UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH

Course guide
295451 - 295TM012 - Advanced Fluid Science and Engineering Technologies

Last modified: 02/10/2025

Unit in charge: Barcelona East School of Engineering
Teaching unit: 729 - MF - Department of Fluid Mechanics.

Degree: MASTER'S DEGREE IN MECHANICAL TECHNOLOGIES (Syllabus 2024). (Compulsory subject).

Academic year: 2025 **ECTS Credits:** 6.0 **Languages:** Spanish

LECTURER

Coordinating lecturer: JAN MATEU ARMENGOL - FRANCESCO CAPUANO

Others: Primer quadrimestre:
JOAN CALAFELL SANDIUMENGE - Grup: T1
FRANCESCO CAPUANO - Grup: T1
JAN MATEU ARMENGOL - Grup: T1
RICARDO JAVIER PRINCIPE RUBIO - Grup: T1

LEARNING RESULTS

Knowledges:
K.01. Critically interpret the physical principles governing the behaviour of systems and advanced applications in the fields of mechanical design, manufacturing processes, strength of materials, fluid mechanics, thermodynamics and heat transfer.
K.08. Identify data analysis tools to characterise, synthesise, explain and predict the behaviour of physical systems in the field of mechanical engineering.
K.04. Correctly interpret technical documentation related to the design of facilities, processes and products in the context of research and development projects in the mechanical engineering field.
K.05. Identify emerging technologies, both in the mechanical domain and in the field of new information and communication technologies, that can be applied to mechanical engineering projects.
K.02. Identify the fundamental equations governing physical phenomena associated with complex problems in mechanical engineering.
K.07. Define appropriate analytical, experimental and/or computational models to study relevant problems in mechanical engineering.

Skills:
S.02. Correctly apply the analytical, computational and/or experimental techniques best suited to the analysis of a case or project in the mechanical field.
S.08. Integrate knowledge from different areas of the mechanical field in the design and development of projects, systems and engineering solutions.
S.05. Critically examine the results of the analysis of a process or product, taking into account the limitations of the techniques used.
S.03. Use advanced numerical simulation and virtual prototyping techniques to solve complex mechanical problems.
S.01. Comprehensively apply experimental techniques, calculations, evaluations, appraisals, expert reports, studies, work plans and related tasks in the development of mechanical engineering projects, applying compulsory specifications, regulations and standards at each stage of the process.

Competences:
C.03. Manage the acquisition, structuring, analysis and visualisation of data and information in the mechanical field and critically evaluate the results of this process.
C.02. Work as part of a multidisciplinary team, whether as a team member or in a leadership role, to contribute to the development of projects with pragmatism and a sense of responsibility, undertaking commitments with due regard to the resources available.
C.04. Ensure, within the limits of one's professional competence, compliance with ethical standards, professional guidelines and current legislation regarding fundamental rights, taking into account the goal of reducing inequalities, the gender perspective, and the principles of accessibility, inclusion and non-discrimination in the design of technical solutions and in the management of projects and teams.
C.05. Propose advanced scientific and technological solutions to complex industrial challenges in the field of mechanical engineering.

TEACHING METHODOLOGY

The teaching methodology combines interactive frontal lectures (based on blackboard handwriting and dynamic, visually-supported presentations) with laboratory (tutorials + hands-on) sessions. During the class, students are constantly stimulated to engage in interactive discussions via practical examples, exploring real-world applications across various industries and fields. Theoretical lectures are closely integrated with hands-on experimental and computational labs, allowing students to actively participate in setting up experiments, collecting data, and analyzing results. Based on the teaching material and under the instructor's guidance, the students perform individual work to delve into the details of experimental and numerical tools/techniques utilized during the lab sessions, and to acquire related post-processing skills. Finally, a seminar series featuring guest lecturers provides insights into cutting-edge research and industry applications.

LEARNING OBJECTIVES OF THE SUBJECT

This course will equip students with the theoretical foundation as well as interpretive and predictive tools necessary for solving complex engineering problems related to fluid mechanics, preparing them for industrial applications or advanced applied research in mechanical engineering; nonetheless, the learning outcomes are transversal to fields such as aerospace, energy, environmental and biomedical engineering. At the end of the course, the students should be able to:
- Formulate and manipulate the mathematical equations that govern fluid flows across different flow regimes and in a wide range of physical complexity, and derive suitable approximations
- Identify, describe and characterize complex fluid mechanics phenomena that involve turbulent flows, fluid-structure interactions and multiphysics coupling
- Devise appropriate techniques (numerical, analytical or experimental) to address relevant fluid mechanics problems in complex engineering systems
- Possess an overview of the main experimental techniques to measure and visualize flow fields
- Set-up, run and analyze the results of a computational fluid dynamics (CFD) simulation using commercial software, and have a basic understanding of the related computational approach
- Critically interpret and analyze the results of experiments or computations, with awareness of the applicability and limitations of models/techniques employed
- Apply advanced fluid mechanics principles and tools to the design of real systems
- Describe current challenges in fluid dynamics and how they are being tackled

STUDY LOAD

Type	Hours	Percentage
Self study	96,0	64.00
Hours large group	40,5	27.00
Hours small group	13,5	9.00

Total learning time: 150 h

CONTENTS

Fundamentals

Description:
Remarks on the governing equations of fluid flow and associated induced equations. Dimensionless numbers and flow regimes. Idealized models: irrotational flow, Stokes flow, incompressible flow and related approximations: low-Mach and Boussinesq models. Analytical solutions of steady and unsteady flows. Introduction to advanced models for describing complex and multi-physics flows discussed in the course, and related examples.

