Syllabus Cursus Master's Degree in Engineering, Mechanics.

Sorbonne University CMI5

Energy and Environment (EE)

List of Teaching Units

Semester 9

Core Units

- Technoscience, ethic and society
- Energy Challenges of the 21st Century

Theme Tools and Methods for Zero Energy Buildings (OMEBA)

- Turbulent flow Modelling
- Physical and numerical aspects, regulation of modelling in the building industry.
- Highly energy-efficient thermal comfort.
- Radiative and convective transfers: modelling and simulation.

Aerodynamics and Environmental Impact (AIR)

- Turbulent flow Modelling
- Numerical simulation for power engineering
- Aero-acoustics and energetics of aircraft engines
- Radiative and convective transfers: modelling and simulation.

Theme Combustion, emission limitation, new energies (CLEANER)

- Fuels for the energy transition
- Aero-thermochemical Modelling, applications to propulsion
- Aero-acoustics and energetics of aircraft engines
- Battery storage and electric propulsion

Semester 10

- Certification
- Deepening Project
- Graduation internship

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		Title Teaching Unit - Master Cycle - Level 5e A -S9	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 *
		Energy and Environment (EE)								
		Energy Challenges of the 21st Century	MU5MEE01	28	30			58	60-80	6
	Enseignements électifs de thématique	**Tools and Methods for Zero Energy Buildings (OMEBA)**								
		Turbulent flow Modelling	MU5MEE05	22	22	12		56	80-90	6
		Physical and numerical aspects, building regulations.	MU5MEE07	31	16			47	50-70	6
		Highly energy-efficient thermal comfort.	MU5MEE08	32	10	24		66	50-70	6
		Radiative and convective transfers: modelling and simulation.	MU5MEE04	35	17	6		58	80-90	6
		Aerodynamics and Environmental Impact Theme (AIR)								
		Turbulent flow Modelling	MU5MEE05	22	22	12		56	80-90	6
		Numerical simulation for power engineering	MU5MEE02	8		48		56	60-80	6
		Aero-acoustics and energetics of aircraft engines	MU5MEE09	36	16	4		56	60-80	6
		Radiative and convective transfers: modelling and simulation.	MU5MEE04	35	17	6		58	80-90	6
		Theme Combustion, emission limitation, new energies (CLEANER)								
		Fuels for the energy transition	MU5MEE03	42		18		60	80-90	6
		Aerothermochemical Modelling, applications to propulsion	MU5MEE06	24		43		67	80-90	6
		Aero-acoustics and energetics of aircraft engines	MU5MEE09	38	16	4		58	60-80	6
		Battery storage and electric propulsion	MU5MEE12	18	18			36	40-60	6
Total Tronc commun 6+ 6* ECTS - Total thématique 24 ECTS - Total CMI5 - S9 EE = 30 ECTS + 6*										

	Title Teaching Unit - Master Cycle - Level 5e A -S9	Code	Lecture	Discussion session	Lab	SSA	Hours Attendance	Work Personal	EC TS
CMI5 S10	Certification TOIC /TOEFL	MU4LVANT				30		30-40	3*
	Projet d'approfondissement	MU5EEG04				40		50-60	3*
	Stage de fin d'études	MU5MES03					800	80-100	30
Total CMI 5 - S10 30 ECTS + 6 *									

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

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Semester 9

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Technosciences, Ethic and Society

Level LECTURE5 - **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.

References. 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

Energy Challenges of the 21st Century

Level CMI5 - **Semester** S9 - **Credits** 6 ECTS - **Code** MU5MEE01
Master of Science for Mechanical Engineers with a specialization in Energy and Environment

Pedagogical presentation.

The course is divided into two parts. The first part recalls the concepts of energy conversion Modelling both in terms of energy balance and exercise. The aim is to study and analyse energy systems. Emphasis will be placed on a large number of illustrations in various application sectors. The proposed studies will focus on innovations and new systems that tend towards rational use of energy.
At the same time, a series of conferences will be proposed in order to complete the knowledge in the field of energy conversion but also in related aspects of energy economics, climate change, sustainable development, on the evolution of energy carriers, their storage and availability.

Content of the Teaching Unit.

Study and analysis of energy systems. The aim of this part is to present the principles of energy conversion for conventional and renewable energy resources and to explain the most important parameters that define energy conversion efficiency, resource implications and the economics of energy conversion technologies. After a reminder of modelling principles, many energy conversion systems will be analysed and an optimisation phase will be proposed.
Program :
Overview of energy issues
Thermodynamic principles applicable to energy conversion systems, review of thermodynamic cycles, heat pumps and refrigeration cycles, cogeneration
Energy and energy balance writing for a control volume
Renewable energy carriers, their physical principles and the essential equations: Solar (photovoltaic and thermo-collectors/concentrators), geothermal, biomass (a.o. gasification, biogas, liquid biofuels), hydraulic, wind, etc.
Applications :
Exergy of a steam generator, Cycle Combined gas turbine power plant, Wind turbine Energy and energy balance, Geothermal and district heating, Compressed air vehicle, LNG terminal, Gas liquefaction, Solar tank, Internal combustion engine, Fuel cells and hydrogen as an energy carrier, Thermal energy from the sea, Solar thermal systems, External heat input engines: Combined heat and power production, Cogeneration and trigeneration (cold or hot cogeneration)
Conference cycle
The idea propagated during these conferences is to exploit energies in a "sustainable" vision. Breaks are necessary, as well as changes in behaviour, in order to achieve greater control of global energy consumption with regard to its type of production. A presentation of the challenges we are facing (climate, development, resources) and scenarios for the planet's energy future are proposed and analysed. The strong constraints posed by the threat of global warming and access to energy resources lead us to envisage a transition scenario towards a society that consumes less fossil fuels (coal and hydrocarbons). In this hypothesis, it is a question of examining the possible energy disruptions: major sectors where should efforts be made? Moving towards scientific and technical disruptions (in the fields of renewable energies, electricity storage, nuclear power, etc.) and how to speed up the process.
The following list of conferences is not exhaustive but gives a thematic range of what is usually presented.

