CENTRALE NANTES

MASTER OF SCIENCE, TECHNOLOGY AND HEALTH

MECHANICAL ENGINEERING

COMPUTATIONAL MECHANICS

YEAR 2
AUTUMN SEMESTER

PROGRAMME SUPERVISORS:
NICOLAS CHEVAUGEON, SEBASTIEN COMAS-CARDONA

Établissement public sous tutelle du
ministère de l'Enseignement supérieur,
de la Recherche et de l'innovation

GROUPE CENTRALE

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COMPUTATIONAL CONFIGURATIONAL MECHANICS
MECHANICAL ENGINEERING – COMPUTATIONAL MECHANICS
YEAR 2 - AUTUMN SEMESTER

LEAD PROFESSOR: Nicolas Moës, *nicolas.moes@ec-nantes.fr*

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.

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
- Application

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.

Keywords

Configurational changes, moving interfaces, Eshelby tensors.

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

COMPUTATIONAL METHODS FOR INCOMPRESSIBLE FLOWS

MECHANICAL ENGINEERING – COMPUTATIONAL MECHANICS
YEAR 2 - AUTUMN SEMESTER

LEAD PROFESSOR: M. Visonneau, *michel.visoneau@ec-nantes.fr* & A. Leroyer, *alban.leroyer@ec-nantes.fr*

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

- 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

Keywords

CFD, incompressible flow

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

DOMAIN DECOMPOSITION AND ITERATIVE SOLVERS
MECHANICAL ENGINEERING – COMPUTATIONAL MECHANICS
YEAR 2 – AUTUMN SEMESTER

LEAD PROFESSOR: N. Chevaugeon, *nicolas.chevaugeon@ec-nantes.fr*

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

Keywords

Linear solver, large system, programming, Krylov subspace, conjugate gradient, preconditioner

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

EXTENDED FINITE ELEMENT METHOD AND LEVEL SET TECHNIQUES

MECHANICAL ENGINEERING – COMPUTATIONAL MECHANICS
YEAR 2 - AUTUMN SEMESTER

LEAD PROFESSOR: N. Chevaugeon, *nicolas.chevaugeon@ec-nantes.fr, &* N. Moës, *nicolas.moës@ec-nantes.fr*

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.

Keywords

XFEM, Levelset, Crack Fracture mechanics

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

MODEL REDUCTION
MECHANICAL ENGINEERING – COMPUTATIONAL MECHANICS
YEAR 2 - AUTUMN SEMESTER

LEAD PROFESSOR: Jose V. Aguado, *jose.aguado-lopez@ec-nantes.fr*

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;
- an 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; study independently; use library resources; 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:

- Model reduction techniques based on the use of the Proper Orthogonal Decomposition;
- Towards an adaptive reduced approximation basis;
- Reduced modelling and parallel time integration;
- Coupling FEM and reduced modelling: treatment of fixed and moving interfaces;
- The Proper Generalized Decomposition (PGD);
- Applications in computational science and engineering;

Course material

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

Keywords

Model reduction, POD, PGD

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LABO	PROJECT	EXAM
English	3	20 hrs	0 hrs	0 hrs	4 hrs	2 hrs

Numerical Methods for Simulation of Coupled Problems

Mechanical Engineering – Computational Mechanics
Year 2 - Autumn Semester

LEAD PROFESSOR: L. Stainier, *laurent.stainier@ec-nantes.fr* & A. Leroyer, *alban.leroyer@ec-nantes.fr*

Objectives

At the end of the course the students will have:

- knowledge and understanding of: the challenges in numerical simulation of coupled problems, 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 a specific type of coupled problem. In particular, 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 the project work for various thermo-mechanical problems (thermo-plasticity, thermo-visco-elasticity, shape memory alloys, etc).

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.

Keywords

Multi physics, coupled problems, strong/weak coupling

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LABO	PROJECT	EXAM
English	3	12 hrs	0 hrs	8 hrs	2 hrs	2 hrs

NUMERICAL METHODS FOR UNCERTAINTY QUANTIFICATION
MECHANICAL ENGINEERING – COMPUTATIONAL MECHANICS
YEAR 2 - AUTUMN SEMESTER

LEAD PROFESSOR: A. Nouy, *antony.nouy@ec-nantes.fr*

Objectives

At the end of the course the students will have:

- knowledge and understanding of: challenges in uncertainty quantification in computational science; basics of functional approaches in probability and their use at the different steps in uncertainty modelling, identification and numerical propagation through a computational model.
- an ability to: classify, formulate and analyze stochastic models; assess advantages, applicability and limitations of stochastic numerical methods and select a suitable method according to the desired probabilistic quantities and interest
- an ability to manipulate elementary statistical and probabilistic tools for uncertainty modelling (random variables and processes); implement basic spectral stochastic methods for the solution of stochastic PDEs.
- an ability to: study independently; use library resources; implement numerical methods for the solution of stochastic problems; effectively take notes and manage working time.

Course contents

This module introduces advanced numerical methods for uncertainty quantification in computational and predictive science. A particular attention is given to functional approaches for uncertainty quantification, namely spectral stochastic methods based on polynomial chaos type representations. Numerical methods are detailed for the quantification of input uncertainties and their propagation though physical models, in particular those involving stochastic partial differential equations. Some advanced topics are discussed such as adaptive approximation and enrichment, geometrical uncertainties, multiscale approaches, model reduction based on tensor product approximation for high-dimensional parametric and stochastic models.

Course material

- Lecture notes, a selection of recent research papers on the topic.
- J. Jacod, P. Protter. Probability essentials. 2nd ed. Springer, 2004.
- O.P. Le Maitre and O.M. Knio. Spectral methods for uncertainty quantification. Springer, 2010.
- Nouy (2009). Recent developments in spectral stochastic methods for the numerical solution of stochastic partial differential equations. Arch Comput Methods Eng 16 (3): 251–285

Keywords

CFD, turbulence, external flow, cavitation

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

PHYSICAL MODELLING OF FLUIDS
MECHANICAL ENGINEERING – COMPUTATIONAL MECHANICS
YEAR 2 - AUTUMN SEMESTER

LEAD PROFESSOR: M. Visonneau, *michel.visonneau@ec-nantes.fr* & A. Leroyer, *alban.leroyer@ec-nantes.fr*

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,
- 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
- data bases

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

Keywords

CFD, turbulence, external flow, cavitation

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LABO	PROJECT	EXAM
English	4	14 hrs	0 hrs	12 hrs	4 hrs	2 hrs

MODERN LANGUAGES - FRENCH

MECHANICAL ENGINEERING – COMPUTATIONAL MECHANICS

YEAR 2 - AUTUMN SEMESTER

LEAD PROFESSOR: Silvia Ertl – *silvia.ertl@ec-nantes.fr*

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 (2 semesters), 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.

Course material

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).

Keywords

reception (listening and reading), production (spoken and written), interaction (spoken and written), knowledge, skills, linguistic competence, sociolinguistic competence, pragmatic competence, register, cultural differences, non-verbal communication, business vocabulary

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LABO	PROJECT	EXAM
French	4	0 hrs	32 hrs	0 hrs	0 hrs	0 hrs

Modern Languages – Cultural and Communicational English
Mechanical Engineering – Computational Mechanics
Year 2 - Autumn Semester

LEAD PROFESSOR: Spencer Hawkridge- *spencer.hawkridge@ec-nantes.fr*

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 team-building 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).

Keywords

Culture and communication, inter-cultural environment, team-building, digital tools, etc.

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LABO	PROJECT	EXAM
English	4	14 hrs	16 hrs	0 hrs	0 hrs	2 hrs