Last update: 06-05-2019

230487 - PHYSFLU - Physics of Fluids

Coordinating unit: 230 - ETSETB - Barcelona School of Telecommunications Engineering
Teaching unit: 748 - FIS - Department of Physics
Academic year: 2019
Degree: BACHELOR'S DEGREE IN ENGINEERING PHYSICS (Syllabus 2011). (Teaching unit Optional)
ECTS credits: 6 Teaching languages: English

Teaching staff

Coordinator: Meseguer Serrano, Alvaro

Others: Ribas Prats, Francesca

Prior skills

Mechanics, Thermodynamics. Vector calculus, Differential equations (PDE and ODE), Fourier analysis, complex variables. Numerical methods for ordinary differential equations and for systems of algebraic equations. Matlab.

Requirements

Mecànica, Termodinàmica, Numerical and Computational Methods I & II (or equivalent courses on numerical methods). Mètodes Matemàtics I i II.

Degree competences to which the subject contributes

Specific:

FG2. Ability to solve basic problems in mechanics, elasticity, thermodynamics, fluids, waves, electromagnetism and modern physics, and its application in solving engineering problems.
FG1. Knowledge of the scientific method and its applications in physics and engineering. Ability to formulate hypotheses and make critical analysis of scientific problems in the field of physics and engineering. Ability to relate the physical reality with their mathematical models and vice versa.
INF2. Ability to solve problems in physics and engineering using fundamental numerical methods: experimental data processing, interpolation, roots of nonlinear equations, numerical linear algebra and optimization, quadrature and integration of differential equations, properly weighting their different aspects (accuracy, stability and efficiency or cost).
INF1. Understanding and mastery of computer programming, use of operative systems and computational tools (scientific software). Skills to implement numerical algorithms in languages of low (C, F90) and high (Matlab) level.
MAT2. Ability to select numerical and optimization methods suitable for solving physical and engineering problems. Ability to apply the knowledge of numerical algorithms and optimization.
MAT1. Ability to solve math problems that may arise in engineering. Ability to apply knowledge about linear algebra, geometry, differential geometry, differential and integral calculus, ordinary and partial differential equations, probability and statistics.

Generical:

08 CRPE EF. ABILITY TO IDENTIFY, FORMULATE, AND SOLVE PHYSICAL ENGINEERING PROBLEMS. Planning and solving physical engineering problems with initiative, making decisions and with creativity. Developing methods of analysis and problem solving in a systematic and creative way.

Teaching methodology

Theoretical lectures followed by problem solving tutorials and computational practicals. During the second half of the course, the student will have to solve individual assignments using either analytical or numerical methodologies.

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Learning objectives of the subject

To understand fundamental principles of continuum media such as the concept of balance of mass, momentum and energy, finally culminating in the Navier-Stokes equations and their solution for some canonical cases. The course also addresses other physical mechanisms such as rotation or buoyancy to understand the dynamics of geophysical flows. To understand the concept of flow instability and its implications towards an understanding of the phenomenon of turbulence. Finally, to acquire essential skills to solve problems related with the motion of fluid systems, either by means of analytical or numerical methodologies.

Study load

Total learning time: 150h	Hours large group:	65h	43.33%
	Self study:	85h	56.67%

Content

1. Inviscid incompressible flows	Learning time: 10h Theory classes: 10h

Description:
1.1 Fluids: general properties, characterization and kinematics. Continuum hypothesis. Density.
1.2 Material (Lagrangian) derivative.
1.3 Pathlines, streamlines. Steady flows.
1.4 Volume and mass fluxes. Incompressible fluids.
1.5 Ideal fluids (I): surface stresses and volume forces.
1.6 Mass conservation.
1.7 Momentum balance equation for inviscid fluids (Euler).
1.8 Ideal fluids (II): Bernouilli's Theorem. Vorticity.
1.9 Vorticity equation. 2D case: streamfunction. Mass flow.
1.10 Steady two-dimensional incompressible and irrotational inviscid flows: complex potential.
1.11 Circulation. Kelvin's Theorem.

