NUMERICAL METHODS FOR PARTIAL DIFFERENTIAL EQUATIONS

Credits: 5	**Compulsory:** Yes

Lecturer: Marco Discacciati

Contents

This module presents the fundamentals of modern and classical numerical techniques for linear and nonlinear partial differential equations, with application to a wide variety of problems in science, engineering, and other fields. Topics include Finite Difference, Finite Volume and Boundary Element discretizations, and an overview of direct and iterative methods for systems of equations as well as a basic review of numerical methods for eigenvalue problems.

1. Overview of partial differential equations.
2. Finite difference methods for elliptic equations.
3. Finite difference methods for parabolic equations (including consistency, stability and convergence issues).
4. Finite difference methods for hyperbolic equations.
5. Introduction to finite volumes.
6. Introduction to integral equation methods and boundary elements.
7. Solution techniques:
    - Direct solution methods and their implementation.
    - Iterative solvers (stationary and Krylov methods).
    - Overview of techniques for Eigenvalue problems.

Intended Learning Outcomes: to demonstrate…

A knowledge and understanding of:	The fundamentals of the behaviour and numerical approximation of partial differential equations; truncation error and solution error; consistency, stability and convergence; direct and iterative solution of linear systems of equations and eigenvalue problems.
An ability to: (thinking skills)	Understand and formulate basic numerical procedures and solve illustrative problems; identify the proper methods for the corresponding PDE.
An ability to: (practical skills)	Understand practical implications of behaviour of numerical methods and solutions; logically formulate numerical methods for solution by computer with a programming language (Matlab, Fortran 77 or C).
An ability to: (key skills)	Study independently; use library resources; use a personal computer for basic programming; effectively take notes and manage working time.

Assessment

30% continuous assessment assignments, 70% from end of semester examination (50% open-book).

Practical work: Exercises will be set, which will involve coding some of the presented methods.

FINITE ELEMENTS

Credits: 5	**Compulsory:** Yes
Lecturer: Eugenio Oñate	

Contents

This module introduces the basic concepts of the Finite Element Method (FEM), including derivation of formulations, analysis of the resulting methods and essential aspects of the implementation. The presentation is motivated by linear practical problems (heat transfer, elasticity, etc.) and it is illustrated and complemented with hands-on applications. The module also includes an introduction to other topics such as transient problems, convection dominated problems, error assessment and adaptivity.

1. Weighted residuals.
2. Rayleigh-Ritz.
3. Boundary conditions (matrix transformation, Lagrange multipliers, penalty, Nitsche).
4. Finite element discretization.
5. Isoparametric transformation, numerical integration.
6. Introduction to finite element implementation.
7. Introduction to transient problems (modal analysis and method of lines).
8. Error estimation and adaptivity.

Intended Learning Outcomes: to demonstrate…

A knowledge and understanding of:	The fundamentals of linear finite elements; the derivation of weak forms and their resolution; why finite elements approximate the solution of a PDE; the basic structure of a FE code; how to solve transient problems.
An ability to: (thinking skills)	Identify the key issues when performing a finite element analysis of an engineering problem; employ appropriate order polynomials together with appropriate integration rules; identify different methods for prescribing boundary conditions.
An ability to: (practical skills)	Solve linear solid mechanics and heat transfer problems by hand using FE; use a simple FE computer code to set up and produce results for computational simulation of simple engineering problems; formulate and implement simple key aspects of a FE code.
An ability to: (key skills)	Study independently; use library resources; use a personal computer for solving FE problems and do some basic programming; effectively take notes and manage working time.

Assessment

30% continuous assessment assignments, 70% from end of Semester open-book examination

Practical work: Exercises will be set which will involve use of a FE program and some coding.

CONTINUUM MECHANICS	
Credits: 5	**Compulsory:** Yes
Lecturer: Carlos Agelet de Saracibar	

Contents

A fully comprehensive module on nonlinear continuum mechanics for engineers with an in-depth review of fundamental concepts, including motion, descriptions, strains, stresses, balance laws, variational principles and an introduction to computational plasticity.

