editions)

On capillary phenomena:

- Drops, Bubbles, Pearls & Waves' by de Gennes, Brochart-Wyart and Quéré (Belin)

Resources available to students. Handout and course materials.

Scientific knowledge developed in the unit.

- Mathematical description of free surface phenomena.
- Models for oscillations and instabilities.

Skills developed in the unit.

- Observe and measure phenomena during LAB with image analysis.
- Program the models in versions adapted to the observations.

Hourly volumes in and out of the classroom.

Total attendance hours: 60 hours divided into 40 hours of lecture, 10 hours of discussion sessions and 10 hours of TP. Expected personal work: 40 - 50 hrs.

Evaluation. Final written exam (/60) and a project (/40)

Teacher. S. Zaleski

SCIENCES SORBONNE UNIVERSITÉ

Numerical methods for incompressible flows

Level CMI5 - **Semester** S9 - **Credits** 3 ECTS - **Code** MU5MEF04 Master of Mechanics - Fluid Mechanics and Applications.

Pedagogical presentation.
The objectives of the course are to give students the theoretical foundations necessary to understand and solve the specific difficulties of the simulation of incompressible flows. Students will be encouraged to program parts of numerical code illustrating the theory and to evaluate the validity of the results obtained. The concepts presented will be illustrated in practice using the matlab software.

Content of the Teaching Unit.
8 sessions of 4 hours: 1- Incompressibility - Classification of EDPs - Discretisation 2- Consistency, stability and convergence of numerical schemes. Fourier analysis. Interpolation and approximation. 3- (TP1) Analysis of Fourier 4- Regularity of the solution. Comparison between finite volume approach, finite element approach, spectral methods. Spectral methods for elliptic equations. 5- (TP2) Stability and convergence of numerical schemes. 6- Iterative methods. Stokes problem. 7- (TP3) Iterative methods. Stokes problem. 8- Pressure resolution (Uzawa operator, projection methods, influence matrix).

Prerequisites. CMI4 course course on numerical methods- Knowledge of matlab useful, but not mandatory

Bibliographical references.

- Canuto, Hussaini, Quarteroni, Zang, "Spectral Methods: Fundamentals in single domains", 2010, Springer
- Hirsch « Numerical Computation of internal and external flows », 2007, Elsevier

Resources available to students. Handout and course materials.

Scientific knowledge developed in the unit.

- Mathematical description of free surface phenomena.
- Models for oscillations and instabilities.

Skills developed in the unit.

- Observe and measure phenomena during LAB with image analysis.
- Program the models in versions adapted to the observations.

Hourly volumes in and out of the classroom.
Total attendance hours: 32 hours divided into 20 hours of lecture and 12 hours of lab. Expected personal work: 20-30 hrs.

Evaluation. Continuous assessment exam (/60) and Lab (/40)
Teacher. S. Zaleski

SCIENCES SORBONNE UNIVERSITÉ

Flows in natural environments

Level CMI5 - **Semester** S9 - **Credits** 3 ECTS - **Code** MU4MEF04 Master of Mechanics - Fluid Mechanics and Applications

Pedagogical presentation.
This module aims to present an overview of environmental hydrodynamic phenomena: flows in rivers, wave propagation and underground flows, as well as some notions of erosion and sedimentation. The tools to model and understand these phenomena are the Saint Venant equations, linear wave propagation and Darcy's law. Simplified examples will be coded in Python, realistic examples will be discussed in Basilisk.

Content of the Teaching Unit.
- General fluid mechanics reminders. Wave dynamics, swell, dispersion relationship
- Saint-Venant & Flood Modelling, dam failure, floods, overflows, etc.
- Non-linear and dispersive effects: Tidal bore and soliton
- Sub- and super-critical flows over obstacles in channels
- Associated numerical methods in finite volumes, Riemann solver
- Bottom flow coupling: erosion, Shields number, Exner's law
- Darcy's linear and non-linear law & Richards' law for imbibition
- Subsurface flow models, aquifères.

