CENTRALE NANTES

MASTER OF SCIENCE, TECHNOLOGY AND HEALTH

2021-2022

YEAR 2

MECHANICAL ENGINEERING

COMPUTATIONAL MECHANICS

PROGRAMME SUPERVISOR(S):
Nicolas CHEVAUGEON

YEAR 2 - Autumn Semester

CORE COURSES

Course code	Title	ECTS Credits
CCMEC	Computational Configurational Mechanics	3
CFDIF	Computational Methods for Incompressible Flows	3
CPLED	Numerical Methods for Simulation of Coupled Problems	4
DDIS	Domain Decomposition and iterative Solvers	4
MODRED	Model Reduction	3
NUMUQ	Numerical Methods for Uncertainty Quantification	3
PMFLU	Physical Modeling of Fluids	3
XFEM	Extended Finite Element Method and Level Set Techniques	3

LANGUAGE COURSES

Course code	Title	ECTS Credits
CCE3	Cultural and Communication English	4
ESP3	Spanish Language	4
FLE3	French Language	4

YEAR 2 - Spring Semester

CORE COURSES

Course code	Title	ECTS Credits
THESIS	Internship / Thesis project	30

Computational Configurational Mechanics [CCMEC]

LEAD PROFESSOR(S): Nicolas MOËS

Objectives

At the end of the course the students will have:
- knowledge and understanding of the difference between material and immaterial evolving surfaces, of the importance of both interfacial and bulk balance laws and of the similarities and differences between moving interfaces among several physical phenomena.
- an ability to recognize an immaterial moving interface.
- an ability to set up the balance laws for a given physical phenomenon, extract the dissipation expression on the moving front, understand the quantities between which a constitutive model is needed to predict the front speed
- a good understanding of the equations for the following application areas: gas shock, phase change, fracture, surface tension.

Course contents

The course presents the use of configurational mechanics to model moving boundaries which
are not material boundaries (such as shocks in gas, phase change front, cracks, boundary of a contact zone, etc). In some cases, it is shown that the explicit representation of these boundaries
allows us to create powerful computational tools. The topics are organized as follows:
- Introduction to configurational boundaries
- Kinematics in the configurational setting
- Introduction to the Eshelby tensor
- Balance laws for the bulk and interfaces both in reference and current configurations
- Phase change and shock waves
- Fracture mechanics
- Interface stress and energy
- More exotic applications

Course material

- Lecture notes provided by the lecturer.
- Gurtin, M. E. Configurational forces as basic concepts of continuum physics, Springer, 2000.
- Maugin, G. A. Configurational forces, CRC Press, 2011.
- Kienzler, R., & Herrmann, G. Mechanics in material space, Springer, 2000.

Assessment

Individual assessment: EVI 1 (coefficient 1.0)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
English	3	18 hrs	0 hrs	0 hrs	4 hrs	2 hrs

Master Programme - Mechanical Engineering - Computational Mechanics

YEAR 2 - Autumn Semester

Computational Methods for Incompressible Flows [CFDIF]

LEAD PROFESSOR(S): Alban LEROYER / Michel VISONNEAU

Objectives

At the end of the course the students will have:
- knowledge and understanding of the basic elements needed to build a reliable numerical and physical modelling strategy for incompressible flow.
- an ability to understand the basic properties which must be fulfilled by the modelling strategies at continuous and discrete levels.
- an ability to understand the limitations and requirements of discretization methods needed to solve RANSE for high Reynolds flows around complex geometries.
- an ability to study independently; use library resources; use a personal computer for basic programming; effectively take notes and manage working time.

Course contents

This module presents the modelling strategies which are used to compute viscous incompressible flows by solving the Reynolds-Averaged Navier-Stokes Equations.
It covers mainly:
- a description of fully unstructured finite volume discretization strategies
- a study of coupling strategies to account for the incompressibility constraint and various pressure velocity coupling algorithms
- a description of a general face-based unstructured finite volume discretization
- a critical review of various applications ranging from shape optimization for ship hulls or aircraft wings and optimal flow control in aerodynamics

Course material

- Moukalled F. and Mangani L. and Darwish M., The Finite Volume Method in Computational Fluid Dynamics, Springer Verlag, 2016
- Peric and J. Ferziger., Computational Methods for Fluid Dynamics, Springer Verlag, 2002C.
- Hirsch, Numerical Computation of Internal and External Flows (Second Edition), Elsevier, 2007
- Peyret R., Handbook of Computational Fluid Mechanics, Academic Press, 1996.
- Marnet-CFD Best Practice Guidelines for Marine Applications of CFD: https://pronet.wsatkins.co.uk/marnet/guidelines/guide.html