1. Tensor algebra and analysis (definitions, invariants, gradient, divergence, curl, integral theorems…).
2. Kinematics: movement and deformation (deformation tensors).
3. Small strains and compatibility.
4. Stress tensors.
5. Balance principles.
6. Constitutive theory (laws of thermodynamics, strain energy, elasticity).
7. Boundary value problems of linear elasticity (2D).
8. Introduction to plasticity (von Mises, Tresca, Mohr Coulomb).
9. Ideal fluids and potential flow.
10. Viscous incompressible flow (with an introduction to turbulence).

Intended Learning Outcomes: to demonstrate…

A knowledge and understanding of:	The fundamentals of solid mechanics with application to elasticity; the fundamentals of fluids mechanics.
An ability to: (thinking skills)	Understand different aspects (geometry, equilibrium and constitutive theory) of formulating engineering problems in solid and fluid mechanics, realize the difficulties in obtaining closed form solutions and a necessity for approximation techniques.
An ability to: (practical skills)	Develop practical skills related to tensor calculus; formulate and perform analysis of several classes of engineering problems in solid and fluid mechanics.
An ability to: (key skills)	Study independently; use library resources; effectively take notes and manage working time.

Assessment

70% from end of Semester examination (40% use of lecture notes allowed), 30% by course work.

ADVANCED FLUID MECHANICS

Credits: 5	**Compulsory:** Yes
Lecturer: Antonio Huerta	

Contents

1. Basic Concepts & Revision: Summary of vector analysis: Classical theorems: Greens, Gauss Stokes - Eulerian/Lagrangian derivatives and Reynolds transport theorem (3hrs).
2. Governing Equations: Continuity equations and conservation laws. Mass, momentum and energy conservation. Equation classification. Boundary conditions. Examples. (2hrs).
3. Ideal Fluids: Incompressible, irrotational potential flow. Streamlines, stream function. Examples.
4. Viscous Incompressible Flow: Incompressible Navier-Stokes equations: Couette flow, Poiseuille flow, pipe flow. (10 hrs.).
5. Compressible flow features and equations (1 hr.).
6. The nature of turbulence (3 hrs.).
7. Contrasting analytical, numerical and experimental approaches for solving engineering problems (1hr.).

Intended Learning Outcomes: to demonstrate…

A knowledge and understanding of:	Analytical analysis of fluid flows. Derivation of Fluid Flow Equations (Mass Momentum Energy) Euler to Navier Stokes.
An ability to: (thinking skills)	Construction and understanding of basic analytical tools and solutions for modelling different classes of flows, (from ideal to viscous flow) and contrasting these with numerical and experimental analysis approaches
An ability to: (practical skills)	Understand practical implications of different flow types, appreciation of dominant forces and interpretation of solutions.
An ability to: (key skills)	Study independently and use library resources. Effectively take notes and manage working time.

Assessment

50% continuous assessment assignments, 50% from end of Semester closed book examination.

COMPUTER MODELLING

Credits: 5	**Compulsory:** No
Lecturer:	

Contents

Tutored weekly class where case studies and practical examples are reproduced by the students. Topics covered by the other modules are reviewed and worked in depth using scientific and commercial software.

1. Basics on computers (hardware, software, memory, finite precision).
2. Introduction to computer modeling.
3. Academic test cases of finite differences, finite volume, finite elements and boundary elements.
4. Preprocessing: structured and unstructured mesh methods.
5. Discretization errors and adaptivity.
6. Introduction to 3D computations.