- Climate change, yesterday, today, tomorrow. Regional climatological analysis, weather patterns and variability (wind, solar). Industrial combustion. Combustion in onshore gas turbines, emission control and alternative fuels. Biofuels: pathways and impacts. Hydrogen - applications, environmental and economic considerations, prospects. Alternative aeronautical fuels. Energy recovery from waste. The challenges of air transport. Ground propulsion and biofuels.
- Optimization of air conditioning systems. Energy and Eco design of buildings. Deep-sea oil production. Coupling and storage of electrical energy. Concentrated solar energy, emergence of a high-potential sector. Solar energy, low-energy building design, how to improve energy performance from the design stage. Networked energy management and smartgrid.

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Prerequisite. Knowledge of energy systems and the basics of thermodynamics at master's level.

Bibliographical references.

- Moran M. J. and Shapiro, H. N., Fundamentals of Engineering Thermodynamics, 3rd edition, John Wiley & Sons, 1998.
- 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.
- L. Borel, Thermodynamics and Energy, polytechnic and university presses of the French-speaking part of Switzerland.

Resources available to students

Course handout in pdf format, with slides presented in the lecture hall if necessary. Topics of discussion sessions and the answer keys, annals of the exams of the last few years with answer keys and comments as well as numerous complementary documents. Speakers' boards.

Scientific knowledge developed in the unit.

General knowledge, very varied conferences on energy, climate, storage, transport.
Presentation of the challenges we face (climate, development, resources)
Quantify the efficiency and main emission sources of energy conversion processes
Explain the efficiency and main emission sources of energy conversion processes
Model of energy conversion systems and industrial processes
Elaborate energy conversion scenarios
Describe the principles and limitations of major energy conversion technologies
Compare energy conversion systems

Skills developed in the unit.

- Write energy and exercise balances of any systems
- Optimization concept
- Write a scientific or technical report.
- Access and evaluate appropriate sources of information.
- Identify the different roles that are involved in well-functioning teams and take on different roles, including leadership roles.

Hourly volumes in and out of the classroom.

Total attendance hours: 58 hours divided into 20 hours of lectures, 8 hours of classes, 30 hours of discussion sessions.
Expected personal work: 60-80 h

Evaluation.

Evaluation on the basis of a report giving a precise scientific view of one of the topics dealt with at the conferences and a three-hour written examination.

Knowledge test weighting distribution: Written 80% - C.C. 20

Teacher. Mr P. Guibert, Mr A. Matynia

Tools and methods for zero energy buildings (OMEBA)

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Turbulent flow Modelling

Level CMI5 - **Semester** S9 - **Credits** 6 ECTS - **Code** MU5MEE05
Master of Science for Mechanical Engineers with a specialization in Energy and Environment

Pedagogical presentation.
The objective 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, as well as an introduction to the modelling of turbulent flows with a view to predicting their dynamics through numerical simulation. Finally, an introduction to the use of major calculation codes for research and engineering will be given.

Content of the Teaching Unit.

- Objects and methods of the CFD. Advection/diffusion mechanisms in Navier-Stokes. Structured and unstructured meshes.
- Interpolation (1D) and polynomial (2D, 3D) approximation. Error and precision order. Finite volumes, high order spatial discretization, reconstruction problem. Remarks on generalization DG and h-p.
- LSQ reconstruction in unstructured mesh (general method and concrete examples).
- Flow at cell interfaces (Riemann's problem and examples: incompressible, compressible).
- Advection-diffusion equation (analytical solution, numerical approximation and spectral error). Spectral accuracy and time integration (explicit, implicit, stability). Linear stability analysis of known numerical patterns: effect of spatial order.
- Discrete system solution: explicit DNS, implicit RANS/PANS (preconditioned Krylov solvers). Solving large non-linear systems: an open problem. Description turbulent flows. Characteristic scales of turbulence.
- Instantaneous compressible Navier-Stokes equations. Overall average. Reynolds and Favre decompositions. Compressible turbulent flows. Averaged Navier-Stokes equations.
- Transport equations at Reynolds voltages in incompressible and compressible flows.
- Statistical Modelling of turbulence. Classification and description of the different approaches. Transport equation of the dissipation rate of turbulent kinetic energy.
- Modelling with 2 k-e type transport equations in compressible flow. Turbulent flow in a plane channel. Reynolds stress Modelling. Low-Reynolds and wall effects. Model of k-e turbulence in a planar channel.
- Triple speed correlation Modelling. Application to the established plane channel. Reynolds tensor anisotropy tensor. Notion of achievability. Position of the physical problem (aircraft wing transonic drag crisis) and use of the software (aerodynamics).
- Mesh size, boundary conditions, choice of turbulence model, calculations. Comparison with measurements, physical analysis of the results, critical analysis of the model (NASAturbmodels website).

Prerequisites. Fluid mechanics. Navier Stokes equations. Incompressible and compressible flows. Conservative and non-conservative forms. Index notations.

Scientific knowledge developed in the unit.

- Analysis of a compressible turbulent flow.
- Determination of advanced numerical schemes.
- Understanding compressible turbulence models.

Skills developed in the unit.

- Operate a database.
- Analyze results obtained with turbulence models.
- Use advanced numerical simulation software.
- Analyze, criticize results and write a scientific report.
- Work as a team.

Hourly volumes in and out of the classroom.
Total attendance hours: 56 hours divided into 22 hours of C, 22 hours of discussion sessions and 12 hours of project.
Expected personal work: 80-90 hrs.

Evaluation. Evaluation is based on a 3-hour exam (60%) and a project oral (40%).

Teacher. Mrs. I. Vallet, Mr. G. Gerolymos and Mr. B. François

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Physical, numerical and regulatory aspects of building modelling

Level CMI5 - **Semester** S9 - **Credits** 6 ECTS - **Code** MU5MEE07
Master of Science for Mechanical Engineers with a specialization in Energy and Environment

Pedagogical presentation.
This course aims to give students an overview of the field of thermal Modelling/simulation of buildings. After an introduction to the context of the course, a first part of the course focuses on the bioclimatic aspects of buildings and the choice of systems, within a regulatory simulation framework.
The second part deals with the physical and numerical aspects of envelope and system modelling.
Through numerical projects, the course focuses on the application of detailed dynamic simulation to the design and evaluation of control strategies in buildings and integrated energy production systems.