Prerequisite. Basic concepts of fluid mechanics from CMI3, notions of numerical schemes from CMI4

Références bibliographiques. Billingham King, “Wave motion” Cambridge 2001, Landau Lifschitz "Fluid Mechanics" (1987), Hubert Chanson "The hydraulics of open channel flow" Elsevier 1999. Eleterio Toro "Riemann Solvers" Springer 2009

Resources available to students. Handouts and course materials, Python notebooks, Basilisk pages.

Scientific knowledge developed in the unit.
- Material balances and amount of movement. Boundary conditions.
- Notions about hyperbolic systems
- Analogies with thin films: lubrication and boundary layers.

Skills developed in the unit.
- Phenomenological flow analysis.
- Flow Modelling with environmental applications

Methodological and cross-cutting skills
- Scientific approach of the modeler and implementation of a resolution strategy: identification of dominant phenomena, simplification of the problem, asymptotic, numerical resolution and critical analysis of the results.
- Appropriate use of the digital tools available at Master level
- Group project on a complex practical problem

Hourly volumes in and out of the classroom.
Total attendance hours: 27 hours divided into 13.5 hours of lecture and 13.5 hours of discussion session. Expected personal work: 30 - 40 hrs.

Evaluation. Written exam (/80) draft (/20)

Teacher. Pierre-Yves Lagrée

SCIENCES SORBONNE UNIVERSITÉ

Vortex in hydro-dynamics

Level CMI5 - **Semester** S9 - **Credits** 3 ECTS - **Code** MU5MEF06 Master of Mechanics - Fluid Mechanics and Applications.

Pedagogical presentation.
To familiarize students with one of the central concepts of fluid mechanics: vorticity and vortices. Numerous examples will show the presence of coherent structures of the tower-log type in very diverse flows of a fundamental (turbulence), geophysical and environmental, or applied (aeronautics in particular) nature. This course introduces the physical and analytical tools necessary to understand the notion of vortex, their dynamics and their characterization. This course is also intended for PhD students.

Content of the Teaching Unit.
Vorticity: definitions, examples, origin, Biot-Savart law, Kelvin's theorem, Helmholtz conservation laws. Two-dimensional approach: formation, point vortices, vorticity spots, Kelvin waves, fusion, near-wall dynamics, dipoles. Three-dimensional vortices: some Navier-Stokes solutions, vorticity filaments, formation, instabilities, reconnection. Applications in aerodynamics. Vortex and boundary layer, vortex and free surface, vortex and mixing, geophysical vortices, vortex and singularity.

Prerequisites. Basics of incompressible fluid mechanics (Navier-Stokes equation).

Bibliographical references.

- Hydrodynamique Physique, Guyon, Hulin et Petit, Editions du CNRS (2012). Elementary fluid dynamics, Acheson, Clarendon Press, Oxford (1990).

Resources available to students. Course notes.

Scientific knowledge developed in the unit.

- Vorticity Modelling in fluid mechanics.

Skills developed in the unit.

- Apply the concepts of vorticity to aerodynamic flows.
- Study of flows close to the walls.
-

Hourly volumes in and out of the classroom.
Total attendance hours: 30 h divided into 15 h lecture and 15 h project. Expected personal work: 20 - 30 hrs.

Evaluation. Written exam (50%), article study (50%).

Teacher. S. Chibbaro

SCIENCES SORBONNE UNIVERSITÉ

Digital Project

Level CMI5 - **Semester** S9 - **Credits** 3 ECTS - **Code** MU5MEF32 Master of Mechanics - Fluid Mechanics and Applications.

Pedagogical presentation.
This project aims to put into practice all the concepts seen in the course of the project on the basis of a case study. The students will mainly have to confront analytical methods with numerical solutions after a bibliographical study which will allow them to make a reasoned choice of the methods to be used.

Content of the Teaching Unit.
The content is associated with the topic that covers (more or less) the entire programme.

Prerequisites. Master's courses.

Bibliographical references. Depends on the subject and must be researched by the students.

Resources available to students. Software records, bibliographical research tools.

Scientific knowledge developed in the unit.

- Complementary training specific to the subject worked on.

Skills developed in the unit.

- Apply the concepts seen in class to practical cases.
- Choose the appropriate numerical methods.
- Programming, using calculation codes.
- Write and present an internship report.