Assessment

Individual assessment: EVI 1 (coefficient 1.0)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
English	3	18 hrs	0 hrs	0 hrs	4 hrs	2 hrs

Master Programme - Mechanical Engineering - Computational Mechanics

YEAR 2 - Autumn Semester

Numerical Methods for Simulation of Coupled Problems [CPLED]

LEAD PROFESSOR(S): Alban LEROYER / Laurent STAINIER

Objectives

At the end of the course the students will have:

▪ knowledge and understanding of: the challenges of coupled problems in numerical simulation, the broad classes of coupled problems, the different algorithmic approaches which are used in practice, their relative advantages and associated difficulties;
▪ an ability to: identify and classify coupled problems of various types, identify sources and mechanisms of coupling and their implication from a computational point of view; logically formulate an adapted algorithmic strategy for different practical coupled problems and translate the formulation to a practical computational approach using existing tools as much as possible; study independently; use library resources; solve coupled problems with existing finite element code(s).

Course contents

The course will present and discuss various computational approaches for the numerical simulation of coupled problems. The first part of the course will consider the problem from the abstract point of view of coupled systems. We will identify and describe:

▪ the various classes of coupled problems (weak vs. strong coupling),
▪ the various classes of algorithmic approaches (monolithic, staggered, sequential),
▪ the problems and difficulties linked to field transfer.

In the second part of the course, these concepts will be put into practice for two specific types of coupled problem.
Firstly, we will address thermo-mechanical problems. The different potential sources of coupling will be reviewed, as well as their implication from the computational point of view. The different algorithmic approaches will then be put into practice in project work for various thermo-mechanical problems (thermo-plasticity, thermo-visco-elasticity, shape memory alloys, etc).
Secondly, a focus will be made on Fluid-Structure Interaction, especially in hydrodynamics configuration where stabilisation issues occur due to added mass phenomenon. For this application, computer-based classes followed by a project using the industrial CFD suite Fine/Marine are provided to highlight the concepts learned during the lectures.

Course material

A selection of recent research papers on computational strategies for coupled problems will be used in the course. A good starting point is the following paper:
"Partitioned analysis of coupled mechanical systems", C.A. Felippa, K.C. Park, C. Farhat, Comput. Methods Appl. Mech. Engrg. 190, 3247-3270, 2001.

Assessment

Individual assessment: EVI 1 (coefficient 1.0)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
English	4	10 hrs	4 hrs	16 hrs	0 hrs	2 hrs

Master Programme - Mechanical Engineering - Computational Mechanics

YEAR 2 - Autumn Semester

Domain Decomposition and iterative Solvers [DDIS]

LEAD PROFESSOR(S): Nicolas CHEVAUGEON

Objectives

At the end of the course the students will have:
- knowledge and understanding of algorithms and methods to solve large linear system problems on parallel architecture.
- an ability to recognize pattern, structures and properties of large linear systems and to choose the best tools to solve them efficiently.
- an ability to program and use a linear solver component.
- basic knowledge of a parallel algorithm for linear solver.
- an ability to study independently; use library resources; effectively take notes and
- manage working time.

Course contents

Most numerical methods to solve partial differential equations on large problems end up with the need to solve large linear systems of equations.
This module presents advanced numerical methods for high performance computing and techniques that exploit the specificities of available computational resources in order to solve these problems. The following topics will be addressed:
- Data structure to store large sparse matrix in a distributed environment.
- Direct methods for large systems of equations
- Iterative solvers for large systems of equations and acceleration of convergence (Krylov
- methods, multigrid preconditioning, etc)
- Domain decomposition methods for PDEs (formulations, mesh partitioning, algorithms)

Course material

- Lecture notes
- Toselli, O. Widlund, Domain Decomposition Methods - Algorithms and Theory Springer 2005
- Y. Saad, Iterative methods for sparse linear systems SIAM 2003
- G. H. Golub, C. F. Van Loan, Matrix Computations, The Johns Hopkins University Press 1996

Assessment

Individual assessment: EVI 1 (coefficient 1.0)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
English	4	18 hrs	0 hrs	8 hrs	4 hrs	2 hrs

Model Reduction [MODRED]

LEAD PROFESSOR(S): Jose-Vicente AGUADO

Objectives

At the end of the course the students will have:

▪ knowledge and understanding of: the current difficulties encountered by standard incremental and mesh-based simulation techniques; proper orthogonal decomposition; separated representations for circumventing curse of dimensionality;
▪ ability to: identify the need for model reduction in problems taken for different areas of computational science and engineering; formulate reduced models for different kind of models identified in many areas: computational biology, computational mechanics, forming processes simulation, etc; develop simulation codes making use of model reduction; effectively take notes and manage working time.