Specific objectives:
Command the governing equations of fluid flow, their mathematical structure and physical implications in a wide range of flow regimes and physical complexity. Refresh fundamental theoretical results and learn additional analytical tools to study fluid flow. Expand the knowledge of available analytical solutions of the Navier-Stokes equations.

Related activities:
Volumetric pump. Objectives of practical session: i) expand knowledge on turbomachinery; ii) analyze a low-Reynolds application with pulsatile flow and compare with analytical solution.

Full-or-part-time: 28h
Theory classes: 6h
Laboratory classes: 4h
Self study : 18h

Visualization, measurement and prediction of flow fields

Description:
Limitations of theoretical models. Experimental approach: overview of flow visualization and measurement techniques. Experiments vs. computations. Introduction to computational fluid dynamics (CFD): overview of a numerical solution method.

Specific objectives:
Gather a basic understanding of modern tools and techniques to visualize and predict complex unsteady and three-dimensional flow fields both qualitatively and quantitatively; have a critical perspective on employing experimental vs. computational methods for studying fluid dynamics problems. Learn the basics of a CFD workflow.

Related activities:
Computational lab: Illustration of CFD software and setup of a simulation; post-processing and visualization of flow fields
Visualization/experimental lab: post-processing of experimental data
Objectives of practical session: i) learn how to set-up a CFD case; ii) visualize and manipulate experimental or computational flow datasets.

Full-or-part-time: 31h
Theory classes: 6h
Laboratory classes: 4h
Self study : 21h

Turbulent flows

Description:
Flow instabilities and transition to turbulence. Phenomenology of turbulent flows and statistical description of turbulence. Free-shear turbulent flows: wakes, jets, mixing layers. External flows. Wall-bounded turbulent flows. Reynolds averaged equations and related stresses: the closure problem. Turbulence modeling.

Specific objectives:
Learn the phenomenology of unstable and turbulent flows in canonical configurations. Understand the difficulties associated with quantitative description of turbulence. Gather a basic grasp of turbulence modeling.

Related activities:
Experimental lab: turbulent flow using wind tunnel
Computational lab: RANS vs. LES/DNS simulation
Specific objectives of hand-on sessions: i) measure and analyze a turbulent signal; ii) understand the conceptual and practical difference between scale-resolving and Reynolds-averaged approaches; iii) compare experimental and numerical results; iv) learn how to visualize complex three-dimensional datasets.

Full-or-part-time: 33h
Theory classes: 10h
Laboratory classes: 4h
Self study : 19h

Multi-physics flows

Description:
Introduction to multi-physics flows. Fluid-structure interaction in engineering and biological applications. Fundamentals of two-phase flows. Overview of reactive flows and coupling among energy, mass, and momentum transport equations. Data-driven modeling in fluid mechanics.

Specific objectives:
Acquire core competencies in the phenomenology and modeling of complex flows occurring in real-world industrial processes, including flows interacting with deformable structures, flows with a dispersed or stratified second phase, and flows with multi-physics. In addition, modern concepts of data-driven modeling are introduced.

Related activities:
Experimental lab: fluid-structure interaction experiment
Specific objectives of hands-on session: i) analyze experimental signals and extract relevant frequencies; ii) visualize phenomenology of FSI.

Full-or-part-time: 29h
Theory classes: 8h
Laboratory classes: 2h
Self study : 19h

Project-based learning

Description:
Tutoring of the group project chosen by the students among those proposed.

Full-or-part-time: 29h
Guided activities: 10h
Self study : 19h

GRADING SYSTEM

Midterm theoretical test (30%)
Laboratory performance (10%)
Group project (60%)

BIBLIOGRAPHY

Basic:

- Ferziger, Joel H.; Peric, Milovan; Street, Robert L. Computational Methods for Fluid Dynamics. Fourth edition. Cham: Springer, [2019]. ISBN 9783319996912.
- Çengel, Yunus A; Cimbala, John M; Kanoglu, Mehmet. Fluid mechanics : fundamentals and applications. 2a ed. Boston [etc.]: McGraw-Hill, cop. 2010. ISBN 9780071284219.

Complementary:

- Tritton, D. J. Physical fluid dynamics. 2nd ed. Oxford : New York: Clarendon Press ; Oxford University Press, cop. 1988. ISBN 9780198544890.
- Kundu, Pijush K; Cohen, Ira M; Hu, Howard H. Fluid mechanics. 2nd ed. San Diego [etc.]: Academic Press, cop. 2002. ISBN 0121782514.
- Tavoularis, Stavros. Measurement in fluid mechanics. Cambridge [etc.]: Cambridge University Press, 2005. ISBN 0521815185.
- Davidson, Peter. Turbulence : an introduction for scientists and engineers. Second edition. Oxford: Oxford University Press, [2015]. ISBN 9780198722595.
- Pope, S. B. Turbulent flows. Repr. with corr. Cambridge, UK [etc.]: Cambridge University Press, 2003. ISBN 9780521591256.