Hourly volumes in and out of the classroom.
Total attendance hours: 4 hours of project presentation. Expected personal work: 60 - 80 h.

Evaluation. Written project report (50%), oral presentation (50%).

Teacher. A. Antowiak

Thematic

Aerodynamics and Aeroacoustics

SCIENCES SORBONNE UNIVERSITÉ

Airborne Acoustics

Level CMI5 - **Semester** S9 - **Credits** 5 ECTS - **Code** MU5MEF07 Master of Mechanics - Fluid Mechanics and Applications.

Pedagogical presentation.

- acquire/consolidate the basics in acoustics (in fluid media);
- address different problems of air acoustics (diffraction, refraction, propagation models, effects du environment (heterogeneities in temperature, wind, ...));
- make the link between industrial problems and fundamental concepts (noise pollution, acoustic pollution of the transports ground and air...).

Content of the Teaching Unit.

- basics of acoustics (wave equation, classical solutions, reflection/transmission, acoustic energy);
- wave equation in a flowing medium;
- geometric acoustics;
- waveguide;
- notions of non-linear acoustics;
- Kirchhoff's theorem;
- acoustic sources;
- basics of aeroacoustics;
- basics of vibro-acoustics;

Prerequisites. Fluid mechanics balance equations

Bibliographical references.

- Pierce, Acoustics, an introduction to Its Physical Prinicples and Applications, Acoustical Society of America
- D. Blackstock, Fundamentals of Physical Acoustics, J. Wiley & sons
- F. Coulouvrat & R. Marchiano, Atmospheric Propagation (Course note)

Resources available to students. Course notes

Scientific knowledge developed in the unit.

- Acoustics Modelling (non-linear, vibro-acoustics, airborne acoustics).

Skills developed in the unit.

- Consolidate the basics in acoustics (in a fluid environment).
- Know how to link industrial problems with scientific concepts.

Hourly volumes in and out of the classroom.
Total attendance hours: 30 hours divided into 20 hours lecture, 10 hours discussion session. Expected personal work: 20 - 30 hrs.

Evaluation. Written exam.

Teacher. Arnaud Antkowiak

Fundamental aerodynamics

Level CMI5 - **Semester** S9 - **Credits** 3 ECTS - **Code** - MU5MEF08
Mention Master science for the engineer **mention** mechanical, course Fluid Mechanics and Applications

Pedagogical presentation.

The EU is an introduction to the incompressible and compressible aerodynamics of aircraft. Emphasis is placed on determining flows around wing profiles and finite wingspan wings through aerodynamic coefficients, pressure distribution and shock description. The EU provides the basic concepts necessary for design and R&D in the aeronautical or automotive fields.

Content of the Teaching Unit.

Flight mechanics recalls, aerodynamic coefficients. Incompressible external aerodynamics: flows around airfoil bodies, viscous effects, disbonding, transition, airfoil polar; thin profile theory; introduction to Xfoil software; finite wingspan, induced flow, induced drag. Compressible aerodynamics: shock waves and expansion beams on supersonic airfoils; study of the operation of air inlets and nozzles in a transsonic regime. LAB : 1/ wing profile in wind tunnel (aerodynamic coefficients, pressure distribution, boundary layer separation) ; TP/ compressible numerical simulation of the same profile and comparison. Projet : dimensionnement of a wing. Use of Xfoil for the study of the profile, and coding (under Matlab for example) of a numerical tool to process the wing of finished wingspan.

Prerequisite. Bases of fluid mechanics (CMI3, CMI4).

Bibliographical references.

- FAURE, Th. 2008 Applied Fluid Dynamics. Aerodynamic applications. Dunod, Paris.
- ANDERSON, Jr, J.D. 2001 Fundamentals of aerodynamics. 3rd edition. McGraw Hill, Columbus.
- BERTIN & CUMMINGS 2008 Aerodynamics for engineers. 5th edition. Prentice Hall.

Resources available to students

Course and DISCUSSION SESSIONS handouts.

Scientific knowledge developed in the unit.

- Compressible flows.
- Pressure and shock distribution.

