Syllabus Cursus Master's Degree in Engineering, Mechanics.

Sorbonne University CMI4 S7

List of Teaching Units

Core Units

- Mechanics of continuous solid and fluid media
- Waves and vibrations
- Scientific computing, signal processing and data
- Career guidance
- Project Management
- Entrepreneurship

Mechanics of Solids: Materials and Structures (MS2)

- Behaviour of solid materials
- Finite element structure analysis

Fluid Mechanics: Fundamentals and Applications (MF2A)

- Numerical methods in linear evolution
- Small and large Reynolds number hydrodynamics

Acoustic (Acou)

- Sensors for acoustics
- General Acoustics

Energy and Environment (EE) Pathway

- Mechanical energy engineering
- Fundamentals of Energy Efficiency

Computational Mechanics (Comp Mech)

- Small and large Reynolds number hydrodynamics
- Finite element structure analysis

Advanced Systems and Robotics (SAR)

- Linear automatic
- Introduction to Robotics and Artificial Intelligence
- Object-oriented programming in Python

Updated 01/03/2020

SCIENCES SORBONNE UNIVERSITÉ

	Title of Teaching Unit - Master Cycle Level CMI 4 - Semester S7	Code	Lecture sessions	Discussion sessions	Lab	SSA	Hours Attendance	Work Personal	ECTS
CMI4 S7	Mechanics of continuous solid and fluid media	MU4ME001	28	28			56	70-90	6
	Waves and vibrations	MU4ME003	8	24	20		52	70-90	6
	Scientific computing, signal processing and data	MU4MEN01	20	28		40	48	80-100	6
	Career guidance	MU4MEOI2		30		30	30	30-40	3
	Project Management	MU4RBZ13		16		16	32	50-60	3 *
	Entrepreneurship	MU4RBZ10		24		4	28	30-40	3 *
Specialized teaching according to the course of your choice	**Mechanics of Solids: Materials and Structures (MS2)**								
	Behaviour of solid materials	MU4MES02	12	14			26	30-40	3
	Finite element structure analysis	MU4MES01	20	14	20		54	60-80	6
	Fluid Mechanics: Fundamentals and Applications (MF2A)								
	Numerical methods in linear evolution	MU4MEF01			24		24	30-40	3
	Hydrodynamics, small and large numbers Re	MU4MEF02	28	28			56	60-80	6
	Acoustic (Acou)								
	Sensors for acoustics	MU4MEA02	12	10	8		30	30-40	3
	General Acoustics	MU4MEA01	14	14	14		42	50-80	6
	Energy and Environment (EE)								
	Mechanical energy engineering	MU4MEE03			48		48	40-50	3
	Fundamentals of Energy Efficiency	MU4MEE01	22	24	4		60	60-80	6
	Computational Mechanics (Comp Mech)								
	Finite element structure analysis	MU4MES01	20	14	20		54	60-80	6
	Hydrodynamics, small and large numbers Re	MU4MEF02	28	28			56	60-80	6
	Advanced Systems and Robotics (SAR)**								
	Linear automatic	MO1RBR03	24	16	8		48	60-80	6
	Introduction to Robotics and Artificial Intelligence	MO1RBR05	28	12	12		52	60-80	6
	Object-oriented programming in Python	MU4RBIO1	8	6	16		30	30 -50	3
	Total Common Core 21 ECTS + 6* ECTS - Total Course 9 -12 ECTS - Total CMI4 S7 = 60 ECTS + 6*								

* Non-contractual units (not included in the calculation of the semester average (appear in the diploma supplement)

** SMAR Course, Common Core: MU4ME001 (reduced to 3 ECTS part solids), MU4ME003 (reduced to 3 ECTS part Vibrations)

Updated 01/03/2020

Mechanics of continuous solid and fluid media

Level CMI4 - **Semester** S7 - **Credits** 6 ECTS - **Code** MU4ME01 - Mechanical Master's **degree**

Pedagogical presentation.
This unit is a course to deepen the basics of Continuous Media Mechanics acquired in the Bachelor's degree in Solids and Fluids. One part is devoted to modelling and methods for advanced problem solving of elastic structures and curvilinear media. In particular, behaviours of anisotropic and thermo-elastic structures are studied, as well as elastic arcs. The fluid part aims at presenting tools for solving complex problems of incompressible fluid mechanics, by highlighting the existence of viscous boundary layers, studying their properties and their consequences on high Reynolds number flows.

Content of the Teaching Unit.
Solids
- Bases of infinitesimal elasticity. Laws of behaviour in anisotropic thermo-elastic.
- Principle of virtual powers.
- Application of the virtual power method to the construction of models of curvilinear media.
- Energy theorems in elasticity. Applications to the construction of approximate solutions.
- Introduction to geometric non-linearity.

Fluids
- Dimensional Analysis & Scale Invariance
- Order of magnitude and physical analysis
- Singular Disturbances & The Viscous Boundary Layer

Prerequisites. Solid knowledge of continuous media mechanics developed in the units of L3, LU3ME004, LU3ME006, and LU3ME007.

Bibliographical references.
Solids
- G. Duvaut, Mécanique des Milieux Continus, Edition Masson, Paris 1990.
- H. Dumontet, G. Duvaut, F. Léné, P. Muller and N. Turbé, Exercices de mécanique des milieux continus, Masson, 1994.
- Jean Salençon, Mécanique des Milieux Continus, Tomes 1 et 2, éd. de l'École Polytechnique, 2005.

Fluids
- E. Guyon, J.P. Hulin, L. Petit, Hydrodynamic Physics, EDP Sciences, 2012
- J. S. Darrozes and C. François, Mécanique des fluides incompressibles, Lecture Notes in Physics, Springer-Verlag 1970.
- G. I. Barenblatt, Scaling, self-similarity, and intermediate asymptotics, Cambridge University Press, 1996.
- E. J. Hinch, Perturbation methods, Cambridge University Press, 1991.

Resources available to students. Course handouts and presentation materials, tutorial topics, corrected annals.

Scientific knowledge developed in the unit.
- Advanced knowledge in continuous media mechanics, modelling and resolution methods.

Skills developed in the unit.
- Know how to analyse the phenomena involved, make appropriate hypotheses.
- To be able to formulate the equations and boundary conditions of an advanced problem in the mechanics of continuous media.
- Know how to solve the problem in particular configurations.

Hourly volumes in and out of the classroom.
Total attendance hours: 56 hours divided for each part (solids, fluids) in 14 hours of class and 14 hours of tutorials. Expected personal work: 70 - 90 h

Evaluation. The evaluation is done for each part (solid, fluid) on the basis of two writings with one written 1 (non-penalizing / 30) one written 2 / 100. The final mark is calculated according to the SUP formula (written 1/3 + final written *2/3 , final written).

Teacher. Mrs H. Dumontet (Solids) and R. Wunenburger (Fluids)

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Waves and vibrations

Level CMI4- **Semester** S7 - **Credits** 6 ECTS - **Code** MU4ME003 - Master's degree in Mechanics

Pedagogical presentation.
The objective of this unit is to present the fundamental theory of: (i) the linear vibration of elastic structures and (ii) mechanical waves.