Course contents

Numerous models encountered in science and engineering remain nowadays, despite the impressive progress recently attained in computational simulation techniques, intractable when the usual and well experienced discretization techniques are applied for their numerical simulation. Model reduction allows spectacular simulation speed-up, of several orders, and also solving models never until now solved (3D models involving extremely small-time steps and models suffering the so-called curse of dimensionality). The topics are organized as follows:

▪ A posteriori model reduction techniques, including the Proper Orthogonal Decomposition and the Reduced Basis method.
▪ Algebraic methods for matrices and tensors, including the Singular Value Decomposition and tensor formats.
▪ A priori model reduction techniques, and specifically, the Proper Generalized Decomposition method, for parametric problems, in-plane-out-of-plane separated representations and vector field problems.
▪ Applications in computational science and engineering.

Course material

▪ Lecture notes
▪ A dozen recent research papers in English on model reduction.

Assessment

Individual assessment: EVI 1 (coefficient 1.0)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
English	3	20 hrs	0 hrs	0 hrs	4 hrs	0 hrs

Numerical Methods for Uncertainty Quantification [NUMUQ]

LEAD PROFESSOR(S): Anthony NOUY

Objectives

This course is an introduction to numerical methods for uncertainty quantification in computational science. At the end of the course the students will have knowledge and understanding of: challenges in uncertainty quantification in computational science; modelling and estimation of uncertainties; numerical methods to propagate uncertainties through a model; sensitivity analysis; methods for the construction of surrogate or reduced order models.

Course contents

The course addresses the following topics:
- probabilistic modelling and estimation of uncertainties
- propagation of uncertainties (monte-carlo methods, variance reduction, estimation of rare events)
- sensitivity analysis
- approximation of models and reduced order modelling

Course material

- R. Ghanem, D. Higdon, H. Owhadi (eds). Handbook of uncertainty quantification. Springer. 2017
- Sullivan, T. J. (2015). Introduction to uncertainty quantification (Vol. 63). Springer.
- R. Y. Rubinstein and D. P. Kroese. Simulation and the Monte Carlo method, volume~10. John Wiley & Sons, 2016.

Assessment

Individual assessment: EVI 1 (coefficient 1.0)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
English	3	18 hrs	0 hrs	0 hrs	4 hrs	2 hrs

Physical Modeling of Fluids [PMFLU]

LEAD PROFESSOR(S): Alban LEROYER / Michel VISONNEAU

Objectives

At the end of the course the students will have:

- knowledge and understanding of: the limitations of physical models, the evolution of physical models with respect to computational power.
- an ability to: chose an appropriate physical model for a given problem; set properly a CFD solver for standard physical configurations; analyse and review the numerical results; study independently; manage a numerical project on a computer

Course contents

This module is devoted to the analysis of the main physical modelling strategies used to
compute viscous incompressible flows. It covers:

- an overview of the main turbulence closures used in high Reynolds incompressible flows ranging from statistical closures to Large Eddy Simulation models

Computers labs to put into pratices the constraints regarding the mesh generation and the influence of the turbulence modelling are delivered using the industrial CFD suite Fine/Marine.
- a review of the most recent cavitation models and an analysis of the underlying physics,
- a critical illustration of the predictive capabilities of these models for various experimental databases

Course material

- Lecture notes.
- D.C. Wilcox, Turbulence Modelling for CFD, DCW Industries, 2002
- C. Hirsch, Numerical Computation of Internal and External Flows (Second Edition), Elsevier, 2007
- Marnet-CFD Best Practice Guidelines for Marine Applications of CFD
- https://pronet.wsatkins.co.uk/marnet/guidelines/guide.html

Assessment

Individual assessment: EVI 1 (coefficient 1.0)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
English	3	14 hrs	0 hrs	6 hrs	2 hrs	2 hrs