Content of the Teaching Unit.
Modelling part. Elements of the building system: walls, air zones, occupants, external stresses, behaviour, regulation. Modelling approach: internal phenomena, thermal and mass interactions, spatial discretization, shape of the system of equations, temporal discretization, simulation. Conduction in walls. Enthalpy transport between zones and in fluid loops.
Phase change materials. Solar collector, internal exchanges by convection and radiation. External exchanges and stresses. Behaviour of the occupants.
Thermal regulation part. Regulatory landscape around the energy performance of buildings: European directive EPBD, Grenelle de l'Environnement, thermal regulations, DPE, certification labels.
Presentation of the thermal regulations for new buildings (RT 2012 RT 2020): the main principles, the requirements, the phenomena taken into account, the conventional aspects, the Th-Bât rules, the calculation method (Th-BCE 2012).
TP: Modelling of a studio, example including all notions and entities seen in the course.
TP: Model of a solar collector, simulation of regulation strategies, highlighting of a simple model.
TP: Model of a studio with solar heating including a stock using phase-change materials.
TP: regulatory calculations.

Prerequisite. Heat transfers.

Resources available to students. Course handout in pdf format and lecture boards if available. Topics of discussion sessions and the corrected papers, annals of the exams of the last years with the corrected papers and comments as well as many complementary documents.

Scientific knowledge developed in the unit.
- Dynamic thermal modelling approach.
- Energy issues in the building sector
- Thermal regulation of buildings
- Thermal Comfort Basics
- Methodology for the physical analysis of phenomena
- Dynamic thermal modelling approach
- Notions of numerical methods
- Application software

Skills developed in the unit.
- Thermal regulation of buildings.
- Methodology of physical analysis of phenomena.
- Writing summary reports. Team work.
- Critical analysis of results. Initiative and practicality.

Hourly volumes in and out of the classroom.
Total attendance hours: 47 hours divided into 31 hours of lecture, 16 hours of Lab.
Expected personal work: 50 - 70 h .

Evaluation. The evaluation is based on LAB reports (50%) and an oral presentation (50%).

Teacher. P. Joubert; A. Novel NOVEL; A. Sergeant; S. Riou

Updated 01/03/2020

SCIENCES SORBONNE UNIVERSITÉ

Highly efficient thermal comfort

Level CMI5 - **Semester** S9 - **Credits** 6 ECTS - **Code** MU5MEE08

Master of Science for Mechanical Engineers with a specialization in Energy and Environment

Pedagogical presentation.

After a reminder of the principles of thermodynamics and an introduction to the methods of systemic analysis and energy integration (in particular the pinch method), the course focuses on presenting the main technologies used for thermal comfort in buildings. Steam compression cycles for the production of heat and cold are presented and modelled. Exercise analysis will be applied to the study of the sources of irreversibilities of these systems and especially the students are trained to use this technique to choose the working fluids and the thermodynamic architecture of the cycles (temperature shift, transcritical cycles, multi-stage cycles). The course also deals with the problem of refrigerants and the regulation of their use by legislation. Humid air is an essential component of comfort; air conditioning consists in modifying the balance of humid air indoors. The various possible transformations are used by desiccant wheel systems to blow air at the desired conditions. The thermo-dynamic analysis of the cycle makes it possible to evaluate its energy consumption. Heat input by solar collectors is possible. Sorption, the active principle of desiccant wheels, can also be used in a closed cycle, for which the most developed technology is liquid sorption. Once these machines have been described, their thermodynamic analysis allows their performance to be evaluated and high-performance cycles to be envisaged.

Content of the Teaching Unit.

Several sessions of practical work are organized on devices such as :

- Reversible heat pump with variable speed on compressor, fans and pumps
- Experimental cold storage platform
- Aeraulic model for the study of adiabatic cooling of air by water evaporation

A second part of the course focuses on the modelling of a building and its use scenarios, calculations of the thermal needs of a building, interpretation of the results and research. Refrigeration Systems and Heat Pumps, Cycle Efficiency. Introduction of the concept of exergy, energy analysis. Humid air - humidification - direct and indirect evaporative cooling - performance calculations, water adsorption - desiccant wheel dehumidification - Pennington cycle cooling.

- Physical phenomena and mathematical models in building thermics. DISCUSSION SESSIONS on the presentation of Alcyone and the capture of a multi-zone building. DISCUSSION SESSIONS on the presentation of Pléiades, the calculation of the thermal needs of a building, the interpretation of the results and the search for alternatives to reduce energy needs.
- LCA in the building: standards, methods, steps. DISCUSSION SESSIONS on the presentation of NovaEquer, the capture of the building studied on Pléiades, simulation and interpretation of results.
- Energy storage for cold production. LAB Cold production unit, cold storage, adiabatic cooling.

Prerequisite. Advanced thermodynamics. Basics of heat exchangers (balances, efficiency). Thermal.

Scientific knowledge developed in the unit.

- Thermodynamics of refrigeration / air conditioning.
- Humid air treatment
- Air handling unit
- Refrigeration cycle by vapour compression or absorption

Skills developed in the unit.

- Carry out a systemic analysis of a set of energy needs.
- Highlight the need for energy storage in the building.
- Understanding and analysing an air handling unit.
- Analyse a refrigeration cycle by vapour compression or absorption.
- Know how to calculate the evolution of humid air in an air handling unit.
- Know how to read the humid air diagram.
- Know how to use advanced scientific software.
- Know how to manipulate complex experiments (sensors, conditioners, data acquisition, experimental design).

Hourly volumes in and out of the classroom.

Total attendance hours: 66 hours divided into 32 hours of lecture, 10 hours of discussion sessions and 24 hours of lab. Expected personal work: 50 - 70 h

Evaluation. The evaluation is based on a 2-hour review (40%) of the lab (20%) and CC (40%).

Teacher. M. D. Leducq, M. Pons, M. Cohen and F. Trinquet.

SCIENCES SORBONNE UNIVERSITÉ

Radiative and convective transfers: modelling and simulation

Level CMI5 - **Semester** S3 - **Credits** 6 ECTS - **Code** MU5MEE04
Master of Science for Mechanical Engineers with a specialization in Energy and Environment

Pedagogical presentation.
The aim of the EU is to provide students with the theoretical tools needed to model heat transfer. The different modes of heat transfer are presented and emphasis is placed on applications to complex systems. The student is thus led to proceed by himself to a progressive analysis of such systems, in order to model, in a rigorous and judicious way, the various heat transfers involved. A practical application of the lessons will be carried out throughout the module in the form of projects on calculation machines.
Keywords: Convective transfer. Intensification of transfers. Radiative transfers. Radiation from opaque bodies. Radiation of gases, radiation of combustion products. Radiative Transfer Equation. Sensitivity to the radiative properties of semi-transparent media.

