CENTRALE
NANTES

ENGINEERING PROGRAMME

2024-2025

Year 2 / Year 3

Specialisation option

Advanced Modelling and Analysis of Structures

OD MAAS

PROGRAMME SUPERVISOR
Patrice CARTRAUD

Autumn Semester

Course unit	ECTS Credits	Track	Course code	Title
UE 73	12	Core course	ARCHI MEF MODYN MSCOM	Architectured Structures Finite Element method Solid Dynamics and Modal analysis Composite Structures
UE 74	13	Core course	HYPER IFS P1MAAS PLAST SERMS	Numerical Methods for NonLinear Mechanics Fluid-Structure Interaction Project 1 Plasticity Models Fracture and Damage mechanics

Spring Semester

Course unit	ECTS Credits	Track	Course code	Title
UE 83	14	Core course	COUPLED CRASH NUMEXPE OUVERT P2MAAS	Multiphysic couplings Crashworthiness and Transportation Safety Numerical methods for experimental analysis Advanced scientific topics and conferences Project 2

Architectured Structures [ARCHI]

LEAD PROFESSOR(S): Patrice CARTRAUD

Requirements

Continuum mechanics

Objectives

This course presents the theory of beams and their modeling by finite elements. Basics of homogenization theory are given, with an application to a periodic lattice material.

Course contents

- beam theory (Euler-Bernoulli model)
- finite element modeling
- homogenisation methode for architectured structure
- finite element project

Course material

Bauchau, O. A., & Craig, J. I. (2009). Structural analysis: with applications to aerospace structures (Vol. 163). Springer Science & Business Media.
Hjelmstad, K. D. (2007). Fundamentals of structural mechanics. Springer Science & Business Media.
Reddy, J. N. (Ed.). (1999). Theory and analysis of elastic plates. Taylor and Francis.

Assessment

Collective assessment: EVC 1 (coefficient 0.5)

Individual assessment: EVI 1 (coefficient 0.5)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	12 hrs	10 hrs	9 hrs	0 hrs	1 hrs

Finite Element method [MEF]

LEAD PROFESSOR(S): Grégory LEGRAIN

Requirements

Objectives

To present the fundamentals of the Finite Element Method and aspects of its implementation. The framework is restricted to elliptic cases in 1D and 2D.

Course contents

- Classification of PDEs
- Weak formulation / variational formulation
- Bubnov-Galerkin / Ritz-Galerkin methods
- Finite elements in 1D / 2D
- Isoparametric finite elements
- Implementation, consideration of boundary conditions

Course material

- The Finite Element Method: Linear Static and Dynamic Finite Element Analysis. T.J.R. Hughes
- Analyse des solides déformables par la méthode des éléments finis. M. Bonnet, A. Frangi

Assessment

Collective assessment: EVC 1 (coefficient 0.4)

Individual assessment: EVI 1 (coefficient 0.6)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	12 hrs	8 hrs	10 hrs	0 hrs	2 hrs

ENGINEERING - OD MAAS

Year 2 / Year 3 - Autumn Semester - Course Unit 73 / 93

Solid Dynamics and Modal analysis [MODYN]

LEAD PROFESSOR(S): Pascal COSSON / Patrick ROZYCKI

Requirements

Elementary functions, Differentiation, Integration, Differential equations, Vector Analysis, Linear Algebra

Objectives

In everyday life, there are many systems that evolve over time. In mechanics, for example, there are robots, mechanisms, physical crash tests dummies or vehicles. Whatever the field of application, the engineer must always be able to ensure the feasibility, the implementation, the dimensioning and the safety of these systems. How can engineers meet the above objectives starting from simple analytical approaches, more complex modeling and fundamental knowledge on solving methods and how can they interact to increase the potential of these systems?

The course has two main aims: the first is to provide the keys to developing simple analytical models that are sufficiently representative of the considered system to provide a quick answer to a given problem. The second aim is to develop sound knowledge of numerical methods to solve the equations and thus forge a critical mind according to the advantages/disadvantages of these methods.

From the knowledge acquired through this course, the students will propose simple modelling and a numerical resolution of a given problem, as well as taking a critical look at the numerical results obtained from commercially available software.