Content of the Teaching Unit.
Vibrations (5 sessions)

- Linear vibrating systems with n degrees of freedom (dof): n dof conservative systems, free system modal response, response under harmonic, periodic, transient, any excitation; resonances; dissipative systems, response to any excitation, damped resonance. Modal analysis and identification.
- Continuous media: Standing waves, Influence of boundary conditions.
  - One-dimensional media in ropes, tension-compression in bars, torsion in shafts, bending in straight beams.
  - Two-dimensional media: Waves in membranes, Bending vibration of flat plates, Impulse and frequency response, Modal and operational deformations.
- Approaching methods.
- Reduction to 1 dof: Rayleigh method. Reduction to 2-3 dof: Rayleigh-Ritz method,
- Introduction to finite elements.

Waves (3 sessions)

- Propagation equations in large physical systems of a mechanical nature,
- Study of the main physical phenomena associated with propagation (reflection-transmission, dispersion, attenuation)
- Several examples and applications: basic examples in which vibration and wave couplings occur; examples of fluid-structure coupling, where the wave propagating in the fluid is coupled to a vibration of a solid; other applications: wave interaction with an oil platform; noise in the passenger compartment of a car (radiating walls); vibrations of seismic origin.

Prerequisites. Basic knowledge in rigid solid dynamics acquired in Bachelor's and Continuous Studies. Linear 2nd order differential equation with constant coefficients.

Bibliographical references.

- Del Pedro M. & Pahud P. - Vibratory Mechanics - PPUR, 1999.
- J. L. Guyader: Vibration of Continuous Media, Hermes, 2002.
- C. Lesueur: Rayonnement acoustique des structures, Eyrolles, 1988.
- H.J.-P. Morand, R. Ohayon: Fluid-Structure Interactions, Lavoisier, 2007.
- M. Bruneau: Introduction to Acoustic Theories, University of Maine Publication, 1983.

Resources available to students. Lectures, discussion sessions subject and answer keys, Annals.

Scientific knowledge developed in the unit.

- Basics of vibration theory and wave propagation.

Skills developed in the unit.

- To know how to apply knowledge in the study of vibration problems, wave propagation.
- Follow experimental procedures.
- Write a project report and present it.

Hourly volumes in and out of the classroom.
Total in-class hours: 52 hours divided into 4 sessions of 2 hours of classes and 12 sessions of 2 hours of Discussion sessions and 20 hours of Labs.
Expected personal work: 70-90 hrs.

Evaluation. The evaluation is based on several continuous checks (60%), a Lab report (40%).

Teacher. Mr R. Marchiano

Scientific Computing, Signal and Data Processing

Level CMI4- **Semester** S7 - **Credits** 6 ECTS - **Code** MU4MEN01 - Master's degree in Mechanics

Pedagogical presentation.
This module covers the fundamental aspects necessary for the analysis and understanding of numerical methods applied to systems. The objective is to train students in the theory and practice of methods for the analysis of digital signals and systems, as well as in the synthesis of the latter.

Content of the Teaching Unit.
Digital signal processing:

- Reminders on continuous time: Study of continuous time signals: time approach, frequency approach (serial/Fourier transform). Study of continuous-time systems: properties, input/output relationships, standard responses, time description (differential equation, convolution), frequency description (frequency response, transfer function).
- Discrete-time signals: Sampling, Shannon's theorem, Analog-to-Digital conversion. Description and analysis of discrete-time signals: classical signals, DFT, FFT.
- Discrete time systems. Time representations: standard responses, RIF and RII systems, recurrence equation, discrete convolution. Frequency representations: Z-transform, frequency response, and transfer function. Stability of discrete systems. Applications to digital filter synthesis.

Scientific computing and data processing

- Introduction to Python: Matplotlib, Numpy
- Linear algebra: Vectors, matrices, Introduction of different solvers. Principal component analysis (SVD).
- Introduction to optimization methods. Machine architecture. Introduction to parallel computing.

Prerequisite. Licensing mathematics (Fourier transforms), programming notions (Matlab, octave, and/or python).

Bibliographical references.

- A.W.M. Van Den Enden, N.A.M. Verhoeck, Digital Signal Processing, Dunod, 2003
- M. Bellanger, P. Aigrain, Digital signal processing: theory and practice, Dunod, 2006
- Tutorials https://johansson/scientific-python-lecture https://jupyter4edu.github.io/jupyter-edu-book/ https://nbgrader.readthedocs.io/en/stable/

Resources available to students. Lectures, subject of Discussion sessions and corrected annals, subject of practical work and guides.

Scientific knowledge developed in the unit.

- Knowledge of continuous or sampled signal theory. Time and frequency representations.
- Introduction to advanced programming techniques and common data processing tools and algorithms.

Skills developed in the unit.

- Autonomy in the face of the numerical solution of a scientific problem
- Practice of the principles of scientific programming and data processing.
- Understanding the constraints of sampling
- Know how to calculate and interpret a spectrum. Know how to choose a filter. Know how to synthesize a filter

Hourly volumes in and out of the classroom.
Total classroom hours: Part Scientific Calculus - 22 h divided 6 h of class, 16 h of Lab, independent project. Signal Processing - 26 hours divided into 14 hours of class, 12 hours of practical work.
Expected personal work: 80 h - 100 h.

Evaluation. Part Scientific Calculus: Lab (/50, Solving a simple problem in relation to Lab and presentation of the results in a python notebook), pair project (/50, understanding of the subject, modelling, relevance of the choice of methods, analysis, clarity of presentation, quality of the graphs). Signal processing part: Written (/75), Lab (/25).

Teacher. Mrs F. Ossart, Mr R. Marchiano.

Career Guidance

Level CMI4 - **Semester** S7 - **Credits** 3 ECTS - **Code** MU4MEOI2 - Mechanical Master's **degree**

Pedagogical presentation.
The aim of this teaching unit is to support students in the construction of their professional project and to encourage their integration in the long term. It is organised around various activities: meetings with actors from the industrial and socio-economic world (forums, general and thematic conferences) which contribute to the knowledge of the sectors of activity and the professions of the disciplines, various workshops to learn how to decipher job or internship advertisements, prepare for a recruitment interview, make a skills assessment. In particular, soft skills workshops are organized and led by the SAFRAN industrial group around three themes: recruitment and digital (CV advice, digital branding, interview preparation, strategy and organization), oral fluency (presentation and pitching tips, stress management techniques, training in front of an audience), collective intelligence (collective and immersive challenge, collaborative applications, team presentation in front of an audience).

Content of the Teaching Unit.

- Soft skills workshops: Analysis of internship and job advertisements, CV construction, writing the cover letter, conducting interviews, interview simulations.
- LinkedIn workshop, digital identity
- Alumni-SU Interventions
- Cycle of thematic conferences by industrialists, trade conferences by professionals (EDF, PSA, Safran, Saint-Gobain)
- Atrium of Professions

Prerequisite. Knowledge of the company.

Bibliographical references.

Resources available to students. Various presentation materials.

Scientific knowledge developed in the unit.

- Knowledge of industrial issues (thematic conferences of applied research).
- Knowledge of recruitment strategies and practices.

Skills developed in the unit.