Content of the Teaching Unit.
Economic and societal context; forced convection reminders :

- Natural convection. Natural ventilation, Effect of confinement. Laminar and turbulent plumes
- TP: modelling of natural convection in cavities.
- TP: modelling of the coupling of convection and radiation.
- TP: modelling of a chimney.
- Digital project: application to an industrial or building case.

Reminders on radiative transfers between opaque bodies:

- Physics of semi-transparent media. Radiative Transfer Equation.
- Method for the numerical resolution of the Radiative Transfer Equation (discrete ordinates).
- Radiative transfer modelling levels within CFD codes.
- TP: Evaluation of radiative properties in a semi-transparent medium (flame).
- TP: Solving the Radiative Transfer Equation in a semi-transparent medium (flame).

Prerequisite. Fluid mechanics Thermal transfers: basics.

Resources available to students. Course handout in pdf and boards presented in the lecture hall. Topics of DISCUSSION SESSIONS, graded papers, exam annals with graded papers and comments, complementary documents.

Scientific knowledge developed in the unit.

- Modelling of convective and radiative transfers.
- Numerical simulation of fluid mechanical and thermal coupling.
- Numerical simulation of radiative transfers in semi-transparent media

Skills developed in the unit.

- Use CFD software, matlab.
- Numerically solve conservation equations.
- Write a report.
- Work as a team.

Hourly volumes in and out of the classroom.
Total attendance hours: 58 hours divided into 35 hours of lecture, 17 hours of Lab and 6 hours of project.
Expected personal work: 80-90 h

Evaluation. The evaluation is based on a 3-hour exam (65%) of Lab (15%) and a project oral (20%).

Teacher. Mrs. A. Sergeant; G. Legros

Aerodynamics and Environmental Impact (AIR)

Updated 01/03/2020

Turbulent flow Modelling

Level CMI5 - **Semester** S9 - **Credits** 6 ECTS - **Code** MU5MEE05
Master of Science for Mechanical Engineers with a specialization in Energy and Environment

Pedagogical presentation.
The objective 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, as well as an introduction to the modelling of turbulent flows with a view to predicting their dynamics through numerical simulation. Finally, an introduction to the use of major calculation codes for research and engineering will be given.

Content of the Teaching Unit.

- Objects and methods of the CFD. Advection/diffusion mechanisms in Navier-Stokes. Structured and unstructured meshes.
- Interpolation (1D) and polynomial (2D, 3D) approximation. Error and precision order. Finite volumes, high order spatial discretization, reconstruction problem. Remarks on generalization DG and h-p.
- LSQ reconstruction in unstructured mesh (general method and concrete examples).
- Flow at cell interfaces (Riemann's problem and examples: incompressible, compressible).
- Advection-diffusion equation (analytical solution, numerical approximation and spectral error). Spectral accuracy and time integration (explicit, implicit, stability). Linear stability analysis of known numerical patterns: effect of spatial order.
- Discrete system solution: explicit DNS, implicit RANS/PANS (preconditioned Krylov solvers). Solving large non-linear systems: an open problem. Description turbulent flows. Characteristic scales of turbulence.
- Instantaneous compressible Navier-Stokes equations. Overall average. Reynolds and Favre decompositions. Compressible turbulent flows. Averaged Navier-Stokes equations.
- Transport equations at Reynolds voltages in incompressible and compressible flows.
- Statistical Modelling of turbulence. Classification and description of the different approaches. Transport equation of the dissipation rate of turbulent kinetic energy.
- Modelling with 2 k-e type transport equations in compressible flow. Turbulent flow in a plane channel. Reynolds stress Modelling. Low-Reynolds and wall effects. Model of k-e turbulence in a planar channel.
- Triple speed correlation Modelling. Application to the established plane channel. Reynolds tensor anisotropy tensor. Notion of achievability. Position of the physical problem (aircraft wing transonic drag crisis) and use of the software (aerodynamics).
- Mesh size, boundary conditions, choice of turbulence model, calculations. Comparison with measurements, physical analysis of the results, critical analysis of the model (NASAturbmodels website).

Prerequisites. Fluid mechanics. Navier Stokes equations. Incompressible and compressible flows. Conservative and non-conservative forms. Index notations.

Scientific knowledge developed in the unit.

- Analysis of a compressible turbulent flow.
- Determination of advanced numerical schemes.
- Understanding compressible turbulence models.

Skills developed in the unit.

- Operate a database.
- Analyze results obtained with turbulence models.
- Use advanced numerical simulation software.
- Analyze, criticize results and write a scientific report.
- Work as a team.

Hourly volumes in and out of the classroom.
Total attendance hours: 56 hours divided into 22 hours of C, 22 hours of discussion sessions and 12 hours of project.
Expected personal work: 80-90 hrs.

Evaluation. Evaluation is based on a 3-hour exam (60%) and a project oral (40%).

Teacher. Mrs. I. Vallet, Mr. G. Gerolymos and Mr. B. François

Updated 01/03/2020

Numerical simulation for power engineering

Level CMI5 - **Semester** S9 - **Credits** 6 ECTS - **Code** MU5MEE02
Master of Science for Mechanical Engineers with a specialization in Energy and Environment

Pedagogical presentation.

The objective of this course is to approach numerical simulation in energetics from a practical point of view, with most of the teaching given in the form of practical work. The most important steps in the implementation of a numerical simulation will be covered in a concrete way:

- Determining the calculation area. Meshing.
- Selection of physical models and numerical methods.
- Follow-up of the simulation. Visualization, post-processing and interpretation of results.

During these sessions, the CEDRE software (developed by ONERA, used in the aerospace field by Safran, ASL, MBDA,...) and StarCLECTURE+ (commercial software developed by CD-Adapco, widely used in the industry) will be used.

Content of the Teaching Unit.

Workshop 1: DIGITAL ENERGY SIMULATION WITH CEDAR

Highlighting the specificities of numerical simulation in energetics (multi-fluid flows, multi-species flows, reagents, complex diffusion laws, couplings,...). Main steps in the realization of a numerical simulation and presentation of the CEDRE code (developed by ONERA, used by Safran, ArianeGroup, MBDA and Airbus).
Overview of the most widespread approaches to turbulence modelling/simulation (RANS, LES, hybrid RANS/LES methods, DNS)
Fundamentals of temporal integration (implicit/explicit, stability, precision,...)
Examples of numerical simulations in energetics (aeronautical combustion chambers, rocket engines, stato and superstator reactors)".
Basics of numerical simulation of non-reactive flows.

