

# Course guide 250957 - ELEFINFLUI - Finite Elements in Fluids

#### Last modified: 28/03/2024

Unit in charge: Teaching unit:	Barcelona School of Civil Engineering 751 - DECA - Department of Civil and Environmental Engineering.		
Degree:	MASTER'S DEGREE IN NUMERICAL METHODS IN ENGINEERING (Syllabus 2012). (Compulsory subject). ERASMUS MUNDUS MASTER'S DEGREE IN COMPUTATIONAL MECHANICS (Syllabus 2013). (Optional subject).		
Academic year: 2023	ECTS Credits: 5.0 Languages: English		

Coordinating lecturer:	MATTEO GIACOMINI
Others:	MATTEO GIACOMINI, ANTONIO HUERTA CEREZUELA

# DEGREE COMPETENCES TO WHICH THE SUBJECT CONTRIBUTES

#### Specific:

**LECTURER** 

8378. Practical numerical modeling skills. Ability to acquire knowledge on advanced numerical modeling applied to different areas of engineering such as: civil or environmental engineering or mechanical and aerospace engineering or bioengineering or Nanoengineering and naval and marine engineering, etc..

8379. Knowledge of the state of the art in numerical algorithms. Ability to catch up on the latest technologies for solving numerical problems in engineering and applied sciences.

8380. Materials modeling skills. Ability to acquire knowledge on modern physical models of the science of materials (advanced constitutive models) in solid and fluid mechanics.

8382. Experience in numerical simulations. Acquisition of fluency in modern numerical simulation tools and their application to multidisciplinary problems engineering and applied sciences.

8383. Interpretation of numerical models. Understanding the applicability and limitations of the various computational techniques.

8384. Experience in programming calculation methods. Ability to acquire training in the development and use of existing computational programs as well as pre and post-processors, knowledge of programming languages ??and of standard calculation libraries.

# **TEACHING METHODOLOGY**

The course consists of 0,6 hours per week of classroom activity (large size group) and 1,2 hours weekly with half the students (medium size group).

The 0,6 hours in the large size groups are devoted to theoretical lectures, in which the teacher presents the basic concepts and topics of the subject, shows examples and solves exercises.

The 1,2 hours in the medium size groups is devoted to solving practical problems with greater interaction with the students. The objective of these practical exercises is to consolidate the general and specific learning objectives.

The rest of weekly hours devoted to laboratory practice.

Support material in the form of a detailed teaching plan is provided using the virtual campus ATENeA: content, program of learning and assessment activities conducted and literature.



# LEARNING OBJECTIVES OF THE SUBJECT

This course covers the essential theoretical aspects as well as their practical uses, specially for specific techniques for the Euler and Navier-Stokes equations.

\* To learn the theoretical and practical fundamentals of the finite elements method applied to the dynamics of fluids to identify the basic theoretical aspects and their inherent computational aspects. \* To learn the fundamentals of the numerical approximations in fluid dynamics: The equations, the spatial and temporal discretisations and the most relevant mathematical aspects, such as the stabilisation of convection and incompressibility condition; understanding of the most important aspects of spatial and temporal discretisations and the most suitable method for the solution of different fluid dynamics problems. \* The students will develop practical skills to work with tensors and formulate and develop the analysis of diverse problems of fluids in engineering.

- \* Conservation Equations.
- \* Stabilisation of the stationary convection equation
- \* Temporal integration of the transient transport equation.
- \* Compressible flow.
- \* Transient convection diffusion problems
- \* Incompressible Viscous flow.
- \* Modeling of turbulence.
- \* Advanced subjects
- Learning resources:

o Donea, J., Huerta, A., Finite Element Methods for Flow Problems, Wiley, 2003

This course covers the essential theoretical and practical aspects of the numerical approximation of partial differential equations modeling flow problems, specifically focusing on Euler and Navier-Stokes equations.

Learning objectives: be able to understand the fundamentals of mathematical modeling the motion of fluids, construct numerical algorithms to simulate convection-diffusion-reaction phenomena, understand the numerical difficulties and basic methods to approximate incompressible flows (Stokes and Navier-Stokes equations) and purely convective inviscid flows (Euler equations). More specifically:

- describe, predict and formulate techniques for steady linear scalar convection-diffusion-reaction problems,
- understand stabilization techniques for convection-dominated flows,
- formulate techniques for inviscid flows,
- understand the major difficulties in handling hyperbolic equations and the concept of well-posed Euler problem,
- describe, predict and formulate techniques for incompressible flows,
- understand the major difficulties in solving Stokes and Navier-Stokes equations.