Related activities:
Problem solving lectures

2. Viscous flows	Learning time: 10h Theory classes: 10h

Description:
2.1 Viscous fluids: viscosity, shear stress and Newtonian hypothesis.
2.2 Navier-Stokes equations. No-slip boundary conditions. Stress-free boundary conditions.
2.3 Dimensional analysis. Reynolds number. Viscous and dynamic time.
2.4 Canonical flows (I) (steady-cartesian): plane Couette-Poiseuille (two-dimensional case: streamfunction formalism).
2.5 Canonical flows (II) (steady-cylindrical): Hagen-Poiseuille flow, Taylor-Couette flow, spiral Poiseuille-Couette flows.
2.6 Canonical flows (III): unsteady cartesian (Stokes problems)
2.7 Self-similar flows: boundary layers Prandtl theory

Related activities:
Problem solving lectures

3. Thermal buoyancy, rotation effects and geophysical flows	Learning time: 10h Theory classes: 10h

Description:
3.1 Flows in rotating frames. Coriolis force.
3.2 Energy balance equation. Boundary conditions.
3.3 Boussinesq approximation and buoyancy.
3.4 Geophysical flows. Reynolds-averaged equations and turbulent mixing.
3.5 Hydrostatic balance. Shallow water model.
3.6 Barotropic waves: Kelvin waves and Poincaré waves. Applications: tides and tsunamis.

Related activities:
Problem solving lectures and computational practicals

4. Hydrodynamic stability theory, transition to turbulence and deterministic chaos	Learning time: 15h Theory classes: 15h

Description:
4.1 Hydrodynamic stability: motivation, phenomenology and history.
4.2 Systems of nonlinear differential equations. Introduction
4.3 Definitions: steady solutions (fixed points), orbits, periodic orbits and limit cycles. Invariant sets.
4.4 Linear stability of fixed points (eigenvalue-vector analysis). Hartman-Grossmann Theorem. Stable unstable manifolds. Hyperbolic points.
4.5 Parameter-dependent systems. Topological equivalence. Local bifurcation (definition).
4.6 Classical bifurcation scenarios: saddle-node, pitchfork and Hopf bifurcations. Examples.
4.7 Formulation of linear stability analysis in Navier-Stokes flows. Normal mode approach. Absolute and convective instabilities.
4.8 Applications and models: Lorenz, Eckhaus, Rayleigh-Benard (stress-free case)

Related activities:
Problem solving lectures and computational practicals

5. Instabilities in parallel shear flows	Learning time: 5h Theory classes: 5h

Description:
5.1 Stability of parallel shear flows. Orr-Sommerfeld equation.
5.2 Applications: linear stability of plane Poiseuille flow.

Related activities:
Computational practicals

6. Instabilities in centrifugal flows	Learning time: 5h Theory classes: 5h
Description: 6.1 Rayleigh criterion of inviscid stability. 6.2 Applications: linear stability of Taylor-Couette flow. Related activities: Computational practicals	

7. Instabilities due to thermal buoyancy	Learning time: 5h Theory classes: 5h
Description: 7.1 Stability of thermal convection flows. 7.2 Applications: linear stability of Rayleigh-Bénard problem. Related activities: Computational practicals	

8. Modelling geophysical flows: long waves in shallow waters	Learning time: 5h Theory classes: 5h
Description: 8.1 Modelling long waves in shallow waters. 8.2 Application: modelling tides and tsunamis. Related activities: Computational practicals	

Qualification system

50% Mid-term exam on fundamentals of fluid mechanics.
30% Assignments based on practicals of Topics 5 to 8.
20% Extra assignment & oral presentation.

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Bibliography

Basic:

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Drazin, P. G. Introduction to hydrodynamic stability. Cambridge, UK [etc.]: Cambridge University Press, 2002. ISBN 0521009650.

Cushman-Roisin, B.; Beckers, J.M. Introduction to geophysical fluid dynamics : physical and numerical aspects [on line]. 2nd ed. Waltham, MA [etc.]: Elsevier Academic Press, 2011 [Consultation: 15/07/2015]. Available on: <http://site.ebrary.com/lib/upcatalunya/docDetail.action?docID=10501108>. ISBN 9780120887590.

Chorin, A.J.; Marsden, J.E. A mathematical introduction to fluid mechanics. 3rd ed. New York [etc.]: Springer-Verlag, 1992. ISBN 0387979182.

Kuznetsov, Y.A. Elements of applied bifurcation theory. 3rd ed. New York: Springer, 2004. ISBN 0387219064.

Wiggins, S. Introduction to applied nonlinear dynamical systems and chaos [on line]. 2nd ed. New York [etc.]: Springer-Verlag, 2003 [Consultation: 15/07/2015]. Available on: <http://link.springer.com/book/10.1007%2Fb97481>. ISBN 0387001778.

Kundu, Pijush K. Fluid mechanics. 6th ed. Academic Press, 2015. ISBN 978-0124059351.