- Getting to grips with the GMSH mesher (http://gmsh.info) and creating a backward facing step mesh (Backward Facing Step, or BFS, configuration). Data entry of a non-reactive numerical simulation of the BFS configuration with the CEDRE code: choice of physical models (turbulence,...) numerical methods, time steps, archived quantities...
- Starting the simulation in parallel (4 cores). Verification of the convergence of the calculation: analysis of the decay of the residuals (fields and integral quantities), flow balancing, visualization and interpretation of the local time step field.
- Post-processing of the results with the Paraview visualization tool (https://www.paraview.org): plotting of velocity fields, turbulent kinetic energy, power lines.

Basics of numerical simulation of reactive flows

- Reminders on turbulent combustion modelling: reaction mechanisms, infinitely fast chemistry models, Borghi diagram. Equilibrium calculations at fixed pressure and enthalpy highlighting the influence of the richness and composition of the fresh gas mixture. Choice of a set of species to carry out the numerical simulation of the reactive BFS configuration.
- Validation of a reduced reaction mechanism for CH_4/air combustion using the simulation of a freely propagating 1D premixed flame (based on the calculation of the flame consumption rate). Implementation of the reactive numerical simulation of the BFS configuration with CEDRE: choice of physical models (turbulence, combustion, diffusion laws...) and numerical methods (spatial discretization and temporal integration), time steps, archived quantities ...
- Study of the combustion/turbulence interaction: draw the Damkhöler and Karlovitz fields, give a synthetic view of how the combustion/turbulence interaction takes place in the studied configuration with the help of a Borghi diagram".

- Example 1 Design of a rocket engine by numerical simulation. Objective: to simulate a rocket engine prototype to evaluate its thrust, combustion efficiency, design cost and avenues for improvement.
- Example 2 Numerical simulation of liquid oxygen atomization in rocket engines. Objective: to implement different numerical approaches to simulate liquid oxygen and its atomization in a prototype rocket engine, with elements of phenomenology relating to the operation of liquid propellant rocket engines under subcritical injection conditions.

WORKSHOP 2: Study of TURBOMACHINES

- Getting to grips with the simulation tool.
- Approach by the realization of a tutorial "numerical simulation of flow and heat transfer on a flat plate".
- Definition of the boundary conditions, Realization of the mesh, Definition of the physical model, Implementation of the post-processing, Study of the mesh convergence".
- Example 1: Sizing a gas turbine. Thermodynamic study of the system, Optimization of parameters, Definition of component specifications, Sizing of components using ANSYS Vista CCD and discussion sessions ".
- Example 2 "Numerical simulation of the compressor and/or turbine using C++", Analysis of the results, pressure, speed and temperature fields. Study of the turbine/compressor coupling".

Prerequisites. Solid foundations in fluid mechanics. Concepts of energetics. Basics of numerical methods for fluid mechanics ("finite volume" methods, off-center/centered schemes, implicit/explicit, CFL.

Bibliographical references.

- L. Pram and E. Lifchitz, Theoretical Physics Volume 6, Fluid Mechanics
- An Introduction to Fluid Dynamics' de G.K. Batchelor (Cambridge University Press)
- R. Borghi and M. Destriau, La combustion et les flammes, éditions Ophrys
- T. Poinsot, D. Veynante, Theorical and numerical combustion
- C. Hirsch, Numerical computation of internal and external flows, Elsevier
- F. Toro, Riemann solvers and numerical methods for fluid dynamics, Springer

Resources available to students. Documents presented in class. Annals.

Scientific knowledge developed in the unit.

- Fundamental concepts for the realization of the numerical simulation of a reactive flow.
- Phenomenology and Modelling elements of turbulent combustion.
- Numerical schemes of temporal integration (implicit/explicit, stability, precision).

Skills developed in the unit.

- Use basic UNIX commands. Make a mesh using GMSH (http://gmsh.info)
- Use the ONERA CEDRE code to carry out numerical energy simulations
- Visualize a solution and perform post-processing with Paraview (https://www.paraview.org)
- Learn how to code an elementary solver for EDP resolution in Mechanics.
- Use STAR code CLECTURE+
- Know how to write a technical report
- Learning to work in a team
- Access and evaluate appropriate sources of information.
- Identify the different roles that are involved in well-functioning teams and take on different roles, including leadership roles.

Hourly volumes in and out of the classroom.
Total attendance hours: 8 hours of class, 48 hours of practical work. 60-80 hours of personal work.

Evaluation.
The evaluation is based on a project report (30%) and oral presentation (20%) and a 3-hour exam (50%).

Teacher. Mr. L. Dorey, Mr. Deligant

Aeroacoustics and energetics of aircraft engines

Level CMI5 - **Semester** S9 - **Credits** 6 ECTS - **Code** MU5MEE09
Master of Science in Mechanical Engineering, Energy and Environment course

Pedagogical presentation.
This course aims to give students a clear vision of the challenges surrounding the design of aero engines. The course is divided into three parts, starting with the presentation of a turbojet engine from a system point of view, allowing a quick and parametric analysis of its performance. We will then focus on the aerodynamic and aero-acoustic problems of aero engines. Finally, we will focus on the engine combustion chamber, with both technological elements and the presentation of very recent approaches allowing the prediction of its essential characteristics (stability, polluting emissions, re-ignition in flight, heat transfers).

Content of the Teaching Unit.
Operation of an aircraft engine from a system point of view. Challenges in the design of an aeronautical combustion chamber. Theoretical elements necessary to understand and solve aerothermochemistry problems occurring in aero-engines.