- To be an actor in the search for information, to be autonomous in a search for an internship.
- Know how to use social networks, create a professional network.
- Interview practice, speaking. Effective dialogue with a professional.
- Taking a step back from his journey and reflecting on his project.
- Being an actor in your professional project, knowing how to enhance your career path.

Hourly volumes in and out of the classroom.
Total attendance hours: 30 hours.
Expected personal work: 30 h - 40 h.

Evaluation. The evaluation is done in the form of continuous controls integrating MCQ notes on conferences, CV writing, cover letter, description of the professional project, respect of deadlines, participation in workshops.

Teacher. Mr A. Lazarus (mechanical path of solids), J.M. Fullana (mechanical path of fluids), J.D. Pollack (acoustic path), Mrs E. Galvez (energy and environment path), B. Gas, J.L. Zarader, M. Boudaoud (robotics path).

Project Management

Level CMI4- **Semester** S7 - **Credits** 3 ECTS - **Code** MU4RBZ13 - Mechanical Master's **degree**

Pedagogical presentation.
The aim of this unit is to provide a global vision of project management as practiced in a company. To do this, the main key points of project management are presented: the methods and tools used in the company, the conditions for the success of a project, the support systems for existing projects. At the same time, this teaching is applied in the context of a project led by the students (group of 4/5 students) with role-playing scenarios.

Examples of projects from previous years **:**

- Developing a new cryogenic rocket engine for Ariane X
- Producing the prototype of a new type of engine for short and medium-haul aircraft
- Finding new markets in the field of interplanetary gears
- Enhance the company's know-how in the field of tidal turbines
- Acquiring electric aircraft engine technology for Aero club

Two trainers provide teaching from the French aeronautics group, Safran, in partnership with LECTURE SESSIONSI training.

Content of the Teaching Unit.

- Identify what a project is
- Manage time and resources
- Analyse the need and adapt its approach to the client
- Getting off to a good start and making structuring choices
- Knowing the roles in a project
- Mastering the economic aspect
- Managing risks
- Ensuring quality
- Discover the main methods used in the project

Prerequisite. Knowledge of the company.

Bibliographical references. Function of the project subject

Resources available to students. Presentation materials, examples.

Scientific knowledge developed in the unit.

- Methods and tools for project management (planning, expenses, budgets ...).

Skills developed in the unit.

- Project management practice.
- Formalization of written reports (Minutes).
- Competence assessment and analysis of managerial approach. operational capacity.
- Teamwork, organization, knowing how to delegate tasks.
- Creativity, risk-taking, initiative.
- Oral communication, defence, argumentation.

Hourly volumes in and out of the classroom.
Total face-to-face hours: 32 hours spread over 4 days of training.
Expected personal work: 50-60 hrs.

Evaluation. The practical cases will be the subject of a restitution of each group in front of a jury (and the whole promotion). The evaluation is based on a mark for involvement in the project, the application of theoretical knowledge, and a mark awarded by the jury when the practical cases are presented.

Teacher. M. M. Derrien, F. Camilieri, Engineers (SAFRAN group),
Y. Berthaud, Mrs H. Dumontet and A. Gensbittel, (Sorbonne University)

Introduction to entrepreneurship

Level CMI4- **Semester** S7 - **Credits** 3 ECTS - **Code** MU4RBZ10 - Mechanical Master's **degree**

Pedagogical presentation.
This teaching unit is organized in the form of a series of thematic conferences led by start-up founders (essentiel.io, Kameleos), speakers from SATT Lutech (a technology transfer acceleration company of which Sorbonne University is a partner) or from Agoranov, the Paris Science & Tech incubator.
In parallel to these interventions, the students apply their knowledge in a start-up project carried out in groups of 4/5 students.

Example of student start-up projects

- Corners: an application for tablet phone/PC, connection via messaging.
- MealBox: Portable heated lunchboxes on rechargeable batteries.
- Iwalker: A connected cane (collects data, sends to the doctor).
- Nutr&Fit: Evaluation of the user's heat consumption, relationship with needs, activities, advice.
- SorBotic: Promoting ethical and Teacher development of robotics.
- Airflow: a service for purifying/distributing clean air in a used way.
- NeoDrink: connected glasses for beverage consumption control.

Content of the Teaching Unit.

- The steps involved in creating a start-up.
- What's an incubator for?
- Kameleos: story of a start-up.
- Intellectual property and how to make technology transfer profitable.
- Visit of the Salon des Entrepreneurs. Palais des Congrès - Paris.
- Presentation of the Pépite de Sorbonne University: support.

Prerequisite. Knowledge of the company.

Bibliographical references.
Various support sites https://www.agoranov.com www.sattlutech.com

Resources available to students. Various presentation materials.

Scientific knowledge developed in the unit.

- Concepts of entrepreneurship, the path of business creation, support systems.

Skills developed in the unit.

- Differentiate between an idea and an innovation.
- Understand the concept of business model.
- Identifying what characterizes a start-up.
- Creativity through the project, initiative, risk-taking.

Hourly volumes in and out of the classroom.
Total face-to-face hours: 28 hours divided into 14 sessions of 2 hours, including project support.
Expected personal work: 30 h - 40 h.

Evaluation. Evaluation on the project work and rendering of the file in the form of a canvas (the project, why this project? how is it done? Evidence, investor pitsch, validation of the user profile, the problem, the solution ...).

Teacher. O. Adam

SCIENCES SORBONNE UNIVERSITÉ

Solids Mechanics

Materials and Structures (MS2)

Updated 01/03/2020

Behaviour of solid materials

Level CMI4- **Semester** S7 - **Credits** 3 ECTS - **Code** MU4MES02 - Master's degree in Mechanics

Pedagogical presentation.
The aim of this course is to introduce students to the field of materials, whether they are metals, fragile materials such as rocks or concrete, or polymers. In relation to the structure of materials, students will analyse their behaviour - isotropic or not, elastic, plastic, viscous. We will insist on the microscopic and macroscopic plasticity with different usual plasticity criteria.

Content of the Teaching Unit.

- Material structure, bonding, elasticity.
- Crystallography, defects, plasticity.
- Test means.
- Anisotropic elasticity, thermo-elasticity and visco-elasticity.
- Plasticity criteria
- Thermodynamics
- Constitutive equations

Prerequisite. Mechanics of Continuous Media course in 3rd year (CMI3) and 4th year (CMI4).

Bibliographical references.

- J. Philibert, A. Vignes, Y. Bréchet, P. Combrade, Métallurgie : du minerai au matériau, éd. Masson, Paris, 1998.
- J.P. Bailon and J.M. Dorlot, des matériaux, 3rd edition, Presses internationales polytechniques, 2000.
- J. Douin, Mécanique des milieux continus, introduction à la plasticité des matériaux, Diderot arts et sciences, 1997.
- J. Friedel, Dislocations. Paris, Gauthier-Villars, 1956.
- Y. Quéré, Physique des matériaux, Ellipses, 1988.
- M. F. Asbhy and D. R.H. Jones, Materials, Dunod, 1991.
- J. Hadlik, Le calcul tensoriel en physique avec exercices corrigés, Masson, 1995.

Resources available to students.
Course handout, discussion session's topic and answer keys, Annals. Numerous video documents.

Scientific knowledge developed in the unit.

- Structures of materials and link to macroscopic behaviour.
- Basics of the laws of elasto-plastic behaviour of metals.