Course contents

1. Modelling a rigid bodies system
   - Configuration, joints, Lagrange's equations, kinematically or not admissible configuration etc.

2. Vibrations
   - Systems of 1 or more degree(s) of freedom, eigenvalue problem, free or forced vibrations etc.

3. Time integration schemes
   - Euler, Runge Kutta, Newmark, implicit or explicit methods, stability etc.

Course material

M. Géradin & A. Cardon, Flexible Multibody Dynamics - A Finite Element Approach, Wiley, 2001

D. Le Houedec, Mécanique des Solides, Nantes

Assessment

Individual assessment: EVI 1 (coefficient 1.0)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	12 hrs	8 hrs	12 hrs	0 hrs	0 hrs

ENGINEERING - OD MAAS

Year 2 / Year 3 - Autumn Semester - Course Unit 73 / 93

Composite Structures [MSCOM]

LEAD PROFESSOR(S): Laurent GORNET

Requirements

Objectives

Thin structures, such as plates and shells, are widely used in various engineering applications such as in aeronautics, automotive or ship-building structures and the sports and leisure industry. The quest for performance (and weight savings - aerospace sector or competition equipment) is also behind the development of composite material structures.
The objective of this course is to present the modelling methods for these thin composite structures.

Course contents

Anisotropic elasticity
Theory of plates: Kirchhoff-Love and Reissner-Mindlin theories
Classical lamination theory
Failure criteria of composite structures
Finite element project

Course material

J.-L. Batoz, G. Dhatt, Modélisation des structures par éléments finis,vol 2 Poutres et plaques, vol 3 coques, Hermès, Paris 1992.
J.N. Reddy, Mechanics of laminated composite plates, CRC Press, 1997
S.P. Timoshenko and S. Woinowsky-Krieger, Theory of plates and shells, MacGraw-Hill, New-York, 2nd edition, 1959.

Assessment

Individual assessment: EVI 1 (coefficient 1)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	16 hrs	8 hrs	8 hrs	0 hrs	0 hrs

Numerical Methods for NonLinear Mechanics [HYPER]

LEAD PROFESSOR(S): Laurent STAINIER / Nicolas CHEVAUGEON

Requirements

Basics of continuum mechanics (linear elasticity)
Basics of finite element method

Objectives

This course provides an appropriate formulation of the governing equations of a non linear mechanical problems and their numerical solutions. Geometrical non linearities - large displacement and large strain - are studied, as well as contact non linearities.
These models are used in numerous engineering problems such as vehicle crashworthiness and manufacturing processes (forming, rolling etc).
A finite element project is proposed at the end of the course.

Course contents

- simple examples of non linear problems, introduction to continuation methods
- tensor algebra
- kinematics and stresses in large strain
- variational formulation and numerical solution with finite elements
- constitutive equations: hypo- and hyperelasticity
- tangent and gradient operators
- computational contact mechanics
- dynamic finite element analysis

Course material

Nonlinear Continuum Mechanics for Finite Element Analysis, Second Edition, J. Bonet and R.D. Wood, Cambridge University Press, 2008.
Nonlinear Finite Elements for Continua and Structures, T. Belytschko, W.K. Liu and B. Moran, Wiley, 2000.

Assessment

Collective assessment: EVC 1 (coefficient 0.5)

Individual assessment: EVI 1 (coefficient 0.5)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	12 hrs	10 hrs	8 hrs	0 hrs	2 hrs

Fluid-Structure Interaction [IFS]

LEAD PROFESSOR(S): Hervé LE SOURNE / Patrice CARTRAUD / Ye Pyae SONE OO

Requirements

Objectives

Understand fluid/structure interaction phenomena. Judge the importance of these interactions in a physical problem, know and know how to choose modeling methods, their advantages and their limitations. Perform a simulation of a fluid / structure interaction problem.

Course contents

I. Introduction
- Interaction principle
- Example of the Tacoma bridge

II. Some examples of fluid/structure interactions in nuclear engineering
- Pressurized water reactors
- Steam generators,
- In-pool storage racks, etc.