Intended Learning Outcomes: to demonstrate…

A knowledge and understanding of:	Practical hands-on use of computers to solve finite difference, finite volume finite element and boundary element problems; basic preprocessing issues.
An ability to: (thinking skills)	Understand and identify key features to be considered when performing computational simulations of simple engineering problems.
An ability to: (practical skills)	Solve simple academic test cases for all the different numerical techniques for PDEs; develop practical skills related to use of simple academic codes as well as using a commercial code; analyze and assess the output of computational simulations; write report ranging from the definition of the problem at hand to the analysis of the results; public presentation of a complete simulation.
An ability to: (key skills)	Work as team member; produce work to a deadline; write and present work clearly, within a given time and in accordance with the level of understanding of the audience; study independently; use library resources; manage working time.

Assessment

30% individual projects, 50% group project, 20% oral examination.

PROGRAMMING FOR ENGINEERING AND SCIENCE

Credits: 5	**Compulsory:** No
Lecturer: Josep Sarrate	

Contents

The purpose of this module is to introduce the basis of the scientific programming. These fundamental programming skills will be acquired using MATLAB. However, the basic concepts may be extended to any other high level programming language. At the end of the module graduates have acquired elementary programming skills in a high-level programming language. Moreover, they have learned to write computer programmes that allow them to implement the algorithms needed to solve problems in their own area of science or engineering.

1. Introduction to MATLAB: components and environment.
2. Numbers, variables, operators and functions.
3. Arrays and matrices.
4. Plotting curves and surfaces.
5. Loops and decisions.
6. Simple input/output facilities
7. Advanced topics: MATLAB tools and profiling.

Intended Learning Outcomes: to demonstrate…

A knowledge and understanding of:	The key issues of object-oriented programming in scientific and engineering applications; C++ language features to implement object-oriented concepts; the advanced and modern techniques of code improvement and optimization.
An ability to: (thinking skills)	Develop a structured programming approach to solve scientific problems; recognize the MATLAB features that allow implementing a given algorithm…
An ability to: (practical skills)	Implement and develop MATLAB codes to solve problems in a scientific or engineering environment; generate a graphic representation of a given set of data; optimize the performance of an existing MATLAB code using the profiler.
An ability to: (key skills)	Study independently; use library resources; use computational resources, submit the projects in time; produce project reports and present them.

Assessment

100% continuous assessment assignments.

Practical work: Exercises will be set, which will involve coding and analyzing some of the presented programming techniques.

COMPUTATIONAL SOLID MECHANICS

Credits: 5	**Compulsory:** Yes
Lecturer: Xavier Oliver	

Contents

This module focuses on numerical methods applied to modeling non-linear material behaviour in solids. Emphasis is done in the integration of the constitutive models and the insertion of material nonlinearity in finite element settings. The presentation covers both the essential theoretical aspects as well as hands-on applications.

1. Constitutive modeling of materials.
2. Elasticity and visco-elasticity.
3. Continuum damage and visco-damage.
4. Plasticity and visco-plasticity.
5. Material stability.
6. Computational techniques in non-linear material modeling of solids.
7. Advanced topics: contact mechanics and extension to finite strains.

Intended Learning Outcomes: to demonstrate…

A knowledge and understanding of:	The fundamentals of the behaviour of engineering materials and their numerical modeling.
An ability to: (thinking skills)	Understand and identify the key issues relevant to material modeling: identification of the dissipation mechanisms associated to each non-linear behaviour; set up the physically meaningful values for the material properties; identify the proper numerical methods for solving the solids mechanics problem.
An ability to: (practical skills)	Implement and use computer programs to solve solid mechanics problems accounting for material non-linearity; use any one programming language to develop computer codes; use mesh generators to produce appropriate meshes for analysis; use post-processing software and produce graphical representation of results.
An ability to: (key skills)	Study independently; use library resources; submit the projects in time; produce project reports and present them.

Assessment

50% continuous assessment assignments, 50% from end of Term examination (50% open-book).

Practical work: Exercises will be set, which will involve coding some of the presented methods.

COMPUTATIONAL STRUCTURAL MECHANICS AND DYNAMICS

Credits: 5	**Compulsory:** Yes

Lecturer: Miguel Cervera

Contents

This module presents the concepts, formulations and applications of the finite element method for analysis of structures with classical and new materials (composites) under static and dynamic loading. The focus is on linear problems, although a brief introduction to non-linear structural analysis is also given. The different methods cover the most common structural typologies found in engineering practice, such as dams, tunnels, tanks, shells, buildings, bridges, mechanical components, sheet metal parts, etc.