Skills developed in the unit.

- Know how to calculate orders of magnitude of stresses, deformation in materials.
- Know how to identify classes of behaviour.
- Make the link with the Continuous Media Mechanics (L3, M1) and Chemistry (L1) courses.

Hourly volumes in and out of the classroom.
Total in-class hours: 26 hours divided into 6 x 2-hour class sessions and 7 x 2-hour discussion sessions.
Expected personal work: 30 - 40 h.

Evaluation.
The evaluation is based on a written report lasting 2 hours (/100).

Teacher. Mr Y. Berthaud

SCIENCES SORBONNE UNIVERSITÉ

Finite Element Structure Analysis in Linear Elasticity

Level CMI4- **Semester** S7 - **Credits** 6 ECTS - **Code** MU4MES01- Master of Mechanics **Mention**

Pedagogical presentation.

The aim of this course is to give students the basics of the finite element method in the calculation of linear elastic structures. The method is implemented from generalist codes in practical work and students are trained to analyse the results with discernment.

The course begins with a presentation of local and energetic formulations of elasto-static problems. The principle of searching for approximate solutions is then presented. On this basis, the course describes the main steps of the finite element method and the elements necessary for its practical implementation.

The practical work coming in immediate application of the course and the tutorials allow a progressive and efficient handling of the theoretical and practical tools.

Content of the Teaching Unit.

- Formulations for thermal and linear elasto-static problems: local weak and variational.
- Principle of the search for approached solutions (Methods of Galerkin, Ritz,...).
- Main steps of finite element discretization (Parametric representation, Interpolation, construction of matrices and second elementary members, numerical integration (reduced or not), taking into account blockages, assembly, resolution (direct or iterative), post-processing (visualization...), interpretation of results, quality of approximation.
- Practical numerical work: Solving a stationary thermal problem, Calculation of the boom of a gravity dam using different models, Study of a pressurized reservoir using axisymmetric elements. Dynamic response of a bar under tensile stress.

Prerequisites. Basics of mechanics of continuous media developed in 3rd year and 4th year (CMI4, core). Partial differential equations (weak formulation, 3rd year course), linear algebra and numerical methods (3rd course, CMI3).

Bibliographical references.

- J.L. Batoz, G. Dhatt, Finite Element Structural Modelling, Hermès, 1992.
- Mr Bonnet and A. Frangi, Analyse des solides déformables par la méthode des éléments finis, Éditions de l'École Polytechnique, 2006.
- O. C. Zienkiewicz, The Finite Element Method, 3rd edition, Dunod,1987.

Resources available to students.

Course handouts and materials, discussion sessions subjects and answer keys, Annals and answer keys, technical data sheets, calculation code.

Scientific knowledge developed in the unit.

- Theoretical basis of the finite element method.
- Numerical algorithms based on the finite element method, their advantages and limitations.
- Structure of a finite element code.
- Solutions of classical problems in mechanics, thermic.

Skills developed in the unit.

- Know how to establish weak formulations of linear mechanical problems (thermal, elasticity)
- Implementation of finite element resolution steps.
- Scientific programming (python).
- Study of the convergence of the solution, stability, quality.
- Critical analysis of results, mechanical interpretation.

Hourly volumes in and out of the classroom.

Total attendance hours: 54 hours divided into 20 hours of classes, 14 hours of discussion sessions and 20 hours of practical work on machines.

Personal work 60-80 hours.

Evaluation.

The evaluation is based on a 2-hour written paper (60%) and a LAB report (40%) .

Teacher. Mrs S. Dartois.

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Fluid Mechanics and Applications (MF2A)

Updated 01/03/2020

Numerical methods for incompressible flows

Level M2 - **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 PDEs - Discretisation 2- Consistency, stability and convergence of numerical schemes. Fourier analysis. Interpolation and approximation. 3- (Lab1) Analysis of Fourier 4- Regularity of the solution. Comparison between finite volume approach, finite element approach, spectral methods. Spectral methods for elliptic equations. 5- (Lab2) Stability and convergence of numerical schemes. 6- Iterative methods. Stokes problem. 7- (Lab3) Iterative methods. Stokes problem. 8- Pressure resolution (Uzawa operator, projection methods, influence matrix).

Prerequisite. CMI4course 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 discussion sessions and 12 hours of Lab. Expected personal work: 20-30 hrs.

Evaluation. Continuous assessment exam (/60) and LAB (/40)

Teacher. S. Zaleski

Small and Large Reynolds Hydrodynamics

Level CMI4 - **Semester** S7 - **Credits** 6 ECTS - **Code** MU4MEF02 Master of Mechanics - Fluid Mechanics and Applications.

Pedagogical presentation.
This module aims to present a panorama of fluid mechanics from flows dominated by viscosity (e.g. bacteria, fibre optic synthesis) to those dominated by inertia (aerospace, energy, flood dynamics, astrophysical flows). After reviewing the fundamental concepts (boundary conditions, balance equations, forces, modes of transport), this course will focus on understanding flow approximation techniques, in order to be able to predict observables such as the force exerted by a lubrication film or the velocity of a vortex ring. These concepts will be illustrated through studies of historical work, problem solving and numerical experiments in Python.

Content of the Teaching Unit.

- General fluid mechanics reminders & Boundary conditions. Free surfaces. Surface tension.
- Regular disturbances (fields, data, geometry)
- Low Re flows. Reversibility. Drag. (Moffatt's vortex/Taylor's knife study.)
- Thin films. Lubrication. Gravity currents.
- Case study: the Landau and Levich cash deposit
- Notion of Prandtl's boundary layer.
- Inertial flows at high Re. Potential description. Conformal transformation. Saffman-Taylor Digitation
- The separation. Kutta's condition. Aerodynamic drag.
- Influence of rotation. Planetary flows.
- Vorticity Dynamics & Introduction to Turbulence.

Prerequisites. Fluid mechanics (CMI3). Mechanics of continuous media (CMI3-4).

References. Germain, P. (1986). *Mécanique*. Ellipses. Guyon, E., Petit, L., & Hulin, J. P. (1991). *Hydrodynamique physique*. CNRS Interéditions. Batchelor, G. K. (1967). *An introduction to fluid dynamics*. Cambridge University Press. Lighthill, J. (1986). *An informal introduction to theoretical fluid mechanics*. Prandtl, L. & Tietjens, O. K. G. (1957). *Fundamentals of hydro-and aeromechanics.* Dover.

Resources available to students. Handouts and course materials, DISCUSSION SESSIONS topics, Python notebooks, practice exercises, annals, videos.

Scientific knowledge developed in the unit.

- Material balances and amount of movement. Boundary conditions. Description of the movement of the interfaces, especially in the presence of capillary phenomena.
- Low Reynolds Number flows
- Thin films: lubrication and boundary layers.
- Inertial flows (Re >>1). Separation phenomenon. Drag.
- Hydrodynamic forces.

Skills developed in the unit.

- Phenomenological flow analysis.
- Modelling of non-trivial flows.
- Approximation of flows by asymptotic analysis (regular and singular perturbations).