- Realization of RANS numerical simulations of aeronautical combustion chamber.
- Aeronautical propulsion context (manufacturers, evolution of air traffic, environmental impact). Generalities on aeronautical engines, basic definitions: thrust (net/gross), efficiency (propulsive, thermal), SFC (Specific Fuel Consumption), Froude equations. Theoretical and real Gas Turbine Thermodynamic Cycle (TAG) (notions of work, power and efficiency).
- Turbine inlet temperature (TET) as a design issue (influence on efficiency, technologies and materials used for turbine blade design).
- Large engine families (turbojet, turbofan, turboprop). Recall of compressible aerodynamics: definition of the "total" state and use in thermodynamic cycles. System study of a single and dual flow turbojet engine (fan, compressor stage, combustion chamber, high and low pressure turbine stages, nozzle).
- Numerical project (realization of a program in Python 3, associated with a report written with LateX).
- Presentation of the characteristics of real engines (CFM56, GE90, M88), put into perspective with the results of system studies. Evaluation of performance improvement margins for current engines, presentation of new engine concepts: Open Rotor, rotary detonation engines, use of interchangers.
- Basics of Jet-Fuel/air combustion. Reminders of multi-species thermodynamics, calculation of the adiabatic temperature at the end of combustion (in lean and stoichiometric conditions).
- Simple Modelling of an aeronautical combustion chamber: the Perfectly Mixed Reactor.
- Design elements of a real aeronautical combustion chamber (RQL, LPP systems, "two-head" chambers, latest generation TAPS injectors).
- Single-phase and two-phase numerical simulation of an aeronautical combustion chamber of the TAPS type with the CEDRE code.

Context of aeroacoustics related to the environment (from the beginning of civil aviation to supersonic aircraft).

- Noise pollution in air transport. Prospects for improvement. Notions of signal processing, physical characteristics of a signal, Directivity and broadband noise spectrum, Fourier transform, Spectral density, Acoustic spectrum analysis of broadband and line bi-component turbomachines. General information on noise sources in turbomachinery. Models and correlations for noise prediction of turbomachinery.
- Basics of the aeroacoustic analogy, Lighthill's Theory. Formalism by Ffowcs Williams & Hawkings.
- FW&H applied to turbomachinery, Far Field Radiation. Integration of the FW&H equation with consideration of the monopolar and dipolar source. Kinematics and dynamics of the flow in the case of a subsonic axial turbomachine. Study of the associated acoustic radiation. Linearized unsteady aerodynamic theory of a profile. Broadband noise modelling: Noise interaction with upstream turbulence, Trailing edge noise.

Projects: Study of the aerodynamic performance of a centrifugal-type high-speed turbomachine (Ma=0. 8); Aeroacoustic characterization and spectral study of the acoustic behaviour of a high-speed turbomachine.

Prerequisite. Fundamentals of fluid mechanics Mechanics of continuous media.

Updated 01/03/2020

Scientific knowledge developed in the unit.

- Operation of an aircraft engine from a system point of view
- Challenges in the design of an aeronautical combustion chamber
- Theoretical elements necessary to understand and solve aerothermochemistry problems occurring in aeroengines
- Realization of RANS numerical simulations of aeronautical combustion chamber
- General aeronautical culture
- Noise sources in air transport
- Noise generating mechanisms in subsonic turbomachines
- Model for generating aerodynamic noise in rotating machines
- Method of reducing aerodynamic noise

Skills developed in the unit.

- Using the Python programming language
- Using LateX to write a report
- Use ONERA's numerical simulation code for energy CEDRE
- Know how to write a technical report
- Learning to work in a team
- Turbomachine noise Modelling
- Working on scientific journal articles
- Carry out aerodynamic measurements on a standard test bench
- Carry out and analyse acoustic measurements
- Analyzing an acoustic spectrum to reduce source noise

Hourly volumes in and out of the classroom.

Total attendance hours: 56 hours divided into 36 hours of lecture, 16 hours of discussion sessions and 4 hours of Lab.
Expected personal work: 60 - 80 h

Evaluation.

The evaluation is based on a 2-hour review (60%) of the Lab (20%) and Lab (20%) reports.

Teacher. Mr S. Kouidri

Radiative and convective transfers: modelling and simulation

Level CMI5 - **Semester** S9 - **Credits** 6 ECTS - **Code** MU5MEE04
Master of Science for Mechanical Engineers with a specialization in Energy and Environment

Pedagogical presentation.
The aim of the EU is to provide students with the theoretical tools needed to model heat transfer. The different modes of heat transfer are presented and emphasis is placed on applications to complex systems. The student is thus led to proceed by himself to a progressive analysis of such systems, in order to model, in a rigorous and judicious way, the various heat transfers involved. The teaching will be put into practice throughout the module in the form of projects on computing machines. Keywords: Convective transfer. Intensification of transfers. Radiative transfers. Radiation from opaque bodies. Radiation of gases, radiation of combustion products. Radiative Transfer Equation. Sensitivity to the radiative properties of semi-transparent media.

Content of the Teaching Unit.
Economic and societal context; forced convection reminders:
- Natural convection. Natural ventilation, Effect of confinement. Laminar and turbulent plumes
- TP: modelling of natural convection in cavities.
- TP: modelling of the coupling of convection and radiation.
- TP: modelling of a chimney.
- Digital project: application to an industrial or building case.

Reminders on radiative transfers between opaque bodies:
- Physics of semi-transparent media. Radiative Transfer Equation.
- Method for the numerical resolution of the Radiative Transfer Equation (discrete ordinates).
- Radiative transfer modelling levels within CFD codes.
- TP: Evaluation of radiative properties in a semi-transparent medium (flame).
- TP: Solving the Radiative Transfer Equation in a semi-transparent medium (flame).

Prerequisite. Fluid mechanics Thermal transfers: basics.

Bibliographical references.

Resources available to students. Course handout in pdf and boards presented in the lectures. Topics of DISCUSSION SESSIONS, graded papers, exam annals with graded papers and comments, complementary documents.

Scientific knowledge developed in the unit.
- Modelling of convective and radiative transfers.
- Numerical simulation of fluid mechanical and thermal coupling.
- Numerical simulation of radiative transfers in semi-transparent media

Skills developed in the unit.
- Use CFD software, matlab.
- Numerically solve conservation equations.
- Write a report.
- Work as a team.

Hourly volumes in and out of the classroom.
Total attendance hours: 58 hours divided into 35 hours of lecture, 17 hours of Lab and 6 hours of project. 80-90 hours of personal work.

Evaluation. The evaluation is based on a 3-hour exam (65%) of Lab (15%) and a project oral (20%).