Master Programme - Mechanical Engineering - Computational Mechanics

YEAR 2 - Autumn Semester

Extended Finite Element Method and Level Set Techniques [XFEM]

LEAD PROFESSOR(S): Nicolas CHEVAUGEON / Nicolas MOËS

Objectives

At the end of the course the students will have:

▪ knowledge and understanding of the current difficulties encountered by the finite element method; the partition of unity to model surfaces for linear and non-linear problems; the level set technique to evolve surfaces; basic knowledge of non-linear finite elements for static and dynamics.
▪ an ability to: identify the need for extended finite elements and level sets in problems taken for different areas of mechanics; logically formulate a numerical approach using extended finite elements and level sets for different practical problems and translate the formulation to an existing extended finite element code; study independently; use library resources; use an existing extended finite element code; effectively take notes and manage working time.

Course contents

The course presents an extension of the finite element method known as, X-FEM, which is currently widely used in research and has started to appear in industry. This method basically eliminates the need to mesh physical surfaces (cracks, holes, material interfaces) in finite element computations. The surfaces are located and evolved by the level set technique which is also taught in the course. The topics are organized as follows:

▪ Overview of a wide class of problems that cannot be solved efficiently by the finite element method and necessity to extend the method.
▪ The keystones of the extended Finite Element Method: enrichment with the partition of unity and level set representation of surfaces.
▪ Industrial applications in fracture mechanics.
▪ Level sets and fast marching algorithms to evolve surfaces.

Course material

▪ Lecture notes provided
▪ Pommier, S., Gravouil, A., Combescure, A., & Moës, N. (2011). Extended finite element method for crack propagation. Wiley.
▪ Osher, S., Fedkiw, R., Level Set Methods and Dynamic Implicit Surfaces, Springer, 2003.

Assessment

Individual assessment: EVI 1 (coefficient 1.0)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
English	3	16 hrs	0 hrs	6 hrs	0 hrs	2 hrs

Cultural and Communication English [CCE3]

LEAD PROFESSOR(S): Spencer HAWKRIDGE

Objectives

Team-building and Communicational English:
- Understand the general concepts of team-building
- Build a team-building project
- Understand and nurture the creative process
- Enhance self-belief and self-empowerment

Behavioral skills in an inter-cultural environment:
- Strengthen self-confidence and capacity for interaction
- Develop active listening and reformulation skills
- Develop networking skills

Course contents

Cultural and Communicational English: exercises to explore in practice the areas of culture and communication
Field-related or inter-cultural project (for example, construct content for inter-cultural teambuilding activities; example WIOBOX website etc).

Course material

Written and televised press, information and digital tools, general documents business environment and company strategies.
Internet conferences (Ted Talks, etc.), our own educational materials on Hippocampus (Moodle).

Assessment

Individual assessment: EVI 1 (coefficient 1.0)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
English	4	0 hrs	32 hrs	0 hrs	0 hrs	0 hrs

Master Programme - Mechanical Engineering - Computational Mechanics

YEAR 2 - Autumn Semester

Spanish Language [ESP3]

LEAD PROFESSOR(S): Marta HERRERA

Objectives

For beginners:
Practice and reinforcement of the five skills (oral and written expression and comprehension as well as interaction)
Acquisition of vocabulary and linguistic structures
Be able to talk about yourself and those around you
Be able to express oneself during daily activities
Know how to give your opinion

For advanced students:
Practice and reinforcement of the five skills (oral and written expression and comprehension as well as interaction)
Acquisition of specialised vocabulary
Be able to understand the essential content of concrete or abstract subjects including a technical discussion
Be able to communicate spontaneously and fluently
Be able to express oneself in a clear and detailed manner, to express an opinion on a topical subject

Course contents

For beginners:
Personal environment (introduce yourself, express yourself, your tastes, your character, your hobbies, etc.), your surroundings (friends, family, location, climate), your interests (sports, leisure)
Present tense (regular and irregular)
Language patterns to express habit, obligation, "gustar" and its equivalents,
Possessive adjectives
Differences between "es", "está", "hay"
Use of "por" and "para"
Adverbs and frequency patterns
Numeral adjectives

For advanced students:
Knowledge of the Hispanic world (economic, technical, cultural and social environment)
Present tense (regular and irregular)
Imperative
Past tenses
Direct / indirect style
Future tense
Conditional tense
Present and past subjunctive moods