Methodological and cross-cutting skills

- Scientific approach of the modeller and implementation of a resolution strategy: identification of dominant phenomena, simplification of the problem (e.g. geometry), asymptotic or numerical resolution and critical analysis of the results.
- Appropriate use of the digital tools available at Master level
- Group project on a complex hydrodynamic problem

Hourly volumes in and out of the classroom.
Total attendance hours: 56 hours divided into 28 hours of lecture and 28 hours of discussion sessions. Expected personal work: 60 - 80 hrs.

Evaluation. Continuous assessment (/40) and written examination (/60).

Teacher. A. Antkowiak

Updated 01/03/2020

Acoustics

(Acou)

Updated 01/03/2020

SCIENCES SORBONNE UNIVERSITÉ

Sensors for acoustics

Level CMI4- **Semester** S1 - **Credits** 3 ECTS - **Code** MU4MEA02 Master's degree in mechanics

Pedagogical presentation.

The objective of this unit is to make students aware of the notion of measurement, the sensors needed to perform the measurement, the limits and associated approximations. The aim is to discover specific instrumentation and technologies for measuring physical quantities. The applications concern the measurement of acoustic and vibratory quantities, whether in the audible or ultrasonic field. The notions of measurement uncertainty are also covered.

Content of the Teaching Unit.

- Physical mechanism of transduction and conditioning
- Ultrasonic Acoustics - piezoelectricity, directivity.
- Electro-acoustic system and elementary modelling of operation - Microphone, HP, Acoustic load, directivity, Thiele & Small model, dimensioning,...
- Basics of metrology - Organisms, vocabulary, measurement chain, active/passive sensor, type A and B uncertainties.

Prerequisite. Waves and vibrations

Bibliographical references.

- M. Rossi, Traité d'électricité, Vol. 21, Ecole Polytechnique de Lausanne. Sept. 2013.
- Georges Asch, Les capteurs en instrumentation industrielle, Dunod 2017.

Resources available to students.

Documentation, Loudspeakers and adjustable speakers, Arta software, Acoustic sensors (microphones...)

Skills developed in the unit.

- Modelling of electro-acoustic systems
- Analysis and interpretation of sensor and loudspeaker data sheets
- Handling of measuring and audio systems

Hourly volumes in and out of the classroom.

Presential hours: 30 h divided into 12 h of lectures, 10 h discussion sessions, 8 h experimental labs.
Expected personal work: 30-40 hours

Evaluation.

Two 2-hour theoretical evaluation sessions (one intermediate and one final) and a LAB report
(40 %, 40 %, 20 %).

Teacher. B. Fabre

SCIENCES SORBONNE UNIVERSITÉ

General Acoustics

Level CMI4- **Semester** S7 - **Credits** 6 ECTS - **Code** MU4MEA01 - **Mention** Master Mechanics

Pedagogical presentation.

The aim of this teaching unit is to give the theoretical bases of acoustics.

Content of the Teaching Unit.

The chapters covered in this course are :

- Propagation of acoustic waves in perfect fluids.
- Characterization of sound waves.
- Reflection and transmission to a flat interface.
- Radiation from elementary sources.
- Guided waves.
-

Prerequisites.

Continuous media mechanics (L3 level), Vector analysis, Multivariate function, Partial differential equation

Bibliographical references.

- Blackstock, D. T., Fundamentals of physical acoustics, Wiley & Sons, 2001.
- Pierce, A, An Introduction to Its Physical Principles and Applications, Springer, 2019.
- M. Bruneau: Introduction to Acoustic Theories, University of Maine Publication, 1983.

Resources available to students. Course handout. discussion sessions booklet with corrections, Notebook skirt.

Skills developed in the unit.

- Know the basic vocabulary in acoustics,
- Modelling of the linear propagation of acoustic waves,
- Know the basic solutions of the wave equation (travelling and retrograde waves, plane waves, spherical waves),
- Model the speed of sound in the most common media (water/air),
- To know the relevant energy quantities in acoustics (acoustic energy density, sound intensity, sound power),
- Know how to characterize an acoustic wave with appropriate indicators (temporal and frequency representation, decibel, octave band or third octave band),
- Model the presence of interface and propagation in different fluids (refraction phenomenon and amplitudes of reflected and transmitted waves),
- To know the behaviour of elementary sources (monopole and dipole),
- Modelling of waveguide propagation: propagation mode, dispersion and notion of cut-off frequency,
- Identify phenomena occurring in acoustics (free propagation, guided propagation, reflection, transmission, refraction, dispersion, diffraction, absorption).

Hourly volumes in and out of the classroom.

Total hours of attendance: 42 hours divided into 14 hours of lecture, 14 hours of discussion sessions, 14 hours of digital Lab.

Expected personal work: 80 h - 100 h.

Evaluation. One written exam (2 hrs), one Lab exam (2 hrs).

Teacher. R. Marchiano

Energy and Environment

(EE)

Updated 01/03/2020

SCIENCES SORBONNE UNIVERSITÉ

Mechanical Energy Engineering

Level CMI4- **Semester** S7 - **Credits** 3 ECTS - **Code** MU4MEE03 -
Master of Science for Mechanical Engineers with a specialization in Energy and Environment

Pedagogical presentation.

The TU aims to make available different experiences around energy conversion, to carry out practical work sessions covering the topics of RE, combustion, cycles of receiving or driving machines. The theme of the project is chosen by the student from a list proposed by the professor Teacher for the EU. The student can also submit a project idea to a teacher who will supervise it. During these experimental sessions of practical work, the contribution in terms of transversal competences aims at a first learning by doing of theoretical concepts seen in class. The approach includes phases of questioning, understanding and realization. The work is carried out in groups and is subject to a final evaluation. The progress of the sessions is determined through numerous interim reports and presentations. **Examples of sessions**: Renewable energies, Performance of a photovoltaic installation, Pollutant formation, Post-treatment and homologation cycles of a car engine, Low consumption building.

Content of the Teaching Unit.

The following experiments are available: Solar panel field, study of a combustion chamber, operation of a fuel cell, analysis of a hydroelectric power plant, study of a wind turbine.

Prerequisite. Bachelor's and Master's degree in Thermodynamics, knowledge of sensors and signal processing.

Bibliographical references.

- Moran M. J. and Shapiro, H. N., Fundamentals of Engineering Thermodynamics, 3rd edition, John Wiley & Sons, 1998.
- JP Perez, Thermodynamics, Foundations and Applications, Masson, 2001.

Resources available to students

Practical work text on the following site: https://www.plateforme-theoreme-upmc.fr/

Skills developed in the unit.

- Implement the concepts.
- Simplify observed phenomena.
- Acquisition of the mastery of specific measuring devices.
- Knowledge of operation of energy conversion systems.
- Analysis of a complex problem into subsystems. Implementation of resolution methods.
- Access and evaluate appropriate sources of information. Write a scientific or technical report.
- Write a literature review that establishes the state of the art. Collect data.
- Compare the status of achievements with the plan and adjust it accordingly.
- Use an appropriate work methodology, organize a work/itself.
- Communicate effectively and be understood (by people of different languages and cultures).
- Evaluate performance in the group, receive feedback and respond appropriately.

Hourly volumes in and out of the classroom.

Total face-to-face hours: 48 hours divided into 6 practical sessions of 8 hours each.
Expected personal work: 40 - 50 h.