Teacher. Mrs. A. Sergeant; G. Legros

Updated 01/03/2020

SCIENCES SORBONNE UNIVERSITÉ

Combustion, emission controls, new energies (CLEANER)

Updated 01/03/2020

SCIENCES SORBONNE UNIVERSITÉ

Fuels for the energy transition

Level CMI5 - **Semester** S9 - **Credits** 6 ECTS - **Code** MU5MEE03
Master of Science for Mechanical Engineers with a specialization in Energy and Environment

Pedagogical presentation.
Introduction to fuels and combustibles: fuel synthesis; description of fuel-environment interactions. The technological watch on fuels will be evoked as well as the fuels of the future, the new ways of synthesis. Applications will be related to fuel-related pollution control, the synthesis of new fuels, solar fuel, and the life cycle analysis of these fuels.

Content of the Teaching Unit.
Introduction to Fuels and Fuels: Fuel Synthesis

- Fuel-environment interaction, the case of aeronautical and land propulsion.
- Fuel Technology Watch. Fuel of the future, new synthesis routes. Fuel of the future, breakthroughs in synthesis, the case of concentrated solar power.

Applications

- Fuel-related pollution abatement.
- Synthesis of new fuels. Synthesis of solar fuels. Life cycle analysis

Prerequisites. Thermodynamics and fluid mechanics. Basics in physics and chemistry. Energetics. Combustion and pollutants.

Resources available to students. Course handout in pdf format and lecture boards if available. Topics of discussion sessions and the corrected papers, annals of the exams of the last years with the corrected papers and comments as well as many complementary documents.

Scientific knowledge developed in the unit.

- Understand the problem of fuel/mobility optimization.
- Energy Efficiency, Energy Transition.
- Energy and fuels. Life Cycle Assessment.
- Limitation of emissions associated with combustion.
- Instrumentation and Measurement

Skills developed in the unit.

- Know how to manipulate complex experiments (experimental design...).
- Draw up a set of specifications. Pilot a project.
- Know how to operate a database (data manipulation, extraction of relevant data, merging).
- Ability to reason and think clearly. Sense of initiative.
- Work in interaction.
- Ability to make value judgements and autonomous decisions.
- Write reports or technical documents.

Hourly volumes in and out of the classroom.
Total classroom hours: 58 hours, 42 hours of class, 12 hours of practical work and 6 hours of project.
Expected personal work: 80-90 h

Evaluation. The evaluation is based on a 3-hour exam (30%) of Lab (30%) and a project oral (30%) and CC (10%).

Teacher. Mr P. Da Costa, Mrs M. E. Galvez, Mrs A. Ben Amara, Mrs S. Ognier

Updated 01/03/2020

Aero-thermochemical modelling, applications to ground and aeronautical propulsion systems

Level CMI5 - **Semester** S9 - **Credits** 6 ECTS - **Code** -
Master of Science for Mechanical Engineers with a specialization in Energy and Environment

Pedagogical presentation.
The objective of the course is to allow, within the framework of a discipline commonly called "Aerothermochemistry", the acquisition of theoretical bases related to the modelling and simulation of turbulent and reactive flows.
Although general enough to be applicable to any flow in combustion, this teaching reserves a special place for aeronautical and ground propulsion. The specific problem of energy optimisation of systems through modelling of different types also includes the characterisation of the resulting chemical pollutants, which have a negative impact on the environment.
In this context, the teaching focuses on certain achievements related to the operation of two types of internal combustion engines, the first is an aeronautical-type propulsive turbomachine and the second is the internal combustion engine for automotive applications. In general, the key role of one of these essential components, the combustion chamber, will be emphasized, from the point of view of its optimal operation from the point of view of the desired improvement of the thermodynamic cycle, in order to achieve the objectives of reducing gaseous and particulate emissions imposed by the regulations in force, in particular those emanating from the ICAO to which the civil air transport sector is subject, and on the other hand the EURO6 standards for the automotive sector.
The aerodynamic properties will be discussed in order to understand the impacts on the properties of flames or self-ignition regimes.

Content of the Teaching Unit.
Part 1: Aerothermochemistry and Aeronautical Propulsion
- Environmental impact of the aviation sector: general context.
- Establishment of 3D equations from incompressible to reactive multi-species.
- Statistical description of turbulence and compressible turbulent flows, reactive multi-species.
- Turbulent combustion. Interaction between combustion and turbulence.

Part 2: Multi-zero dimensional reduced Modelling approach in project form
- 0D Modelling of combustion in an engine combustion chamber.
- Environmental impact of the automotive sector: general context.
- Mass transfer model, Curl mixing model.
- Modelling of the combustion phase, sub-model based on a phenomenological law, on the development of flame fronts.
- Eddy Burn up" model, and or homogeneous reactor model.
- Two-equation turbulence model. Model k e.
- Wall exchange model, radiation, convection, Empirical and semi-empirical models, Wall laws for heat transfer.
- Gas composition model (dissociation). NOX formation model.
- Parametric study (experimental design). Data analysis and presentation.

Part 3: Practical work
- Engine bench testing, performance and emissions analysis

Prerequisite. Navier-Stokes equations. General thermodynamics. General Chemistry. Differential and integral calculus. Probabilities: Basic knowledge. Knowledge of Matlab.

Resources available to students. Course handout in pdf format and lecture boards if available. Topics of DISCUSSION SESSIONS and the corrected papers, annals of the exams of the last years with the corrected papers and comments as well as many complementary documents.

Scientific knowledge developed in the unit.
- In-depth description of any type of propulsion system.
- Navier-Stokes equations.
- General thermodynamics. General Chemistry and Kinetics.

- Turbulence Modelling. Turbulent combustion : Modelling of typical flames.

Skills developed in the unit.

- Programming tools matlab. Writing calculation code similar to published codes.
- Use advanced numerical simulation software.
- Equation of models specific to combustion processes.
- Analyze results obtained with turbulence models.
- Analyze, criticize results and write a scientific report.
- Work as a team.

Hourly volumes in and out of the classroom.

Total attendance hours: 57 hours divided into 24 hours of lecture, 43 hours of Lab.
80-90 hours of personal work.

Evaluation.

The evaluation is done on the basis of the Lab (30%) and the project (70%).

Teacher. D. Gaffié, P. Guibert, J.F. Krawczynski, S. Pounkin

Aeroacoustics and energetics of aircraft engines

Level CMI5 - **Semester** S9- **Appropriations** 6 ECTS - **Code** MU5MEE09
Master of Science for Mechanical Engineers with a specialization in Energy and Environment

Pedagogical presentation.
This course aims to give students a clear vision of the challenges surrounding the design of aero engines. The course is divided into three parts, starting with the presentation of a turbojet engine from a system point of view, allowing a quick and parametric analysis of its performance. We will then focus on the aerodynamic and aero-acoustic problems of aero engines. Finally, we will focus on the engine combustion chamber, with both technological elements and the presentation of very recent approaches allowing the prediction of its essential characteristics (stability, polluting emissions, re-ignition in flight, heat transfers).