Teaching material

- Class notes

- J. Donea, A. Huerta. Finite Element Methods for Flow Problems. Wiley 2003

# **STUDY LOAD**

Туре	Hours	Percentage
Hours small group	9,8	7.83
Self study	80,0	63.95
Hours medium group	9,8	7.83
Hours large group	25,5	20.38

#### Total learning time: 125.1 h



# CONTENTS

## **Review of basic concepts**

#### **Description:**

Description of the flow motion equations Weak form Discretization Elementary matrices and assembly. Numerical integration Reference element Implementation

Full-or-part-time: 12h Theory classes: 1h Practical classes: 2h Laboratory classes: 2h Self study : 7h

## Steady convection-diffusion problems

#### **Description:**

Analysis of the convection-diffusion equation 1D. Effect of the Péclet number and need for stabilization 1D convection-diffusion equation with constant coefficients: optimal stabilization parameter. Consistent stabilized formulations. FEM solution of a 1D equation. Oscillations for Péclet number > 1. Stabilized formulations. Solution of a 2D problem.

Full-or-part-time: 14h 23m Theory classes: 1h Practical classes: 2h Laboratory classes: 3h Self study : 8h 23m

#### **Pure convection problems**

#### **Description:**

Classical techniques of temporal and space discretization: theta-methods and Galerkin discretization Higher-order time integration schemes. Discretization using least-squares approximation. Stability and accuracy (Courant number). Solving problems 1D and 2D to understand the properties of stability and precision. Influence of Couran's number.

Full-or-part-time: 14h 23m Theory classes: 1h Practical classes: 2h Laboratory classes: 3h Self study : 8h 23m



## **Compressible flow problems**

# **Description:**

Nonlinear hyperbolic scalar equations: weak solutions. Discretization in time and space. Basic properties of Euler equations. Boundary conditions

Introduction to Riemann Solvers for nonlinear hyperbolic equations Solution of the Burgers equation.

Full-or-part-time: 19h 12m Theory classes: 2h Practical classes: 3h Laboratory classes: 3h Self study : 11h 12m

## Viscous incompressible flow problems

#### **Description:**

Inf-sup condition. Temporary and spatial discretization. Weak form using a mixed formulation. Stabilized formulations. Efficient techniques for transient viscous incompressible flows Cavity flow problem. Stable and unstable mixed elements. Effect of the name of Reynolds

Full-or-part-time: 28h 47m Theory classes: 2h Practical classes: 6h Laboratory classes: 4h Self study : 16h 47m

### **Discontinuous Galerkin**

### **Description:**

Basic concepts on modern discontinuous Galerkin methods Formulation and advantages of the hybridizable discontinuous Galerkin for flow problems Implementation details on HDG

Full-or-part-time: 19h 12m Theory classes: 2h Practical classes: 3h Laboratory classes: 3h Self study : 11h 12m



# **GRADING SYSTEM**

The grade of the course is obtained from a continuous assessment during the module. This consists of several activities, both individual and in group, of incremental training, carried out during the module, both in and out of the classroom.

The final grade will be computed as follows:

- 35% written exam on the first part of the module (Test 1);
- 35% written exam on the second part of the module (Test 2);
- 30% classwork (Periodic assignments on practical and programming exercises).

The written tests will assess the assimilation of the fundamental concepts related to the learning objectives of the module and will consist of:

- theoretical questions on the numerical methods presented in class;
- practical exercises requiring to write the discrete formulation for a given method and problem;
- interpretation questions commenting on the expected performance of the methods starting from the theory.

The evaluation of the classwork will assess the incremental learning of the students and will be based upon:

- periodic assignments consisting of both written and programming exercises on the numerical methods seen during the module, to be submitted for correction;

- participation during lectures, exercise and practical classes.

For the distance learning version of the Master, classwork evaluation will only consider the submitted assignments.

# **EXAMINATION RULES.**

The assignments must be submitted via ATENeA by the announced deadline. Late submissions or assignments submitted using other means will not be accepted and will be graded 0.

The assignments must be performed individually: students are encouraged to discuss about the assignments but the submitted work must be the result of one own efforts. Plagiarism in the assignments will be punished with a 0 in the classwork grade.

The written exams (tests 1 and 2) must be performed individually and will be closed-book. Plagiarism will be punished with a 0 in the module grade.

# **BIBLIOGRAPHY**

#### **Basic:**

- Donea, J.; Huerta, A. Finite element methods for flow problems [on line]. Chichester: John Wiley & Sons, 2003 [Consultation: 19/02/2021]. Available on: <u>https://onlinelibrary.wiley.com/doi/book/10.1002/0470013826</u>. ISBN 0471496669.