220311 - Computational Engineering

Coordinating unit: 205 - ESEIAAT - Terrassa School of Industrial, Aerospace and Audiovisual Engineering
Teaching unit: 220 - ETSEIAT - Terrassa School of Industrial and Aeronautical Engineering
Academic year: 2018
Degree: MASTER'S DEGREE IN AERONAUTICAL ENGINEERING (Syllabus 2014). (Teaching unit Compulsory)
ECTS credits: 5 Teaching languages: English

Teaching staff

Coordinator: Carlos David Pérez-Segarra and Juan Carlos Cante Teran

Others: Roberto Flores Le Roux
F.Xavier Trias Miquel

Opening hours

Timetable: The specific timetable is personally agreed on with the student according to his/her availability.

Prior skills

Basic knowledge of solid mechanics and fluid dynamics and heat and mass transfer, as well as programming language.

Requirements

Knowledge equivalent to completion of the leveling course of the master.

Degree competences to which the subject contributes

Specific:

CEEVEHI1. MUEA/MAS: Sufficient applied knowledge of advanced, experimental and computational aerodynamics (specific competency for the specialisation in Aerospace Vehicles).
CE02-MUEA. MUEA/MASE: Sufficient knowledge of advanced fluid mechanics, particularly computational fluid mechanics and turbulence phenomena.
CEEVEHI2. MUEA/MAS: Sufficient applied knowledge of the aeroelasticity and structural dynamics of aircraft (specific competency for the specialisation in Aerospace Vehicles).

Teaching methodology

The course is divided into two main blocks, both dedicated to computational engineering methodologies in the continuum mechanics. One of the blocks is dedicated to computational engineering in the field of fluid dynamics and heat and mass transfer. The other is focused on computational solid mechanics. The two blocks are carried out simultaneously. Main topics are presented in general lectures, 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. These works will be tutored by the lecturers of the subject.

Learning objectives of the subject

The aim of the course is to show basic and advanced methodologies in the field of Computational Engineering in the continuum mechanics. The course is devoted to two main areas: the computational fluid dynamic (CFD) field and the computational solid mechanics (CSM) field. Two important 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, discretizacion techniques, and algorithms to solve the whole governing equations (strongly linked non-linear set of partial differential equations).

Some important issues are also considered as parallelization techniques, solid-fluid interaction, mesh generation, incremental and iterative methods for solution of nonlinear systems of equations and basic vectorized computer implementation tools.

Objectives of the learning process:
- Consolidation of the fundamental knowledge on fluid dynamics and solid mechanics: problem definition, governing equations, initial and boundary conditions, etc.
- Acquiring knowledge on basic computational fluid dynamics and heat transfer: 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 methods. Secant (quasi-Newton) methods. Acceleration and line search.
Acquiring a first practical experience in CFD and CSM, programming own C++ codes.

Study load

Total learning time: 125h	Hours large group:	15h	12.00%
	Hours small group:	30h	24.00%
	Self study:	80h	64.00%

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Content

MODULE 0: Introduction to the Computational Engineering	Learning time: 4h Theory classes: 2h Self study : 2h

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

MODULE 1: Computational Fluid Dynamics. Finite volume methods	Learning time: 60h 30m Theory classes: 6h 30m Laboratory classes: 15h Self study : 39h

Description:

Computational methods applied to fluid dynamics and heat and mass transfer. Attention is specially focused on finite volume methodologies.

Specific objectives:

Review of the mathematical formulation in fluid dynamics and heat and mass transfer. Incompressible and compressible flows under laminar or turbulent regimes. (Theory/problems lectures: 1h)

Discretization of the generic convection-diffusion equation. Numerical schemes for the 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. (Theory lectures: 4 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. (Theory lectures: 5 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. (Theory 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. (Theory lectures: 5 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. (Theory lectures: 2.5 h each)

MODULE 2: Computational Solid Mechanics. Finite element methods.	Learning time: 60h 30m Theory classes: 6h 30m Laboratory classes: 15h Self study : 39h

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)

Qualification system

- Practical works (software development) carried out individually and/or in groups throughout the course in Module 1 (CFD): 50%
- Practical works (software development) carried out individually and/or in groups throughout the course in Module 2 (CSM): 50%
- There are mechanisms to improve the marks corresponding to the practical works in the case of failure.

Regulations for carrying out activities

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Bibliography

Basic:

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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.

Simo, J. C.; Hughes, T. J. R. Computational inelasticity [on line]. New York: Springer, 1998 [Consultation: 05/07/2016]. Available on: <http://link.springer.com/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.

Belytschko, T.; Liu, W. K.; Moran, B. Nonlinear finite elements for continua and structures [on line]. 2nd ed. Chichester [etc.]: John Wiley & Sons, 2013 [Consultation: 05/07/2016]. Available on: <http://site.ebrary.com/lib/upcatalunya/docDetail.action?docID=10788029>. ISBN 9781118700051.

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.