Course guide
220311 - 220311 - Computational Engineering

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Unit in charge: Terrassa School of Industrial, Aerospace and Audiovisual Engineering
Teaching unit: 220 - ETSEIAT - Terrassa School of Industrial and Aeronautical Engineering.

Degree: MASTER'S DEGREE IN AERONAUTICAL ENGINEERING (Syllabus 2014). (Compulsory subject).

Academic year: 2024 **ECTS Credits:** 5.0 **Languages:** English

LECTURER

Coordinating lecturer: CARLOS DAVID PEREZ SEGARRA - JUAN CARLOS CANTE TERAN

Others: Primer quadrimestre:
CARLOS DAVID PEREZ SEGARRA - Grup: 11, Grup: 12
FRANCESC XAVIER TRIAS MIQUEL - Grup: 11, Grup: 12
JUAN CARLOS CANTE TERAN - Grup: 11, Grup: 12
DAVID ROCA CAZORLA - Grup: 11, Grup: 12

PRIOR SKILLS

To follow this course, it is important to have basic knowledge of fluid dynamics and solid mechanics, as well as a programming language (e.g. C++, C, Fortran, Matlab, Python, etc.).
Knowledge equivalent to completion of the leveling course of the master.

DEGREE COMPETENCES TO WHICH THE SUBJECT CONTRIBUTES

Specific:
CE02-MUEA. MUEA/MASE: Sufficient knowledge of advanced fluid mechanics, particularly computational fluid mechanics and turbulence phenomena.
CG09-MUEA. (ENG) Competència en totes aquelles àrees relacionades amb les tecnologies aeroportuàries, aeronàutiques o espacials que, per la seva naturalesa, no siguin exclusives d'altres branques de l'enginyeria.
CE04. MUEA:MASE: The ability to apply the knowledge acquired in various disciplines to solving complex aeroelasticity problems.
CE08. MUEA/MASE: Knowledge and skills in the analysis and structural design of aircraft and space vehicles, including the application of calculation programs and advanced structural design.
CE14. MUEA/MASE: Understanding and mastery of internal aerodynamics laws and their application (and that of other disciplines) to solving complex problems concerning the aeroelasticity of propulsion systems.

Transversal:
CT3. TEAMWORK: Being able to work in an interdisciplinary team, whether as a member or as a leader, with the aim of contributing to projects pragmatically and responsibly and making commitments in view of the resources that are available.

CT5. FOREIGN LANGUAGE: Achieving a level of spoken and written proficiency in a foreign language, preferably English, that meets the needs of the profession and the labour market.

Basic:
CB06. Manage original concepts in research projects.
CB07. Student capacity to use their knowledge in new and multidisciplinary situations.
CB08. Generate decision from incomplete information assuming its social and ethical responsibilities.
CB09. Improve technical communication of results.
CB10. Improve self-learning capacity

TEACHING METHODOLOGY

The course is divided into two main blocks, both dedicated to computational engineering methodologies in continuum mechanics. One of the blocks is focused on computational engineering in the field of fluid dynamics and heat and mass transfer. The other is focused on computational solid mechanics. Main topics are presented in general lectures and in lab sessions, with proposals of different exercises to be carried out by the students.

Self-study is mainly dedicated to the development of practical works, which are individually reviewed based on reports and presentations carried out by the students. The lecturers of the subject will tutor these works.

LEARNING OBJECTIVES OF THE SUBJECT

The aim of the course is to show basic and advanced methodologies in the field of Computational Engineering in continuum mechanics. The course is devoted to two main areas: the computational fluid dynamics and heat transfer (CFD) field and the computational solid mechanics (CSM) field. Two main methodologies are used: finite volume methods and finite element methods.

The course presents the basic tools of analysis, considering aspects related to the mathematical formulation of these problems, discretization techniques, algorithms to solve the whole governing equations (strongly linked non-linear set of partial differential equations), etc.

Some important issues can also be considered in optional works, such as parallelization techniques, solid-fluid interaction, mesh generation, incremental and iterative methods for the solution of nonlinear systems of equations, basic vectorized computer implementation tools, etc.