Details of the FEM formulation are given in each case together with a description of the key computational aspects, aiming to introduce students to the programming of the FEM for structural analysis.

The module lectures are complemented with hands-on applications of the FEM to the analysis of a wide range of structures.

1. Basic concepts of matrix analysis of bar structures.
2. 2D solids.
3. Axisymmetric solid.
4. Three dimensional solids.
5. Beams.
6. Thick and thin plates.
7. Folded plate and curved shells.
8. Axisymmetric shells.
9. Structural dynamics analysis.
10. Introduction to non-linear structural analysis.
11. Miscellaneous topics.

Intended Learning Outcomes: to demonstrate…

A knowledge and understanding of:	The fundamental of the theory and practice of finite element method for analysis of structures under static and dynamic loading; the basic theoretical aspects for the analysis of each structure; the computational aspects involved in the structural analysis.
An ability to: (thinking skills)	Identify the appropriate finite element theory for the analysis of a particular structure; select the correct FEM solution strategy; have a critical appraisal of the numerical results.
An ability to: (practical skills)	Be able to analyze most structural types found in practice using the FEM; be able to use commercial FEM codes for structural analysis; be able to develop a basic FEM code for structural analysis.
An ability to: (key skills)	Study structural analysis independently; use library resources; solve structural analysis problems in personal computers; do some basic programming of FEM for structural analysis; be able to pursue advanced modules in structural analysis; effectively managing working time.

Assessment

70% from end of Term examination (50% open book), 30% by course work.

FINITE ELEMENTS IN FLUIDS

Credits: 5	**Compulsory:** No
Lecturer: Antonio Huerta	

Contents

This module presents the fundamentals of finite element methods in flow problems. Emphasis is given to stabilized methods and time integration. The presentation covers both the essential theoretical aspects as well as hands-on applications. In particular, specific techniques for Euler and Navier-Stokes flows are presented and discussed.

1. Conservation equations.
2. Stabilization of the steady convection equation.
3. Time integration of the unsteady transport equation.
4. Compressible flow.
5. Unsteady convection-diffusion problems.
6. Viscous incompressible flows.
7. Modeling turbulence.
8. Advanced topics.

Intended Learning Outcomes: to demonstrate…

A knowledge and understanding of:	The fundamentals of the behaviour and numerical approximation of the fluid dynamics equations; spatial and temporal discretizations and relevant mathematical aspects; stabilization of convection and incompressibility.
An ability to: (thinking skills)	Understand and identify the key issues relevant to discretization both in space and time; set up appropriate initial and boundary conditions; identify the proper methods for the corresponding problem.
An ability to: (practical skills)	Implement and use computer programs to solve fluid dynamics problems; use any one programming language to develop computer codes; use mesh generators to produce appropriate meshes for analysis; use post-processing software and produce graphical representation of results.
An ability to: (key skills)	Study independently; use library resources; submit the projects in time; produce project reports and present them.

Assessment

50% continuous assessment assignments, 50% from end of Term examination (50% open-book).

Practical work: Exercises will be set, which will involve coding some of the presented methods.

INDUSTRIAL TRAINING	
Credits: 15	**Compulsory:** No
Lecturer: Benjamín Suárez / Pedro Díez	
Contents	
INFORMATION ON THIS SUBJECT WILL BE AVAILABLE SOON	

ENTREPRENEURSHIP

Credits: 5	**Compulsory:** No

Lecturer: Pere Losantos

Contents

1. What is an entrepreneur and why enterprise matters: the six dimensions of entrepreneurship, structure and presentation of opportunities, sources and structure of finance, people and teams.
2. How enterprise is managed internationally, managing early and long-term growth, harvesting and buy-out, sustaining the flow of ideas within a company, case-studies.