Course material

Preparation manuals, our own tailor-made documents, written and internet press, general civilization documents, digital tools

Assessment

Individual assessment: EVI 1 (coefficient 1)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
English	4	0 hrs	32 hrs	0 hrs	0 hrs	0 hrs

French Language [FLE3]

LEAD PROFESSOR(S): Silvia ERTL

Objectives

The objective is to familiarize the learner with the French language and French culture through an entertaining task-based communicative language teaching, focused on speaking combined with:
- Phonetics
- Self-correcting exercises on our learning platform
- Learning Lab activities
- Project work
- Tutoring

Course objectives include the acquisition and reinforcement of vocabulary, syntax, and pronunciation by both traditional means and through the use of digital resources. Students will learn general French, develop language skills of oral and written comprehension and expression.

After completing this course (32 hours + personal work), the students will be able to communicate in spoken and written French, in a simple, but clear manner, on familiar topics in the context of study, hobbies etc. Another important goal of this course is to introduce the student to French culture.

At the end of the course, complete beginners can achieve an A1
level and some aspects of the A2 of The Common European Framework of Reference for Languages. More advanced students may aim for B1/B2 levels. Those who already completed the first year of the French course will be prepared for working in a French business environment.

Course contents

Two different tracks are proposed: track 1 for students newly arrived at Centrale Nantes and track 2 for students who have completed the first year of the French course. Track 1:
Full range of practical communication language exercises: reading comprehension, listening comprehension, written expression, oral expression.
Learners will be able to use the foreign language in a simple way for the following purposes:

1. Giving and obtaining factual information:
- personal information (e.g. name, address, place of origin, date of birth, education, occupation)
- non-personal information (e.g. about places and how to get there, time of day, various facilities and services, rules and regulations, opening hours, where and what to eat, etc.)

2. Establishing and maintaining social and professional contacts, particularly:
- meeting people and making acquaintances
- extending invitations and reacting to being invited
- proposing/arranging a course of action
- exchanging information, views, feelings, wishes, concerning matters of common interest, particularly those relating to personal life and circumstances, living conditions and environment, educational/occupational activities and interests, leisure activities and social life

3. Carrying out certain transactions:
- making arrangements (planning, tickets, reservations, etc.) for travel, accommodation, appointments, leisure activities
- making purchases
- ordering food and drink

Track 2:
This track follows on directly from the first-year French course, developing and completing the concepts studied thus far. The main themes are: housing, health and work. These topics will help prepare students for their future work environment. For example, housing is explored in the form of a search for accommodation upon arrival in a new city. Special workshops for CVs and cover letters, elevator pitches and job interviews.

Course material

Preparation manuals, our own tailor-made documents, written and televised press, internet, general civilization documents, digital tools, our own educational materials on Hippocampus (Moodle).

Assessment

Individual assessment: EVI 1 (coefficient 1.0)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
English	4	0 hrs	32 hrs	0 hrs	0 hrs	0 hrs

Internship / Thesis project [THESIS]

LEAD PROFESSOR(S): Nicolas CHEVAUGEON

Objectives

- Be exposed to and adapt to an industrial or research environment
- Put in practice the scientific and technical skills acquired in the previous semesters
- Strengthen interpersonal and communication skills
- Be part of or manage a project
- Organize tasks, analyze results and build deliverables

Course contents

Students should be pro-active and career-oriented in the search for their thesis/internship. The topics are validated by the program supervisor to ensure an adequate Master level. The thesis/internship is evaluated through the submission of a written report and an oral defense.

Course material

- Turabian Kate Larimore, Booth Wayne Clayton, Colomb Gregory G., Williams Joseph M., & University of Chicago press. (2013). A manual for writers of research papers, theses, and dissertations: Chicago style for students and researchers (8th edition.). Chicago (Ill.) London: University of Chicago Press.
- Bui Yvonne N. How to Write a Master's Thesis. 2nd ed. Thousand Oaks, Calif: Sage, 2014.
- Evans David G., Gruba Paul, et Zobel Justin. How to Write a Better Thesis. 3rd edition. Carlton South, Vic: Melbourne University Press, 2011.

Assessment

Individual assessment: EVI 1 (coefficient 1.0)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
English	30	0 hrs	0 hrs	0 hrs	0 hrs	0 hrs