Evaluation. Oral presentation (60%), written report (20%), PT notes (20%).

Teacher. Mrs E. Galvez, Mr S. Pounkin, Mr T. Lebris, Mr P. Guibert.

Updated 01/03/2020

Fundamentals of Energy Efficiency

Level CMI4- **Semester** S7 - **Credits** 6 ECTS - **Code** MU4MEE01
Master of Science for Mechanical Engineers with a specialization in Energy and Environment

Pedagogical presentation. This course provides the set of thermodynamic tools for a robust analysis of the performance of energy conversion systems and for the design of new complex systems. This course does not deal in detail with the basics of thermodynamics, which are assumed to be already known. The teaching of energetics has two main components, very different in nature but of similar difficulty: on the one hand, the theory of exergy is developed in detail, it provides a quite rigorous framework to quantify the quality of transformation of any system, open or closed, in dynamic or non-dynamic regime. The exergy balance is a privileged tool for comparing and optimizing thermodynamic cycles, on the other hand, the modelling of the technologies studied, acquired or new, which is essentially a matter of applied thermodynamics including renewable energies. The topics dealt with concern energy and exergy balance equations, combustion, the study of cycles, and the study of several energy conversion systems (internal combustion engine, gas turbine, steam power plant, solar).

Content of the Teaching Unit.

- Writing of the 1st and 2nd principles, extension of the energy balance to any system. Writing of the generalized energy yield. Presentation of the concept of exer.
- Case study to understand the application of the exercise and the analysis of the results provided.
- Writing of the annual balance sheet t of the generalized annual yield.
- Proposal for conversion system optimization via energy and exercise concepts.
- Study of polygenerated cycles. Presentation of combustion and associated regimes.
- Combustion chamber exergy balance calculation.

Prerequisite. Knowledge of the basics of thermodynamics at the bachelor's level.

Bibliographical references.

- Moran M. J. and Shapiro, H. N., Fundamentals of Engg Thermodynamics, 3rd edition, John Wiley & Sons, 1998.
- Bejan, A., Tsatsaronis and Moran, M., Thermal Design & Optimization, John Wiley & Sons, 1996.
- Kotas, T. J., The Exergy Method of Thermal Plant Analysis, Reprint Edition, Krieger, Malabar, FL, 1995.
- Wood, B. D., Applications of Thermodynamics, Waveland Press Inc., Prospect Heights, Illinois, 1982.
- JP Perez, Thermodynamics, Masson Foundations and Applications, 2001.
- L Borel, Thermodynamique Et Énergétique, Presses polytechniques et universitaires Romande, 2005.
- J. H. Horlock, Combined Power Plants, Pergamon Press, 1992.
- Michel Feidt, Thermo. et optimisation énergétique des systèmes et procédés, Tec & Doc (Editions), 2016.
- B Diu C Guthmann D Lederer B Roulet Thermodynamique ed Hermann, 2007.

Resources available to students. Poly. of the course and boards presented in the lecture hall if necessary. Topics of DISCUSSION SESSIONSs and corrected papers, examination annals with corrected papers and comments and numerous complementary documents.

Scientific knowledge developed in the unit.

- Basics of thermodynamics, variables, state function, entropy, fluid properties, phase change, chemical equilibrium of reactive systems. Energetic and exergetic principle.
- Energy optimization of systems and processes.

Skills developed in the unit.

- To master the notions of mass, energy and dynamic equilibrium, thermodynamics and energetics.
- Calculate the thermodynamic properties of a fluid, wet gas.
- Understand the main thermodynamic cycles. Notion of optimization.
- Analysis of a complex problem into subsystems. Implementation of resolution methods.
- Verification of the homogeneity of the results (simple dimensional analysis).
- Write the various equations from the principles of energy and exergy to deduce the losses and conversion efficiencies.

Hourly volumes in and out of the classroom.
Attendance hours: 50 hours divided into 22 hours of LECTURE SESSIONS, 24 hours of DISCUSSION SESSIONS and 4 hours of project.
Expected personal work: 70 h - 90 h.

Evaluation. Evaluation based on a draft energy performance characterization and a three-hour written exam.
2-hour written exam (70%) - Project Report and oral presentation (30%).

Intervening teachers. Mr P. Guibert

Updated 01/03/2020

SCIENCES
SORBONNE
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Computational Mechanics Course

(Comp Mech)

Updated 01/03/2020

SCIENCES SORBONNE UNIVERSITÉ

Finite Element Structure Analysis in Linear Elasticity

Level CMI4- **Semester** S7 - **Credits** 6 ECTS - **Code** MU4MES01- Master of Mechanics **Mention**

Pedagogical presentation.

The aim of this course is to give students the basics of the finite element method in the calculation of linear elastic structures. The method is implemented from generalist codes in practical work and students are trained to analyse the results with discernment.

The course begins with a presentation of local and energetic formulations of elasto-static problems. The principle of searching for approximate solutions is then presented. On this basis, the course describes the main steps of the finite element method and the elements necessary for its practical implementation.

The practical work coming in immediate application of the course and the tutorials allow a progressive and efficient handling of the theoretical and practical tools.

Content of the Teaching Unit.

- Formulations for thermal and linear elasto-static problems: local weak and variational.
- Principle of the search for approached solutions (Methods of Galerkin, Ritz,...).
- Main steps of finite element discretization (Parametric representation, Interpolation, construction of matrices and second elementary members, numerical integration (reduced or not), taking into account blockages, assembly, resolution (direct or iterative), post-processing (visualization...), interpretation of results, quality of approximation.
- Practical numerical work: Solving a stationary thermal problem, Calculation of the boom of a gravity dam using different models, Study of a pressurized reservoir using axisymmetric elements. Dynamic response of a bar under tensile stress.

Prerequisites. Basics of mechanics of continuous media developed in ^{3rd} year (L3) and ^{4th} year (M1, core). Partial differential equations (weak formulation, ^{3rd} year course), linear algebra and numerical methods ($^{3rd\ year}$ course, L3).

Bibliographical references.

- J.L. Batoz, G. Dhatt, Finite Element Structural Modelling, Hermès, 1992.
- Mr Bonnet and A. Frangi, Analyse des solides déformables par la méthode des éléments finis, Éditions de l'École Polytechnique, 2006.
- O. C. Zienkiewicz, The Finite Element Method, ^{3rd} edition, Dunod,1987.

Resources available to students.

Course handouts and materials, discussion sessions subjects and answer keys, Annals and answer keys, technical data sheets, calculation code.

Scientific knowledge developed in the unit.

- Theoretical basis of the finite element method.
- Numerical algorithms based on the finite element method, their advantages and limitations.
- Structure of a finite element code.
- Solutions of classical problems in mechanics, thermic.

Skills developed in the unit.

- Know how to establish weak formulations of linear mechanical problems (thermal, elasticity)
- Implementation of finite element resolution steps.
- Scientific programming (python).
- Study of the convergence of the solution, stability, quality.
- Critical analysis of results, mechanical interpretation.

Hourly volumes in and out of the classroom.

Total attendance hours: 54 hours divided into 20 hours of classes, 14 hours of DISCUSSION SESSIONS and 20 hours of practical work on machines.

Personal work 60-80 hours.