III. Involved physical phenomena
- Hypothesis
- Response of an immerged structure
  - Fluid inertial effects – hydrodyn. coupling
  - Local confinement
  - Dissipative effects of the fluid
  - Free surface effects
- Structure/fluid impact

IV. Different analysis methods
- Choice of the calculation method
- Hydrodynamic masses
- Modal methods
  - Principles and assumptions
  - Equations of the elastic coupling problem
  - Modal approach
  - FSI problem modal analysis
  - Frequency responses calculated on modal basis
- Direct integration methods
  - Principles and assumptions
  - General equations
  - Lagrangian method
  - Euler/ALE methods
  - Euler/Lagrange approach with coupling

V. Conclusions

Course material

Assessment

Individual assessment: EVI 1 (coefficient 1.0)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	12 hrs	0 hrs	18 hrs	0 hrs	2 hrs

ENGINEERING - OD MAAS

Year 2 / Year 3 - Autumn Semester - Course Unit 74 / 94

Project 1 [P1MAAS]

LEAD PROFESSOR(S): Patrice CARTRAUD

Requirements

Objectives

Projects of the option, second period

Projects of the option represent a work of study and research whose topic is chosen by students among a list of subjects proposed either by teachers or by industrials. These projects are usually carried out in pairs. In the MAAS option, the two slots associated with projects are combined to give a volume of 80 hours to the same project. This project is the subject of a report and a final defense at the end of March, just before the departure of the students for the internship.

Course contents

Bibliography and initial work on the subject. Projects are pursued in the second semester.

Course material

Assessment

Collective assessment: EVC 1 (coefficient 1.0)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	1	0 hrs	0 hrs	0 hrs	32 hrs	0 hrs

CENTRALE NANTES

ENGINEERING - OD MAAS

Year 2 / Year 3 - Autumn Semester - Course Unit 74 / 94

Plasticity Models [PLAST]

LEAD PROFESSOR(S): Laurent GORNET

Requirements

Objectives

The purpose of this course is to study the plasticity in structures. The course presents first of all the formulation of elastic-plastic constitutive laws in solids, and the writing of boundary value problems with such constitutive models. Secondly, the course focuses on numerical discretization and implementation of elastic-plastic constitutive models in a finite element code.

Course contents

The class is subdivided into four chapters:
Part 1 examines the elastic-plastic behavior in solids within the small strains framework;
Part 2 embodies the equations of elastoplasticity introduced in the first chapter on the basis of principle, within a thermodynamical framework;
Part 3 focuses on the writing and the solution of elastic-plastic boundary value problems, still within the small strains framework;
Part 4 describes how numerical simulations of elastic-plastic structures are performed and implemented in computational codes.

A supervised 14-hour project is planned to support the numerical part of the class. This will allow students to implement elastic-plastic constitutive models themselves, and to solve a 1D boundary value problem with the finite element method. Comparisons with respect to other results obtained with industrial finite element codes and/or analytical solutions are also planned.

Course material

- Lemaitre J., Chaboche J.L., Benallal A., Desmorat R. Mécanique des matériaux solides. Dunod, 2009. 3rd edition.
- Simo J.C., Hughes T.J.R. Computational Inelasticity. Springer, 1998.
- Besson J., Cailletaud G., Chaboche J.L., Forest S. Mécanique non linéaire des matériaux. Hermès, 2001.

Assessment

Individual assessment: EVI 1 (coefficient 1.0)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	10 hrs	6 hrs	14 hrs	0 hrs	2 hrs

Fracture and Damage mechanics [SERMS]

LEAD PROFESSOR(S): Laurent GORNET

Requirements

Objectives

Damage mechanics and fracture mechanics are used to study the initiation and propagation of cracks in structures. Both theories allow engineers to simulate damage in fragile and ductile structures. Finite Element simulations conducted using the finite element software Cast3M developed by CEA (the French Alternative Energies and Atomic Energy Commission) illustrate this course. The theoretical and numerical aspects are supplemented by considerations of the physics of the mechanisms of degradation in materials, metal, concrete and the composites.