Intended Learning Outcomes: to demonstrate…

A knowledge and understanding of:	Describe how opportunities are identified and a business plan is generated in order to get started; list the sources of finance that exist and how they are structured; analyse the role of people and what makes a winning team.
An ability to: (thinking skills)	Discuss a case history that lead to success.
An ability to: (practical skills)	Explain how early growth is managed.
An ability to: (key skills)	Analyse how failure can occur and how to guard against it; explain how enterprise can be sustained within an organisation as it grows.

Assessment

Combination of interactive lectures and self-study.

COMPUTATIONAL MECHANICS TOOLS	
Credits: 5	**Compulsory:** No
Lecturer: Irene Arias	

Contents

This module presents an introduction to the first and last step of a numerical simulation in computational mechanics. That is, it presents the numerical techniques involved in the pre and post processing steps On one hand, the principal techniques that allow building a computational mesh from a CAD model are presented. On the other hand, numerical techniques for the visualization of discrete fields defined on a computational grid are discussed. These techniques are introduced solving practical applications using Gid (an existing commercial package).

1. Geometry representation.
2. Meshing algorithms overview.
3. Structured mesh generation.
4. Triangular and tetrahedral mesh generation.
5. Quadrilateral and hexahedral mesh generation.
6. Mesh quality improvement.
7. Fundamentals of scientific visualization.
8. Techniques for discrete field representation.

Intended Learning Outcomes: to demonstrate…

A knowledge and understanding of:	The basic steps of the mesh generation process; the advantages and drawbacks of the most used mesh generation algorithms; the fundamentals of scientific visualization.
An ability to: (thinking skills)	Identify several sources of problems of a given CAD representation; set up the model attributes to build a mesh; select the proper visualization technique for the corresponding result.
An ability to: (practical skills)	To generate a finite element model from a CAD model using several GiD; to visualize the numerical results of a finite element simulation using GiD.
An ability to: (key skills)	Study independently; use library resources; submit the projects in time; produce project reports and present them.

Assessment

100% continuous assessment assignments.

Practical work: Exercises will be set, which will involve coding some of the presented techniques and using several commercial packages.

ADVANCED DISCRETIZATION METHODS

Credits: 5	**Compulsory:** No
Lecturer: Yongxing Shen	

Contents

This module is an extension of the basic concepts included in compulsory modules “Advanced Discretization Methods” and “Finite Element Method”. Advanced topics of modern numerical techniques for partial differential equations are presented, with application to a wide variety of problems in science, engineering, and other fields. Topics include Advanced Finite Elements (Discontinuous Galerkin, level sets, X-FEM) and mesh-free methods.

Advanced Finite Elements:

1. Discontinuous Galerkin (DG) for hiperbolic problems. Riemann solvers and numerical fluxes.
2. DG for elliptic operators.
3. Extended finite elements (X-FEM) and applications (crack simulation, holes and inclusions, material interfaces).
4. Level sets.

Mesh-free Methods:

5. Overview of mesh-free methods.
6. Moving least squares approximation.
7. Element-free Galerkin method.
8. Smooth particle hydrodynamics.
9. Implementation of essential boundary conditions.
10. Coupling of finite elements and mesh-free methods.
11. Particle finite element methods.
12. Discrete element methods.
13. Overview of method and applications.
14. Basic formulation.

Intended Learning Outcomes: to demonstrate…

A knowledge and understanding of:	Modern numerical techniques for the discretization of boundary value problems and its range of applicability.
An ability to: (thinking skills)	Understand and formulate efficient numerical procedures and solve illustrative problems; identify the proper methods for the corresponding boundary value problem.
An ability to: (practical skills)	Understand practical implications of behaviour of numerical methods and solutions; logically formulate numerical methods for solution by computer with a programming language.
An ability to: (key skills)	Study independently; use library resources; use a personal computer for basic programming; effectively take notes and manage working time.

Assessment

50% continuous assessment assignments, 50% from end of Semester examination (50% open-book).