Skills developed in the unit.

- Application of theory to the project.
- Matlab coding of the program.

Hourly volumes in and out of the classroom.

Total attendance hours: 43 h divided into 13 * 1.5 h lecture and 13 * 1.5 h discussion session. A 4 h project is also planned.
Expected personal work: 25 h.

Evaluation.

The evaluation is based on a two-hour written exam.

Teacher.

SCIENCES SORBONNE UNIVERSITÉ

Numerical methods for incompressible flows

Level CMI5 - **Semester** S9 - **Credits** 3 ECTS - **Code** MU5MEF04 Master of Mechanics - Fluid Mechanics and Applications.

Pedagogical presentation.
The objectives of the course are to give students the theoretical foundations necessary to understand and solve the specific difficulties of the simulation of incompressible flows. Students will be encouraged to program parts of numerical code illustrating the theory and to evaluate the validity of the results obtained. The concepts presented will be illustrated in practice using the matlab software.

Content of the Teaching Unit.
8 sessions of 4 hours : 1- Incompressibility - Classification of EDPs - Discrétisation 2- Consistency, stability and convergence of numerical schemes. Fourier analysis. Interpolation and approximation. 3- (TP1) Analysis of Fourier 4- Regularity of the solution. Comparison between finite volume approach, finite element approach, spectral methods. Spectral methods for elliptic equations. 5- (TP2) Stability and convergence of numerical schemes. 6- Iterative methods. Stokes problem. 7- (TP3) Iterative methods. Stokes problem. 8- Pressure resolution (Uzawa operator, projection methods, influence matrix).

Prerequisites. CMI4 course course on numerical methods- Knowledge of matlab useful, but not mandatory

Bibliographical references.

- Canuto, Hussaini, Quarteroni, Zang, "Spectral Methods: Fundamentals in single domains", 2010, Springer
- Hirsch « Numerical Computation of internal and external flows », 2007, Elsevier

Resources available to students. Handout and course materials.

Scientific knowledge developed in the unit.
- Mathematical description of free surface phenomena.
- Models for oscillations and instabilities.

Skills developed in the unit.
- Observe and measure phenomena during LAB with image analysis.
- Program the models in versions adapted to the observations.

Hourly volumes in and out of the classroom.
Total attendance hours: 32 hours divided into 20 hours of lecture and 12 hours of TP. Expected personal work: 20-30 hrs.

Evaluation. Continuous assessment exam (/60) and Lab (/40)
Teacher. S. Zaleski

SCIENCES SORBONNE UNIVERSITÉ

Quantification of uncertainties in CFD

Level CMI4 - **Semester** S9 - **Credits** 3 ECTS - **Code** MU5MEF39 Master of Mechanics - Fluid Mechanics and Applications.

Pedagogical presentation.
The objective of this course is to become familiar with the concepts/tools of uncertainty quantification and stochastic/statistical Modelling of engineering problems, particularly in the context of Computational Fluid Mechanics (CFD). Different stochastic methods based on probability theory will be discussed to enrich the classical deterministic numerical prediction of the mechanical system. These techniques allow in particular a better control of the numerical error, obtaining
This includes the identification of "error bars", the identification of influential parameters such as the study of the sensitivity of the system, the propagation of uncertainties, and risk analysis.
The stochastic models and numerical methods presented will be implemented for concrete examples of fluid flows during computer-based PT with the Matlab software.

Content of the Teaching Unit.
The course is organized as follows:

- Introduction to uncertainty quantification in numerical mechanics
- Probability/statistic reminders
- Introduction to Stochastic Simulation Methods
- Formalism and derivation of stochastic spectral representations
- Digital resolution methods
- Robust optimization
- Applications: illustration on concrete examples of fluid flows revisited in an uncertain contexte

Prerequisites. Mastery of basic notions in probability and statistics facilitates the understanding and acquisition of the concepts of this EU.

Bibliographical references.

- Stochastic finite elements, Ghanem & Spanos, Dover 2003
- Numerical methods for stochastic computations : a spectral methods approach, Xiu, Princeton University 2010
- Stochastic Simulation: Algorithms and Analysis, Asmussen & Glynn, Springer 2007

Resources available to students. Course notes

Scientific knowledge developed in the unit.