Objectives of the learning process:
- Consolidation of the fundamental knowledge of fluid dynamics and solid mechanics: problem definition, governing equations, initial and boundary conditions, etc.
- Acquiring knowledge on basic computational fluid dynamics and heat transfer: FVM, discretization schemes, algorithms to couple the equations, parallelization techniques, etc.
- Acquiring knowledge on basic computational solid mechanics: FEM, nonlinear equilibrium equations, initial stress, tangent and secant stiffness, geometric stiffness, Increment control techniques, Newton and quasi-Newton (secant) methods, acceleration and line search, etc.
- Acquiring a first practical experience in CFD and CSM, programming own codes in the chosen computer language (C++, C, Fortran, Matlab, Python, etc.).

STUDY LOAD

Type	Hours	Percentage
Self study	80,0	64.00
Hours small group	30,0	24.00
Hours large group	15,0	12.00

Total learning time: 125 h

CONTENTS

MODULE 0: Introduction to the Computational Engineering

Description:
Introduction to the Computational Engineering in the field of continuum mechanics

Specific objectives:
Introduction to the Computational Engineering in the field of continuum mechanics.

Mathematical formulation of the governing equations in fluid dynamics and solid mechanics.

Brief review of the numerical methodologies used to solve these equations.

Presentation and objectives of the course.

Full-or-part-time: 4h
Theory classes: 2h
Self study : 2h

MODULE 1: Computational Fluid Dynamics. Finite volume methods

Description:
Computational methods applied to fluid dynamics and heat and mass transfer. Attention is specially focused on finite volume methodologies (FVM).

Specific objectives:
Review of the mathematical formulation in fluid dynamics and heat and mass transfer. Incompressible and compressible flows under laminar or turbulent regimes. (Lectures: 1h)

Numerical resolution of potential flows. Discretization techniques for the diffusion and source terms. Proposal of exercises: flow along a stating or rotating cylinder, flow along aerodynamic profiles. (Lectures: 3 h)

Discretization of the generic convection-diffusion equation. Numerical schemes for the unsteady and convective terms. Review of direct and iterative solvers for the solution of large sets of linear equations (with constant or variable coefficients). Code verification techniques. Proposal of benchmark problems. (Lectures: 4 h)

Turbulent flows. Burger equation: computational and phenomenological analysis. Direct numerical simulation (DNS) of turbulent flows using explicit methods. Symmetry-preserving discretization schemes and time-step control. Statistical analysis of the results. Introduction to large-eddy simulation (LES) models. Proposal of exercises. (Lectures: 8 h)

Resolution of the Navier-Stokes equations (mass and momentum) for incompressible flows. Explicit and implicit methods. Generalization considering the energy equation. Proposal of exercises considering confined and open flows. (Lectures: 4 h)

Analysis of compressible flows. Godunov discretization schemes. Riemann solver for the analysis of flow discontinuities. Couple resolution of the governing equations (mass, momentum, energy, state equation). Proposal of exercises. (Lectures: 4 h)

Topics to be presented in optional seminars: a) Parallelization techniques: MPI vs. OpenMP; b) Mesh generation (blocking-off techniques, immersed boundary techniques, body-fitted, non-structured meshes); c) Finite volume discretization in non-orthogonal meshes (structured or unstructured) and solvers; d) Solid-fluid interaction. (Lectures: 2.5 h each)

Full-or-part-time: 60h 30m
Theory classes: 6h 30m
Laboratory classes: 15h
Self study : 39h

MODULE 2: Computational Solid Mechanics. Finite element methods.

Description:
Computational methods applied to solid mechanics. Attention is specially focused on finite element methodologies.

Specific objectives:
Overview of Nonlinear Problems Sources of nonlinearities in structural problems: material, geometry, forces, boundary conditions. General features of nonlinear response (Theory lectures: 2h).

Formulation of Material Nonlinear Finite Elements. Residual and incremental forms (Theory lectures: 2h).