Evaluation.

The evaluation is based on a 2-hour written paper (60%) and a LAB report (40%) .

Teacher. Mrs S. Dartois.

Updated 01/03/2020

Small and Large Reynolds Hydrodynamics

Level CMI4- **Semester** S7 - **Credits** 6 ECTS - **Code** MU4MEF02 Master of Mechanics - Fluid Mechanics and Applications.

Pedagogical presentation.
This module aims to present a panorama of fluid mechanics from flows dominated by viscosity (e.g. bacteria, fibre optic synthesis) to those dominated by inertia (aerospace, energy, flood dynamics, astrophysical flows). After reviewing the fundamental concepts (boundary conditions, balance equations, forces, modes of transport), this course will focus on understanding flow approximation techniques, in order to be able to predict observables such as the force exerted by a lubrication film or the velocity of a vortex ring. These concepts will be illustrated through studies of historical work, problem solving and numerical experiments in Python.

Content of the Teaching Unit.
- General fluid mechanics reminders & Boundary conditions. Free surfaces. Surface tension.
- Regular disturbances (fields, data, geometry)
- Low Re flows. Reversibility. Drag. (Moffatt's vortex/Taylor's knife study.)
- Thin films. Lubrication. Gravity currents.
- Case study: the Landau and Levich cash deposit
- Notion of Prandtl's boundary layer.
- Inertial flows at high Re. Potential description. Conformal transformation. Saffman-Taylor Digitation
- The separation. Kutta's condition. Aerodynamic drag.
- Influence of rotation. Planetary flows.
- Vorticity Dynamics & Introduction to Turbulence.

Prerequisites. Fluid mechanics (L3). Mechanics of continuous media (L3, M1).

References. Germain, P. (1986). *Mécanique*. Ellipses. Guyon, E., Petit, L., & Hulin, J. P. (1991). *Hydrodynamique physique*. CNRS Interéditions. Batchelor, G. K. (1967). *An introduction to fluid dynamics*. Cambridge University Press. Lighthill, J. (1986). *An informal introduction to theoretical fluid mechanics*. Prandtl, L. & Tietjens, O. K. G. (1957). *Fundamentals of hydro-and aeromechanics.* Dover.

Resources available to students. Handouts and course materials, DISCUSSION SESSIONS topics, Python notebooks, practice exercises, annals, videos.

Scientific knowledge developed in the unit.
- Material balances and amount of movement. Boundary conditions. Description of the movement of the interfaces, especially in the presence of capillary phenomena.
- Low Reynolds Number flows
- Thin films: lubrication and boundary layers.
- Inertial flows (Re >>1). Separation phenomenon. Drag.
- Hydrodynamic forces.

Skills developed in the unit.
- Phenomenological flow analysis.
- Modelling of non-trivial flows.
- Approximation of flows by asymptotic analysis (regular and singular perturbations).

Methodological and cross-cutting skills
- Scientific approach of the modeller and implementation of a resolution strategy: identification of dominant phenomena, simplification of the problem (e.g. geometry), asymptotic or numerical resolution and critical analysis of the results.
- Appropriate use of the digital tools available at Master level
- Group project on a complex hydrodynamic problem

Hourly volumes in and out of the classroom.
Total attendance hours: 56 hours divided into 28 hours of LECTURE SESSIONS and 28 hours of DISCUSSION SESSIONS. Expected personal work: 60 - 80 hrs.

Evaluation. Continuous assessment (/40) and written examination (/60).

Teacher. Arnaud Antkowiak

Updated 01/03/2020

Advanced Systems and Robotics (SAR) Course

Updated 01/03/2020

SCIENCES SORBONNE UNIVERSITÉ

Automatic Linear

Level CMI4- **Semester** S7 - **Credits** 6 ECTS - **Code** MU4RBR03- Master's **degree in** Automatic and Robotics

Pedagogical presentation.

This teaching is structured in two parts.

The objective of Part 1 is to

- To train students in the modelling and analysis of time-invariant linear systems in the time and frequency domains from an input/output description;
- To train students in the synthesis of control laws by output feedback that meets specifications in terms of stability, speed and precision;
- To train students in the implementation of control laws on experimental systems.

Part 2 aims to :

- To train students in the expression of control problems in state representation.
- To train them to solve linear control problems expressed in state representation.
- To highlight the links between the frequency automatic and the state automatic.
-

Content of the Teaching Unit.

Part 1

1. Study and Analysis of time-invariant linear systems in the time domain :
   - Definitions and assumptions. Notions of a system and a signal; Classification of elementary signals; Classification of systems.
   - Modelling and analysis of systems in the time domain. Differential equation; Index response and impulse response; Notions of response time, rise time, overshoot and steady-state error; Illustrative examples.
2. Study and Analysis of time-invariant linear systems in the frequency domain I :
   - Transformed from Laplace. Definition; Convergence region; Properties; Examples.
   - Transfer function. Notions of poles and zeros. Stability condition from poles.
3. Study and Analysis of time-invariant linear systems in the frequency domain II :
   - Bode diagram of a first-order system. Calculation of gain and phase asymptotes and study at the limits; Plotting of gain and phase asymptotes ;
   - Bode diagram of a second-order system. Calculation and plotting of the gain and phase asymptotes and study at the boundaries in the case of a second-order system decomposable into a set of first-order systems; Plotting of the gain and phase asymptotes in the general case of a second-order system.
4. Control of time-invariant linear systems via output feedback I :
   - Output return control. Introduction; Notions of control and servoing; Modelling a closed-loop system; Stability of a closed-loop system; Stability margins; Notions of accuracy and disturbance rejection; Examples.
   - Modelling and concept of disturbance rejection.
5. Control of time-invariant linear systems via output feedback II :
   - Proportional corrector. Definition; Synthesis of a proportional corrector from the Bode diagram; Effect on accuracy, bandwidth and stability margins; Examples.
   - Integral proportional corrector. Definition; Effect on accuracy, bandwidth and stability margins; Examples.
6. Control of time-invariant linear systems via output feedback III :
   - Phase-advance corrector. Definition; Synthesis of a phase-advance corrector from the Bode diagram; Effect on accuracy, bandwidth and stability margins; Examples.
   - Comparison between the different proof-readers studied. Antagonism stability/rapidity and stability/precision; Examples.

Part 2

1. *Introduction to Status Representation*: Status/Input/output Concepts. Examples and equation setting. Notion of equilibrium point. Definition and calculation of the linearized tangent.
2. *Links between state representation and frequency representation*: Case of single-input/mono-output systems. Controllable canonical form. Realization of transfer function. Extension to the case of multi-input/multi-output systems.
3. *Fundamentals of Linear Systems*: Command ability: Definition and Characterization (Kalman). Observability: definition and characterization (Kalman). Stability: definition and characterization (eigenvalues and Routh-Hurwitz criterion).
4. Pole Placement Controller Synthesis: Pole Placement Controller Synthesis. Observer synthesis by pole placement. Principle of separation.
5. *Implementation and adjustment aspects*: Constraints related to sampling, delays, and measurement noise. Adjustment of gains. Implementation of observer/filter by prediction/correction.
6. *Numerical tools and introduction to the LQR command*: Use of numerical tools for the corrector synthesis. Introduction to the LQR command

Prerequisite. Mathematics for the engineer. Knowledge of differential equations; Linear Algebra.

