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, discretization 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 a first practical experience in CFD and CSM, programming own C++ codes.

### Study load

<table>
<thead>
<tr>
<th>Total learning time: 125h</th>
<th>Hours large group:</th>
<th>15h</th>
<th>12.00%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hours small group:</td>
<td>30h</td>
<td>24.00%</td>
</tr>
<tr>
<td></td>
<td>Self study:</td>
<td>80h</td>
<td>64.00%</td>
</tr>
</tbody>
</table>
## Content

<table>
<thead>
<tr>
<th><strong>MODULE 0: Introduction to the Computational Engineering</strong></th>
<th><strong>Learning time:</strong> 4h</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Theory classes: 2h</td>
</tr>
<tr>
<td></td>
<td>Self study: 2h</td>
</tr>
</tbody>
</table>

**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)
- 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)

**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)
220311 - Computational Engineering

**MODULE 2: Computational Solid Mechanics.**

**Finite element methods.**

<table>
<thead>
<tr>
<th><strong>Learning time:</strong> 60h 30m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theory classes: 6h 30m</td>
</tr>
<tr>
<td>Laboratory classes: 15h</td>
</tr>
<tr>
<td>Self study : 39h</td>
</tr>
</tbody>
</table>

**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).

**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:


Complementary:


