

Course guide

205364 - 205364 - Turbulence I: Fundamentals, Simulation and Aerodynamics

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Unit in charge: Terrassa School of Industrial, Aerospace and Audiovisual Engineering
Teaching unit: 724 - MMT - Department of Heat Engines.

Degree: MASTER'S DEGREE IN INDUSTRIAL ENGINEERING (Syllabus 2013). (Optional subject).
MASTER'S DEGREE IN AERONAUTICAL ENGINEERING (Syllabus 2014). (Optional subject).
MASTER'S DEGREE IN SPACE AND AERONAUTICAL ENGINEERING (Syllabus 2016). (Optional subject).
MASTER'S DEGREE IN MECHANICAL ENGINEERING RESEARCH (Syllabus 2024). (Optional subject).
MASTER'S DEGREE IN INDUSTRIAL ENGINEERING (Syllabus 2025). (Optional subject).

Academic year: 2026 **ECTS Credits:** 3.0 **Languages:** English

LECTURER

Coordinating lecturer: Trias Miquel, Francesc Xavier

Others:

TEACHING METHODOLOGY

The course is developed through lectures, practical sessions and supervised hands-on activities. Theoretical sessions are supported by slides, videos and examples from numerical simulations and turbulent-flow databases. Practical sessions are devoted to the preparation and supervision of the assignments, including code explanation, numerical implementation, post-processing of turbulent-flow data and discussion of difficulties encountered by the students. At least two hands-on sessions are planned: one on the one-dimensional heat conduction problem and one on the analysis of turbulent-flow data.

LEARNING OBJECTIVES OF THE SUBJECT

The course introduces students to the fundamental physical mechanisms of turbulent flows and to their relevance in aerodynamics and engineering applications. It provides a first view of turbulence phenomenology, the Navier-Stokes equations, numerical simulation and the main modelling strategies used in computational fluid dynamics.

At the end of the course, students should be able to identify the main features of turbulent flows, interpret basic turbulent-flow data, understand the role of numerical simulation in turbulence research and engineering practice, and relate aerodynamic phenomena such as boundary layers, wakes and separation with the theoretical concepts discussed in class.

STUDY LOAD

Type	Hours	Percentage
Hours large group	27,0	36.00
Self study	48,0	64.00

Total learning time: 75 h

CONTENTS

Module 1: Introduction to turbulence and aerodynamics

Description:

Introduction to the course and to the role of turbulence in engineering, aerodynamics and heat-transfer applications. Presentation of representative turbulent flows, including wakes, jets, shear layers, boundary layers, separated flows and buoyancy-driven flows. Basic discussion of why turbulence is difficult to predict and why numerical simulation has become an essential tool in modern fluid dynamics.

Related activities:

Introductory discussion on students' background and expectations. Analysis of selected examples of turbulent flows from videos, images or simulation databases. Short reading or reflection exercise on the relevance of turbulence in aerodynamic applications.

Full-or-part-time: 12h 30m

Theory classes: 4h 30m

Self study : 8h

Module 2: Governing equations and CFD

Description:

Review of the incompressible Navier-Stokes equations as a mathematical model for turbulent flows. Physical interpretation of convection, diffusion, pressure and incompressibility. Introduction to the basic CFD workflow, including modelling, discretization and numerical solution. Discussion of validation and verification, with emphasis on the distinction between solving the right equations and solving the equations right.

Related activities:

Exercise on the physical interpretation of the terms in the Navier-Stokes equations.
Identification of modelling, discretization and solver errors in simple CFD examples.
Short problem or quiz on governing equations and CFD terminology.

Full-or-part-time: 12h 30m

Theory classes: 4h 30m

Self study : 8h

Module 3: Basic numerical simulation concepts

Description:

Introductory presentation of the main numerical ingredients used in CFD simulations of turbulent flows. Basic finite-volume ideas, spatial discretization, numerical schemes, time integration, stability, CFL condition and linear solvers. The objective is to provide students with the minimum numerical background needed to interpret turbulent-flow simulations.

Related activities:

Hands-on session and practical work related to Assignment 1: one-dimensional heat conduction problem. Simple numerical exercise on finite differences or finite volumes, explicit time integration, stability, comparison with analytical solutions and grid-convergence analysis.

Full-or-part-time: 12h 30m

Theory classes: 4h 30m

Self study : 8h

Module 4: Turbulence phenomenology I

Description:

Introduction to the physical phenomenology of turbulence. Reynolds number, turbulent scales, eddies, kinetic-energy cascade and dissipation. Kolmogorov's classical theory, inertial range, dissipative scales and interpretation of energy spectra. Discussion of the connection between turbulence structure and simulation requirements.

Related activities:

Exercise on turbulent scales and Reynolds-number dependence. Analysis of idealized or numerical energy spectra. Short calculation of characteristic turbulent length and time scales.

Full-or-part-time: 12h 30m

Theory classes: 4h 30m

Self study : 8h

Module 5: Turbulence phenomenology II

Description:

Continuation of turbulence phenomenology with emphasis on interscale energy transfer, vortex stretching and canonical turbulent flows. Introduction to homogeneous isotropic turbulence, shear flows and simplified model problems. Discussion of how canonical flows are used to understand turbulence and to test numerical methods and turbulence models.

Related activities:

Hands-on session and practical work related to Assignment 2: analysis of turbulent- flow data. Post-processing of simulation results, interpretation of flow visualizations, spectra, turbulent kinetic energy, Reynolds stresses and other statistical quantities.

Full-or-part-time: 12h 30m

Theory classes: 4h 30m

Self study : 8h

Module 6: Boundary layers and aerodynamic flows

Description:

Introduction to wall-bounded turbulence and its relevance in aerodynamics. Boundary-layer concepts, wall units, friction velocity, law of the wall, separation and aerodynamic forces. Discussion of the numerical challenges associated with near-wall turbulence and the impact of boundary layers on aerodynamic performance.

Related activities:

Exercise on wall units, friction velocity and boundary-layer quantities. Analysis of velocity profiles in wall-bounded flows. Discussion of aerodynamic examples involving separation, drag and flow control.

Full-or-part-time: 12h 30m

Theory classes: 4h 30m

Self study : 8h

GRADING SYSTEM

Any academic fraud, plagiarism or use or possession of unauthorised means in an assessment activity leads to a mark of zero (0) for the affected test or assignment. Furthermore, in accordance with the University's regulations, if disciplinary proceedings are initiated the subject is recorded as "Pending Assessment" until a decision is reached. These incidents are managed in accordance with the [Action Framework for Academic Integrity in Assessment at the UPC](#).

Partial exam: 20%. Individual written test on the first part of the course.

Final exam: 35%. Individual written test covering the main theoretical and practical contents of the whole course.

Assignments: 45%. Two practical assignments (22.5% each) involving report, numerical implementation or post-processing work when applicable, discussion of the results and connection with the theoretical contents of the course.

Assignment 1: One-dimensional heat conduction problem. Students start from a provided MATLAB code and modify it to implement explicit time-integration schemes, such as forward Euler, Adams-Bashforth or Runge-Kutta methods. The work may include stability analysis, estimation of the optimal time step, comparison with analytical solutions and grid-convergence studies. Students must submit a short report and the corresponding code.

Assignment 2: Analysis of turbulent flows. Students select one or more proposed turbulent-flow cases, download and post-process the corresponding data, and analyse relevant physical quantities such as mean-flow features, boundary layers, shear layers, wakes, turbulence intensity, turbulent kinetic energy, Reynolds stresses, Kolmogorov length scale, grid resolution and scaling with Reynolds or Rayleigh numbers. Students must submit a short report connecting their findings with the theory discussed in class.

The assessment system includes mechanisms for the recovery of unsatisfactory results, in accordance with the academic regulations of the UPC and the ESEIAAT.

Recovery mechanism: Students who fail the course, or who fail the final exam, will have the option of taking a final recovery exam. This exam will be scheduled on the date established in the ESEIAAT academic calendar for the

recovery of elective courses. The mark of this final recovery exam will be between 0 and 10 and will replace the final-exam mark only if it is higher. The assignments are not recoverable. After the recovery exam, the final mark will be

recalculated as:

Final mark = $0,2 \cdot \max(\text{partial exam}, \text{recovery exam}) + 0,35 \cdot \max(\text{final exam}, \text{recovery exam}) + 0,45 \text{ Assignments}$.

BIBLIOGRAPHY

Basic:

- Pope, Stephen B. Turbulent flows. Repr. with corr. Cambridge: Cambridge University Press, 2003. ISBN 0521591252.
- Davidson, Peter A. Turbulence: an introduction for scientists and engineers. 2nd ed. Oxford: Oxford University Press, 2015. ISBN 9780198722595.
- Versteeg, H. K.; Malalasekera, W. An introduction to computational fluid dynamics: the finite volume method. 2nd ed. London: Pearson, 2007. ISBN 9780131274983.

Complementary:

- Tennekes, H.; Lumley, J. L. A First course in turbulence. Cambridge: MIT Press, 1972. ISBN 0262200198.
- Wilcox, David C. Turbulence Modeling for CFD. 3rd ed. La Cañada: DCW Industries, 2006. ISBN 9781928729082.
- Ferziger, Joel H.; Peric, Milovan; Street, Robert L. Computational methods for fluid dynamics [on line]. 4th ed. Cham, Switzerland: Springer, 2020 [Consultation: 20/07/2026]. Available on: <https://link-springer-com.recursos.biblioteca.upc.edu/book/10.1007/978-3-319-99693-6>. ISBN 9783319996936.
- Sagaut, Pierre. Large eddy simulation for incompressible flows: an introduction [on line]. 3rd ed. Berlin: Springer, 2006 [Consultation: 20/07/2026]. Available on: <https://link-springer-com.recursos.biblioteca.upc.edu/book/10.1007/b137536>. ISBN 3540263446.