Content of the Teaching Unit.
Operation of an aircraft engine from a system point of view. Challenges in the design of an aeronautical combustion chamber. Theoretical elements necessary to understand and solve aerothermochemistry problems occurring in aero-engines.

- Realization of RANS numerical simulations of aeronautical combustion chamber.
- Aeronautical propulsion context (manufacturers, evolution of air traffic, environmental impact). Generalities on aeronautical engines, basic definitions: thrust (net/gross), efficiency (propulsive, thermal), SFC (Specific Fuel Consumption), Froude equations. Theoretical and real Gas Turbine Thermodynamic Cycle (TAG) (notions of work, power and efficiency).
- Turbine inlet temperature (TET) as a design issue (influence on efficiency, technologies and materials used for turbine blade design).
- Large engine families (turbojet, turbofan, turboprop). Recall of compressible aerodynamics: definition of the "total" state and use in thermodynamic cycles. System study of a single and dual flow turbojet engine (fan, compressor stage, combustion chamber, high and low pressure turbine stages, nozzle).
- Numerical project (realization of a program in Python 3, associated with a report written with LateX).
- Presentation of the characteristics of real engines (CFM56, GE90, M88), put into perspective with the results of system studies. Evaluation of performance improvement margins for current engines, presentation of new engine concepts: Open Rotor, rotary detonation engines, use of interchangers.
- Basics of Jet-Fuel/air combustion. Reminders of multi-species thermodynamics, calculation of the adiabatic temperature at the end of combustion (in lean and stoichiometric conditions).
- Simple Modelling of an aeronautical combustion chamber: the Perfectly Mixed Reactor.
- Design elements of a real aeronautical combustion chamber (RQL, LPP systems, "two-head" chambers, latest generation TAPS injectors).
- Single-phase and two-phase numerical simulation of an aeronautical combustion chamber of the TAPS type with the CEDRE code.

Context of aeroacoustics related to the environment (from the beginning of civil aviation to supersonic aircraft).

- Noise pollution in air transport. Prospects for improvement. Notions of signal processing, physical characteristics of a signal, Directivity and broadband noise spectrum, Fourier transform, Spectral density, Acoustic spectrum analysis of broadband and line bi-component turbomachines. General information on noise sources in turbomachinery. Models and correlations for noise prediction of turbomachinery.
- Basics of the aeroacoustic analogy, Lighthill's Theory. Formalism by Ffowcs Williams & Hawkings.
- FW&H applied to turbomachinery, Far Field Radiation. Integration of the FW&H equation with consideration of the monopolar and dipolar source. Kinematics and dynamics of the flow in the case of a subsonic axial turbomachine. Study of the associated acoustic radiation. Linearized unsteady aerodynamic theory of a profile. Broadband noise modelling: Noise interaction with upstream turbulence, Trailing edge noise.

Projects: Study of the aerodynamic performance of a centrifugal-type high-speed turbomachine (Ma=0. 8); Aeroacoustic characterization and spectral study of the acoustic behaviour of a high-speed turbomachine.

Prerequisite. Fundamentals of fluid mechanics Mechanics of continuous media.

Updated 01/03/2020

SCIENCES SORBONNE UNIVERSITÉ

Scientific knowledge developed in the unit.

- Operation of an aircraft engine from a system point of view
- Challenges in the design of an aeronautical combustion chamber
- Theoretical elements necessary to understand and solve aerothermochemistry problems occurring in aeroengines
- Realization of RANS numerical simulations of aeronautical combustion chamber
- General aeronautical culture
- Noise sources in air transport
- Noise generating mechanisms in subsonic turbomachines
- Model for generating aerodynamic noise in rotating machines
- Method of reducing aerodynamic noise

Skills developed in the unit.

- Using the Python programming language
- Using LateX to write a report
- Use ONERA's numerical simulation code for energy CEDRE
- Know how to write a technical report
- Learning to work in a team
- Turbomachine noise Modelling
- Working on scientific journal articles
- Carry out aerodynamic measurements on a standard test bench
- Carry out and analyse acoustic measurements
- Analysing an acoustic spectrum to reduce source noise

Hourly volumes in and out of the classroom.

Total attendance hours: 56 hours divided into 36 hours of lecture, 16 hours of discussion sessions and 4 hours of Lab.
Expected personal work: 60-80 hrs.

Evaluation.

The evaluation is based on a 2-hour review (60%) of the Lab (20%) and Lab (20%) reports.

Teacher. Mr S. Kouidri and Mr N. Bertier

Electrical energy storage in the automobile and its challenges

Level CMI5 - **Semester** S9 - **Credits** 6 ECTS - **Code** MU5MEE12
Master of Science for Mechanical Engineers with a specialization in Energy and Environment

Pedagogical presentation.
This is a course with a strong cultural content. The teacher will present the main specifications used in the automotive industry regarding energy storage. The different technologies will be reviewed with emphasis on current developments.
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Content of the Teaching Unit.

- Global energy context and energy storage issues.
- Electric mobility: specifications versus current battery technologies.
- New battery technologies for transport.
- Case studies.
- Li-ion: reaction mechanisms at work and their characterizations.
- Case studies.
- Aging of Li-ion Batteries: Phenomenology and Early Behavioural Patterns.
- Electrothermal behaviour of Li-ion batteries: Joule effect versus entropic effect.
- Case studies.
- Aging of Li-ion Batteries: Predictive Aging Models.

Prerequisites. Thermodynamics course.

Resources available to students. The main documents will be given in class.

Scientific knowledge developed in the unit.

- This course is of an application type. The scientific knowledge has been acquired upstream.

Skills developed in the unit.

- Know how to choose a type of battery according to the targeted application, the context ...
- Analyse battery aging and life cycle.

Hourly volumes in and out of the classroom.
Total attendance hours: 36 hours divided into 18 hours of lecture, 18 hours of discussion sessions.
Expected personal work: 40 - 60 h

Evaluation. Evaluation on the basis of a three-hour written exam.

Teacher. Mr S. Franger

SCIENCES SORBONNE UNIVERSITÉ

Semester 10

Updated 01/03/2020

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.