Bibliographical references.

- Y. Granjon, " Automatique ", Dunod, 2nd edition, 2010.
- B. d'Andrea-Novel and M. de Lara, Linear Control of Dynamical Systems, Elsevier-Masson, 1997.

Resources available to students. Course materials and DISCUSSION SESSIONS, LAB on mock-up

Skills developed in the unit.

Part 1

- Model a time-invariant linear system in the time and frequency domain from an input/output description.
- Analyse the stability and performance of a time-invariant linear system from a transfer function representation and index and impulse responses.
- Synthesize proportional, PID and phase-advance control laws that meet specifications in terms of margin of stability, speed and accuracy.
- Analyse the performance of a closed-loop system in the time and frequency domains.
- Implement the control laws studied on an experimental benchmark using Matlab/Simulink software and digital communication cards.

Part 2

- Model linear commands associated with a control problem expressed in state space.
- Analyse the controllability/observability/stability properties of this linear model.
- Perform a controller or observer synthesis.
- Make gain adjustments to meet specifications.

Hourly volumes in and out of the classroom.
Total attendance hours for each game: 24 hours divided into 6 sessions of 2 hours each, 4 discussion sessions of 2 hours each,
2 sessions of 2 hours of digital PT.
Expected personal work for each part: 30 - 40 h.

Evaluation. For each part: two written exams (/70) + a grade of LAB (/30).

Teacher. Mr Mokrane Boudaoud (Part 1) - Mr Pascal Morin (Part 2)

Introduction to Robotics and Artificial Intelligence.

Level CMI4- **Semester** S7 - **Credits** 6 ECTS - **Code** MU4RBR08 - Master's **degree in** Automatic and Robotics

Pedagogical presentation.
This unit is structured in two parts.
The objective of part 1 devoted to an introduction to robotics is to train students in the modelling of manipulator robots for their control, through the introduction of the notion of robotic task and operational and articular spaces. The course is limited to demonstrating the interest of modelling for simple tasks aiming at reaching a crossing point or following a given trajectory.
Part 2 is devoted to an introduction to Artificial Intelligence and aims to introduce students to artificial intelligence. It includes a general presentation and useful and practical technical knowledge on different aspects of AI: knowledge representation, problem solving and planning, reasoning and decision making in uncertainty, elements of machine learning.

Content of the Teaching Unit.
Part 1

- Mechanical architectures of robots: mobility of handling and locomotion systems, task parameters and principles of robot control.
- Rotation, translation and homogeneous transformation in space.
- Geometrical modelling of manipulator robots: Denavit Hartenberg parameters, operational and joint parameters, direct and inverse geometrical model, point-to-point position control.
- Kinematic modelling, direct and inverse, speed control and trajectory tracking.
- Geometrical features of the manipulators, working space
- Gear and force transmission, manipulability, redundancy
- Extension of the notion of operational space to mobile robots
- LAB 1: Inverse geometric model and point-to-point control (6-axis robot)
  LAB 2: Inverse kinematic model and trajectory tracking (3-axis robot)

Part 2

- What is AI? General problem.
- Knowledge Representations and Logic and discussion session
- Algorithms for Searching in Status Spaces and discussion session /Labs
- Action planning
- Reasoning in the Uncertainty, Bayesian Reasoning and discussion session
- Markov and discussion session/Lab decision-making processes
- Machine Learning Basics.
- LAB 1: Algorithms for Searching in Status Spaces
- LAB 2: Markov Decision-Making Processes

Prerequisite. Part 1 Vector calculus - Matrix calculus - Linear algebra. Part 2: no specific prerequisite

Resources available to students. Transparencies used in the courses. Statements and corrected discussion session.

Skills developed in the unit.
Part 1:

- To know the different components of a manipulator robot
- Model its geometry and kinematics
- Propose control laws to control it
- To know the geometry of the usual robots according to the required tasks

Part 2:

- Know basic concepts of learning and reinforcement learning apply search algorithms in state spaces,
- Understand and apply Bayesian reasoning and Markovian processes.

Updated 01/03/2020

Hourly volumes in and out of the classroom.
Attendance hours Part 1: 24 hours divided into 6 sessions of 2 hours each, 4 sessions of 2 hours of DISCUSSION SESSIONS, 2 sessions of 2 hours of digital DISCUSSION SESSIONS.
Attendance hours Part 2: 28 hours divided into 8 sessions of 2 hours of classes, 2 sessions of 2 hours of DISCUSSION SESSIONS, 2 sessions of 4 hours of digital DISCUSSION SESSIONS.

Expected personal work for each part: 30 - 40 h.

Evaluation. For each part two written exams (/75) + a grade of LAB (/25).

Teacher. Mr F. Ben Amar

Object Oriented Programming in Python.

Level CMI4- **Semester** S7 - **Credits** 3 ECTS - **Code MU4RBI01-** Automatic and Robotics Master's Degree

Pedagogical presentation.

This course introduces the fundamental concepts of Object-Oriented Programming (OOP) and has the following objectives:

- Acquire mastery of the fundamental concepts of OOP (Classes, Objects, Legacy) and the associated mechanisms (encapsulation, abstraction) that will allow you to write structured programs.
- To learn how to model in the form of classes a set of specifications.

The course is structured around examples of UML modelling and the corresponding Python code (commented) in order to allow students to understand the essential notions. Tutorials and hands-on exercises allow them to become familiar with their implementation.

Content of the Teaching Unit.

Course 1 :

- Python algorithm and syntax recall
- Conditional, loops.
- Functions, basic libraries (math).
- Tables (and lists).

Course 2:

- Classes and Objects
- Attributes, methods, encapsulation.
- Builder, destroyer.
- Association / aggregation.
- Operator overload (equality, display, ...). Class attributes and methods.

Course 3: Heritage and Abstraction

The DISCUSSION SESSIONSs and TPs will focus on the problem of finding the zero of a function by dichotomy or by Newton's algorithm. The students will start with a (non-object) implementation in the case of polynomials, then will progressively integrate the code realized in an increasingly complex object modelling allowing to treat various functions (sine, exponential, sum of functions, ...). A personal work will be asked to the students at the beginning of UE to acquire a good knowledge of the Python syntax (non-object).

Prerequisite. Basics of algorithmic

Bibliographical references.

- T. Ziade. Python programming. Editions Eyrolles, 2006.
- C. Delannoy. Initiate yourself to programming. Editions Eyrolles, 2008.

Resources available to students. PDFs of the courses (slides), topics of Tutorials and TPs, source codes to start TPs, quizzes (via Moodle) for evaluation.

Skills developed in the unit.

- Acquire the concepts of OOP programming (in Python).
- Model a simple specification in a UML diagram.
- Propose the corresponding Python implementation.

Hourly volumes in and out of the classroom.

Total face-to-face hours: 30 hours divided into 8 hours classes, 3 discussion session of 2 hours, 4 digital Lab sessions of 4 hours.

Expected personal work: 30-50 hrs.

Evaluation.

The evaluation is based on two written scores (1 MCQ + 1 final exam, 60%) and 1 PT score (40%).

Teacher. Mr T. Dietenbeck.