Course contents

Damage mechanics: thermodynamic of irreversible process, fatigue, behaviour laws (metals, concrete, composites). Objectivity and regularisation of stress softening behaviour laws, numerical techniques.

Fracture mechanics: stress intensity factors, energetic theory, J integral, fracture propagations, scale effect on fracture, fatigue crack propagation.
Tests and model interactions: classical experimental tests (tests on 10 and 25 tons MTS device) of behaviour laws Identification. Damage prediction with finite element codes (Abaqus, Cast3M). Fracture Mechanics with a finite element code (Abaqus, Cast3M).

Course material

Chaboche - Mécanique de la rupture fragile et ductile, JB Leblond, Hermes Lavoisier 2003 - Rupture par fissuration des structures, N. Recho, Hermès 1995 - Introduction aux effets d'échelle sur la résistance des structures, ZP Bazant Hermes Lavoisier 2004 - Computational Inelasticity JC Simo- TJR Hughes, Springer 1997 - Recueil de données technologiques sur la fatigue -Document CETIM - Documents CEA et EDF.

Assessment

Individual assessment: EVI 1 (coefficient 1.0)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	16 hrs	4 hrs	10 hrs	0 hrs	2 hrs

ENGINEERING - OD MAAS

Year 2 / Year 3 - Spring Semester - Course Unit 103 / 83

Multiphysic couplings [COUPLED]

LEAD PROFESSOR(S): Guillaume RACINEUX / Rian SEGHIR / Thomas HEUZE

Requirements

Objectives

The purpose of this course is to present an introduction to coupled multiphysics problems, which are ubiquitous in engineering problems. This course is made up of three complementary parts (of 14 h, 8 h and 10 h) taught by three different speakers (Thomas Heuzé, Rian Seghir and Guillaume Racineux, respectively).
This course aims to deal with a relatively large spectrum concerning multiphysics problems for engineers, including modelling, numerical simulation, experimental analysis of structures and comparison with theory.

Course contents

The first two parts focus on the study of the coupling between thermal effects and mechanics. The first part focuses on the modelling and the numerical simulation of the coupled thermomechanical problem. The coupling mechanisms between these two physics are highlighted through the modelling, then some numerical strategies that can be used for the solution of this coupled system are studied in the case of linear thermoelasticity. A mini-project allows students to code and compare these numerical strategies on an elementary one-dimensional problem.
The second part deals with the experimental analysis of the coupled thermomechanical problem, with regard to the modelling described in the first part. This second part deals with the dialog tests / computation for a thermomechanical coupling, especially of quantities which can be experimentally measured from these which can be computed.
The third part is interested in the coupling between electromagnetism and mechanics. The modelling of the coupled problem is first presented, then applications on magnetic pulse forming tests are carried out in the welding laboratory.

Course material

Couplages multiphysiques, Thomas Heuzé, Ecole Centrale de Nantes, 2020. https://hal.archives-ouvertes.fr/hal-02448292

Assessment

Individual assessment: EVI 1 (coefficient 1.0)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	12 hrs	12 hrs	8 hrs	0 hrs	0 hrs

CENTRALE NANTES

ENGINEERING - OD MAAS

Year 2 / Year 3 - Spring Semester - Course Unit 103 / 83

Crashworthiness and Transportation Safety [CRASH]

LEAD PROFESSOR(S): Patrick ROZYCKI

Requirements

Finite Element Method, Constitutive behaviour law, Plasticity

Objectives

Industrial safety issues, particularly in the area of transportation, require more precise knowledge of the behaviour of materials and structures subjected to rapid and dynamic loading.

This course aims to examine current practices and future trends in this field, with regard to mechanical, numerical and experimental aspects. The main concepts covered are materials modelling for dynamic loading (constitutive laws, strain rate sensitivity, experimental characterisation methods), crash design rules, numerical simulation (tools and integration schemes for the implementation of a model), and experimental methods to characterise structure behaviour.

The students will be able to identify the links between numerical model creation and experimental conditions, and examine the different problems related to each of these tools. This will enhance their critical thinking skills and increase their capacity to provide the best numerical/experimental correlations.