- Modelling uncertainties and their propagation.

Skills developed in the unit.

- Identify influential parameters.
- Implant and a stochastic model in Matlab.
-

Hourly volumes in and out of the classroom.
Total attendance hours: 34 hours divided into 14 hours of lecture, 14 hours of discussion session and 6 hours of lab. Expected personal work: 20 - 30 hrs.

Evaluation. Report from lab Matlab (20% + 30%) + 1 final written exam (50%)

Teacher. Arnaud Antkowiak

Modélisation et simulation en aéroélasticité

Level CMI4 - **Semester** S9 - **Credits** 3 ECTS - **Code** MU5MEF10 Master of Mechanics - Fluid Mechanics and Applications.

Pedagogical presentation. .
The objective of this TU is to present the physical phenomena and fundamental principles governing the occurrence of aeroelastic instabilities when a flexible structure, such as an aircraft wing or a wind turbine, is subjected to aerodynamic excitations. Depending on the situation, these phenomena may lead to premature wear of the structure by fatigue or immediate ruin. Modeling of the coupling between the fluid and the structure then becomes essential to determine precisely the critical conditions of appearance of these instabilities as well as their nature.

Content of the Teaching Unit.
Part 1: Modelling of flutter instabilities

- General Classification of Fluid-Structure Interactions, Collar Force Triangle
- Phenomena of divergence, floating, V-g method.
- Elements of unsteady aerodynamics (functions of Theordorsen, Sears)
- Response of a flexible structure to atmospheric gusts and turbulence on linear aeroelasticity: Hopf bifurcations, limit cycles, chaos

Part 2: Numerical simulation for fluid-structure interactions

- Finite element numerical methods for aeromechanical calculations. Application to calculation mechanical and aeroelastic eigenmodes, calculation of the deformation of the structure under stationary aerodynamic loads, determination of the dynamic response
- Numerical techniques for fluid-structure coupling (decoupled and monolithic approaches,modal truncation method, mesh deformation, ALE formulation, dual time step)

Practical work under Matlab

- Numerical simulation of the buoyancy of an elastic structure in a supersonic flow: Determination of the instability boundary and calculation of the limit cycles of oscillations.

Prerequisites. General knowledge of aerodynamics and structural dynamics. Basic knowledge of numerical flow simulation and structural design..

Bibliographical references.

- P. Hémon, « Vibrations des structures couplées avec le vent », Ed. de l'école Polytechniqe, 2006
- E.H. Dowell « A modern Course in Aeroelasticity », Kluwer Academic Publishers, 3rd Ed. 1995

Resources available to students. Course notes

Scientific knowledge developed in the unit.

- Modelling uncertainties and their propagation.

Skills developed in the unit.

- Identify influential parameters.
- Implant and a stochastic model in Matlab.
-

Hourly volumes in and out of the classroom.
Total attendance hours: 34 hours divided into 12 hours of Lecture, 10 hours of discussion session and 8 hours of Lab. Expected personal work: 20 - 30 hrs.

Evaluation. Report from Matlab Lab (20%) + 1 final written exam (80%)

Teacher. Mr J.C. Chassaing et Mrs A. Vincenti

SCIENCES SORBONNE UNIVERSITÉ

Digital Project

Level CMI5 - **Semester** S9 - **Credits** 3 ECTS - **Code** MU5MEF32 Master of Mechanics - Fluid Mechanics and Applications.

Pedagogical presentation.
This project aims to put into practice all the concepts seen in the course of the project on the basis of a case study. The students will mainly have to confront analytical methods with numerical solutions after a bibliographical study which will allow them to make a reasoned choice of the methods to be used.

Content of the Teaching Unit.
The content is associated with the topic that covers (more or less) the entire programme.

Prerequisites. Master's courses.

Bibliographical references. Depends on the subject and must be researched by the students.

Resources available to students. Software records, bibliographical research tools.

Scientific knowledge developed in the unit.

- Complementary training specific to the subject worked on.

Skills developed in the unit.