Overview of small deformation plasticity theory and visco-plasticity . Notions of convex optimization theory as a base knowledge to the numerical implementation of plasticity (Theory lectures: 3h)

Theory generalization to multiple dimensions. J2 flow theory (Theory lectures: 3h)

Numerical integration algorithms for general constitutive equations. Notions of return-mapping and closest point projection algorithms (Theory lectures: 5h).

Variational setting of the boundary value problem and discretization by finite element methods (Theory lectures: 2.5h).

Computer Implementation of Nonlinear Analysis. Element level calculations. Equation assembly. Nonlinear equation solver. Residual evaluation. Post-processing (Theory lectures: 4h)

Full-or-part-time: 60h 30m
Theory classes: 6h 30m
Laboratory classes: 15h
Self study : 39h

GRADING SYSTEM

The evaluation consists of at least two oral exams based on the presentation and defence of the different assignments carried out, individually or in group, throughout the course in both modules, CFD and CSM.

The CFD part accounts for 50% of the final mark, and the CSM part accounts for the other 50%.

The presentation and defence of the works are individual. Different dates and times will be proposed to be chosen by the student at the end of the first bimester and at the end of the second bimester.

In case of an evaluation mark lower than 5, there will be the possibility of doing a new presentation and defence exam of the work carried out.

EXAMINATION RULES.

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BIBLIOGRAPHY

Basic:

- Patankar, Suhas V. Numerical heat transfer and fluid flow [on line]. New York: McGRaw-Hill, 1980 [Consultation: 16/11/2022]. Available on: https://www-taylorfrancis-com.recursos.biblioteca.upc.edu/books/mono/10.1201/9781482234213/numerical-heat-transfer-fluid-flow-suhas-patankar. ISBN 0070487405.
- Pope, Stephen B. Turbulent flows. Cambridge [etc.]: Cambridge University Press, 2000. ISBN 0521591252.
- LeVeque, Randall, J. Finite volume methods for hyperbolic problems. New York: Cambridge University Press, 2002. ISBN 9780521009249.
- Oñate, Eugenio. Structural analysis with the finite element method: linear statics [on line]. Barcelona: [London]: CIMNE; Springer, 2009-2012 [Consultation: 14/11/2022]. Available on: https://link-springer-com.recursos.biblioteca.upc.edu/book/10.1007/978-1-4020-8733-2.
- Belytschko, T.; Liu, W. K.; Moran, B. Nonlinear finite elements for continua and structures [on line]. 2nd ed. Chichester [etc.]: John Wiley & Sons, 2014 [Consultation: 03/05/2022]. Available on: https://ebookcentral-proquest-com.recursos.biblioteca.upc.edu/lib/upcatalunya-ebooks/detail.action?pq-origsite=primo&docID=1501634. ISBN 9781118700051.
- Simo, J. C.; Hughes, T. J. R. Computational inelasticity [on line]. New York: Springer, 1998 [Consultation: 03/05/2022]. Available on: https://link-springer-com.recursos.biblioteca.upc.edu/book/10.1007/b98904. ISBN 0387975209.
- Bonet, J.; Wood, R. D. Nonlinear continuum mechanics for finite element analysis. 2nd ed. Cambridge: Cambridge University Press, 2008. ISBN 9780521838702.

Complementary:

- Garnier, E.; Adams, N.; Sagaut, P. Large eddy simulation for compressible flows. [s.l.]: Springer, 2009. ISBN 9789048128181.
- Ferziger, J. H.; Peric, M. Computational methods for fluid dynamics. 3rd rev. ed. Berlin [etc.]: Springer, 2002. ISBN 3540420746.
- Babinsky, H.; Harvey, J. Shock wave-boundary-layer interactions. New York: Cambridge University Press, 2014. ISBN 9781107646537.
- Roache, Patrick J. Fundamentals of verification and validation. Hermosa Publishers, 2009. ISBN 9780913478127.

RESOURCES

Other resources:

In addition to the basic bibliography offered in this guide, specific material developed by the lecturers is available on Atenea.