The students will undertake a project to consolidate the learning process: first, they will participate in a dynamic crushing tubes experiment. Then, they will have to provide a numerical model of the experiment. Finally, they will have to analyse the results and highlight the various problems at each step.

Course contents

1. Overview of shocks
   - Nature, type and classification of shocks

2 Crash in the field of transportation
  - Overview, safety, different approaches used

3. Numerical modelling
   - Constitutive laws, different time integration methods, non-linearities

4. Experimental devices
   - Description, different types of tests (front or side-impact)

5 Study of an analytical model for circular or square tubes

6 Simple case study
  - Experiment on a simple structure, numerical simulation and experimental/numerical correlations

Course material

N. Jones, Structural Crashworthiness, Cambridge University Press, 1997

Jorge A.C. Ambrósio, Manuel F.O. Seabra Pereira, F. Pina da Silva, Crashworthiness of Transportation Systems: Structural Impact and
Occupant, Springer Netherlands, 1997

Assessment

Individual assessment: EVI 1 (coefficient 1.0)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	4 hrs	0 hrs	28 hrs	0 hrs	0 hrs

ENGINEERING - OD MAAS

Year 2 / Year 3 - Spring Semester - Course Unit 103 / 83

Numerical methods for experimental analysis [NUMEXPE]

LEAD PROFESSOR(S): Julien RETHORE / Rian SEGHIR

Requirements

Objectives

The main objective is to introduce the bases of full field measurements by Digital Image Correlation and the inverse methods that use their results.

Course contents

- basis of digital image correlation
- practical work (optics,, speckle pattern, camera settings)
- introduction to inverse methods
- Non-linear projection, finite element model updating, virtual fields method
- practical work (crack propagation test, composite material testing, elastomer testing)

Course material

Good practice guide
https://idics.org/guide/DICGoodPracticesGuide_ElectronicVersion-V5g-181022.pdf

Assessment

Collective assessment: EVC 1 (coefficient 1.0)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	8 hrs	8 hrs	16 hrs	0 hrs	0 hrs

ENGINEERING - OD MAAS

Year 2 / Year 3 - Spring Semester - Course Unit 103 / 83

Advanced scientific topics and conferences [OUVERT]

LEAD PROFESSOR(S): Patrice CARTRAUD

Requirements

Objectives

This course aims at introducing specific topics that are not part of the general courses of the option Advanced Modelling and Analysis of Structures:

- The first and main part deals with the place of using data to solve problems in solid mechanics. The use of methods related to artificial intelligence has grown significantly in recent years to help solve various engineering problems, but what about solving physics problems, and more particularly of solid mechanics? This part is interested in showing what it is possible or not to do with these methods, what they bring compared to existing methods, their attractions and their limits. This part lasts 20 hours, includes a good part of practical work, and is provided by Laurent Stainier and Domenico Borzacchiello.

- A cycle of industrial conferences is planned, each of them lasting two hours. In general, the speakers come from computing offices of different companies (Dassault Systèmes, ClusterMeca-Nantes, Medysys, NewclipTechnics, Bureau Veritas, etc.). The purpose is to show students what are the different aspects of their activities, and what are the jobs that students can claim with their training.

Course contents

- Data-driven approaches for solid mechanics
- Conferences

Course material

Assessment

Individual assessment: EVI 1 (coefficient 1.0)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	32 hrs	0 hrs	0 hrs	0 hrs	0 hrs

ENGINEERING - OD MAAS

Year 2 / Year 3 - Spring Semester - Course Unit 103 / 83

Project 2 [P2MAAS]

LEAD PROFESSOR(S): Patrice CARTRAUD

Requirements

Objectives

Projects of the option, third period

Projects of the option represent a work of study and research whose topic is chosen by students among a list of subjects proposed either by teachers or by industrials. These projects are usually carried out in pairs. In the MAAS option, the two slots associated with projects are combined to give a volume of 80 hours to the same project. This project is the subject of a report and a final defense at the end of March, just before the departure of the students for the internship.

Course contents

Project completion, report writing, and project defense.

Course material

Assessment

Collective assessment: EVC 1 (coefficient 1.0)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	2	0 hrs	0 hrs	0 hrs	48 hrs	0 hrs