Practical work: Exercises will be set, which will involve coding some of the presented methods.

COMMUNICATIONS SKILLS 1	
Credits: 5	**Compulsory:** No
Lecturer: Francisco Zarate	
Contents	
INFORMATION ON THIS SUBJECT WILL BE AVAILABLE SOON	
Intended Learning Outcomes: to demonstrate…	
A knowledge and understanding of:	
An ability to: (thinking skills)	
An ability to: (practical skills)	
An ability to: (key skills)	
Assessment	

<table>
<tr><th colspan="2">COMPUTATIONAL WAVE PROPAGATION</th></tr>
<tr><td>Credits: 5</td><td>Compulsory: No</td></tr>
<tr><td colspan="2">Lecturer: Santiago Badia</td></tr>
<tr><th colspan="2">Contents</th></tr>
<tr><td colspan="2">INFORMATION ON THIS SUBJECT WILL BE AVAILABLE SOON</td></tr>
<tr><th colspan="2">Intended Learning Outcomes: to demonstrate…</th></tr>
<tr><td>A knowledge and understanding of:</td><td>The fundamentals of the behaviour and numerical approximation of wave propagation problems; basic concepts of wave theory; overview of computational strategies to simulate the propagation of waves.</td></tr>
<tr><td>An ability to:
(thinking skills)</td><td>Understand and identify the key issues relevant to the discretization of wave propagation problems; identify the appropriate solution methods for each type of problem.</td></tr>
<tr><td>An ability to:
(practical skills)</td><td>Implement and use computer programs to solve wave propagation problems; implement and use different solution methods; critically analyze the results of computer programmes.</td></tr>
<tr><td>An ability to:
(key skills)</td><td>Study independently; use library resources; submit the projects in time; produce project reports and present them.</td></tr>
<tr><th colspan="2">Assessment</th></tr>
<tr><td colspan="2">50% continuous assessment assignments, 50% from end of Semester examination (50% open-book).
Practical work: Exercises will be set, which will involve coding some of the presented methods.</td></tr>
</table>

COUPLED PROBLEMS

Credits: 5	**Compulsory:** No

Format: Lectures: 15 hours; Examples: 10 hours: Private study: 60 hours

Lecturer: Ramon Codina, Joan Baiges

Contents

The starting point is a discussion about the correct transmission conditions between the thermo-mechanics of two continua, which need to be satisfied for any coupling scheme. Coupling procedures in space and time are then described, together with some implementation aspects (scaling, convergence checking, preconditioning). Problems appearing in the application are studied in the last three chapters of the course.

1. Transmission conditions in continuum mechanics
2. Coupling in space of homogeneous problems: domain decomposition methods
3. Coupling in space of heterogeneous problems
4. Coupling in time I: partitioned and monolithic schemes
5. Coupling in time II: fractional step schemes
6. Implementation aspects
7. Fluid structure-interaction
8. Coupling mechanics and thermodynamics
9. Coupling mechanics and electromagnetics

Intended Learning Outcomes: to demonstrate…

A knowledge and understanding of:	The nature of coupled problems appearing in computational physics.
An ability to: (thinking skills)	Understanding the origin of coupling, thinking of possible ways to deal with it and the possible implications, both from the physical and the numerical points of view.
An ability to: (practical skills)	Develop and design algorithms for coupled problems, accounting for stability and convergence with maximum efficiency for given computational resources.
An ability to: (key skills)	Study independently; use library resources; effectively take notes and manage working time.

Assessment

30% continuous assessment assignments, 70% from end of Semester open-book examination.

MASTER THESIS	
Credits: 30	**Compulsory:** Yes
Contents	
INFORMATION ON THIS SUBJECT WILL BE AVAILABLE SOON	
Intended Learning Outcomes: to demonstrate…	
A knowledge and understanding of:	
An ability to: (thinking skills)	
An ability to: (practical skills)	
An ability to: (key skills)	
Assessment	