- Apply the concepts seen in class to practical cases.
- Choose the appropriate numerical methods.
- Programming, using calculation codes.
- Write and present an internship report.

Hourly volumes in and out of the classroom.
Total attendance hours: 4 hours of project presentation. Expected personal work: 60 - 80 h.

Evaluation. Written project report (50%), oral presentation (50%).

Teacher. A. Antowiak

Semester 10

SCIENCES SORBONNE UNIVERSITÉ

Deepening Project

Level CMI5 - **Semester** S10 - **Credits** 3 ECTS - **Code** MU5EEG04 - Master's **degree in** Mechanics

Pedagogical presentation.
This deepening project is complementary to the specialization and can take different forms. It can represent the follow-up of an optional unit of additional specialization in semester S9 to broaden the knowledge base or to enhance a bibliographical part of the internship that would have been significant, or be associated with a scientific production for example in the context of the internship (presentation in a scientific conference, submission of a publication). It can also valorise an important associative investment or translate the validation of a teaching in the form of a MOOC (for example, a shared teaching on the European Virtual Exchange platform of the Sorbonne University Alliance 4eu+ network of partner universities: Charles University of Prague (Czech Republic), Heidelberg (Germany) and Warsaw (Poland), Universities of Milan (Italy) and Copenhagen (Denmark)). This project is usually carried out on an individual basis.

Content of the Teaching Unit.
Depending on the form of the project

Prerequisite miminum. Knowledge acquired in all teaching units since L1.

Bibliographical references. Function of the project subject.

Resources available to students. Function of the project subject and its environment.

Scientific knowledge developed in the unit
- Function of the project subject.

Skills developed in the unit.
- Take a step back from his training path.
- Knowing how to manage a personal project with commitment, defending it with conviction.

Hourly volumes in and out of the classroom.
Expected personal work: about 30 - 40 hours (and often more).

Evaluation. Evaluation usually in the form of a note of the written report, oral defence and involvement.

Teacher. Y. Berthaud, H. Dumontet.

Graduation internship

Level CMI5 - **Semester** S10 - **Credits** 30 ECTS - **Code** MU5MES03 - **Mention** Master Mechanics

Pedagogical presentation.
This end-of-study internship takes place over 24 weeks at the end of the course. The objective is to enable the student to acquire an engineering attitude, in particular autonomy and the ability to work effectively in a team in the company, by relying on the knowledge acquired during the training and the skills developed in the simulation activities (projects, and previous internships). He consolidates the specialization and validates these acquired skills.

This internship can take place in France or abroad, in a company (generally in the R&D departments of large industrial groups) or research laboratory (provided that the student then has significant experience of an internship in a company). It leads to the writing of a report and a defence in French or English. The presentation is made in front of a mixed jury composed of members of the teaching team and external experts, including the supervisor in the case of an internship in a company.

Content of the Teaching Unit.
The course leaders validate the coherence of the subject, its adequacy with the speciality of the training, with the student's professional project and his/her academic results. This internship is the subject of an internship agreement signed by the company/laboratory, the university and the student.

Prerequisite miminum. All the knowledge and skills developed since the beginning of the course.

Resources available to students.
- List and description of previous internship topics. Internship offers.
- Validation procedures, drafting guidelines, internship agreements.
- Bibliographical resources according to the subject.

Scientific knowledge developed in the unit.
- Specific to each internship according to the subject area of the company / laboratory and the missions entrusted.

Skills developed in the unit.
- Knowing how to participate in teamwork, take initiatives, know how to situate oneself and acquire autonomy.
- Know how to apply one's knowledge and apply it to a new open subject.
- Be able to respect specifications and deadlines.
- Be Teacher for the quality of his work.
- Take a step back from his experience, gain confidence in professional integration.
- Know how to communicate about your work in writing and orally.

Hourly volumes in and out of the classroom. 24 weeks of full-time internship between March and the end of August.

Evaluation. Placement report (/35, about fifty pages excluding annexes), tutor evaluation (/30), oral defence (/35 , 25 minutes presentation, 25 minutes questions).

Teacher. Course managers, Mr Y. Berthaud and Mrs H. Dumontet.