UCLouvain

lmeca2323

2022

Aerodynamics of external flows

5.00 credits	30.0 h + 30.0 h	Q2

Teacher(s)	Chatelain Philippe ;Winckelmans Grégoire ;
Language :	English
Place of the course	Louvain-la-Neuve
Main themes	Reminder of the conservation equations for incompressible and compressible flows, dimensional analysis (Vaschy-Buckingham theorem) and applications. Vorticity-velocity formulation of the equations and general results: entropy, vortex tubes (Kelvin and Helmholtz theorems), velocity induced by vorticity (Biot-Savart) in 3-D and in 2-D, vorticity production (at walls, baroclinic term) and diffusion, reformulation of Bernoulli's equation. Incompressible irrotational flows : vortex sheets at wall and in wake, impulsive start of an airfoil, wing of finite span in steady state (Prandtl model, optimal wing). Compressible flows : 2-D steady supersonic flows : small perturbations and acoustic waves, method of characteristics, expansion waves and compression (shock) waves, applications; 1-D unsteady flow : method of characteristics. Laminar boundary layer for the case with variable external velocity (Falkner-Skan, Polhausen, Thwaites). Flow stability (Orr-Sommerfeld) and transition to turbulence. Turbulent boundary layer : law of the wall (Prandtl, von Karman), law of the wake, unification (Millikan, Coles), case with variable external velocity and concept of equilibrium boundary layer (Clauser, Coles). Modelisation of turbulence : Statistical approach (Reynolds) and equations for the averaged fields, closure models (algebraic, with one or two conservation equations), exemples of application.
Learning outcomes	**At the end of this learning unit, the student is able to :** In consideration of the reference table AA of the program "Masters degree in Mechanical Engineering", this course contributes to the development, to the acquisition and to the evaluation of the following experiences of learning: • AA1.1, AA1.2, AA1.3 • AA2.1, AA2.4, AA2.5 • AA3.1, AA3.2 • AA5.2, AA5.4, AA5.5 • AA6.3, AA6.4 1 Extend the education of the student in fluid mechanics towards external flows : the aerodynamics (hydrodynamics) of external flows. The path followed focuses on the physical comprehension of the problems and phenomena covered, as well as their modelisation in an adequate mathematical formalism. Develop the student's ability to use concepts and tools in aerodynamics (hydrodynamics) of external flows, to understand real and complex situations, to model them in a simplified yet sufficient way using an adequate mathematical formalism, and to obtain a physically acceptable solution. Develop the aptitude of the student to also work outside of directed class sessions (exercices and laboratories) and to produce quality and concise written reports.
Evaluation methods	The laboratory sessions and the homeworks correspond to work that is mandatory and that must be performed during the quadrimester; each within a well-defined time period and with a given deadline for the report, that is graded. It is mandatory to participate physically in each of the laboratory sessions led by an assistant. No laboratory report will be accepted from a student who did not participate in the laboratory session. It is not possible to do, or even re-do, any of the work mentioned above outside of the time period that was defined for it within the quadrimester. The final exam is a written exam, with questions that can cover all parts of the course (lectures, exercice sessions, laboratories, homeworks). The calculation of the final grade obtained by the student for the course is a weighted sum of the grade obtained for the final written exam (for 60 %) and of the grades obtained for the work to be performed during the quadrimester (laboratories and homeworks, for 40 %).
Teaching methods	Lectures : there are typically 13 lectures in class, each of 2 hours. Sessions of practical exercices are also organised in class, each of 2 hours, to further develop concepts covered during the lectures and to do some applications The students must also participate to the laboratories (typically 2) that are organised in small groups (typically 5 students); each group must produce one laboratory report, which is also graded. The students must also perform a number (typically 2) of homeworks which require to be able to use programing tools such as Python or Matlab. These homeworks are done in teams of two students

Content	1. **General theory (5 hrs)** • General reminder of the classical formulation of the Navier-Stokes equations. • Dimensional analysis : proof of Vaschy-Buckingham theorem; applications. • Thermodynamics of compressible flows. 2. **Vortex dynamics (8 hrs)** • Conservation equations in vorticity-velocity formulation, for incompressible and compressible flows. • Resultats on the conservation equations and on control volume budgets • Vortex tube in 3-D : theorems of Kelvin and of Helmholtz, applications. • Velocity induced by vorticity : Biot-Savart; application to 3-D vortex tubes and to 2-D vortices (gaussian, etc.). • Vorticity production : at walls, baroclinic term; vorticity diffusion; reformulation of Bernoulli's equation (incompressible and compressible). • 2-D irrotational flows : starting airfoil and vortex sheets; Kutta-Joukowski; Blasius theorem for lift and moment. • Prandtl model for wing of finite span: lift and induced drag, applications (optimal elliptical wing, rectangular wing), Oswald efficiency. 3. **Compressible flow of a perfect fluid (5 hrs)** • 2-D steady supersonic flows : concept of characteristics; small perturbations and acoustic waves; method of characteristics; isentropic expansion waves (Prandtl-Meyer); non isentropic compression waves (shock waves: normal and oblique shocks); applications (e.g., "diamond" profile); wave drag. • 1-D unsteady flows (subsonic or supersonic) : method of characteristics and Riemann invariants; application to propagation to traveling shock and expansion system. 4. **Laminar boundary layers (4 hrs)** • Similarity for the case with power law velocity : Falkner-Skan. • Polhausen method for the general case, and improved method due to Thwaites. 5. **Hydrodynamic stability and transition (1 hr)** • Linearisation in small perturbations of the Navier-Stokes equation, and stability of viscous flows; simplification for parallel flows (Orr-Sommerfeld): application to boundary layer and comparison with experimental results. Case of inviscid flows (Rayleigh): application to the shear layer. • "Route" to turbulence : phenomenological description of transition in a boundary layer. 6. **Turbulent boundary layers (5 hrs)** • Reminders, classical approach and global results for the case with constant external velocity. • Von Karman and Prandtl approach for the effective turbulence viscosity: law of the wall (with logarithmic law), Millikan's argument • Case with general external velocity: experimental results (Clauser, etc.), unification by Coles : law of the wall and law of the wake, composite velocity profiles; computational method for the boundary layer development up to separation. • Concept of "equilibrium turbulent boundary layer" : similarity parameters by Clauser and by Coles. 7. **Modelisation of turbulence (2 hrs)** • Statistical approach by Reynolds and averaged equations. • Closure models : algebraic, with one transport equation, with two transport equations (e.g., k-e, k-w) ; calibration and boundary conditions; applications and comparisons with experimental resultats.
Inline resources	http://moodleucl.uclouvain.be/enrol/index.php?id=8509
Bibliography	• G. K. Batchelor, "An introduction to fluid dynamics", Cambridge University Press 1967 (reprinted paperback 1994). • F. M. White, "Viscous fluid flow" second edition, Series in Mechanical Engineering, McGraw-Hill, Inc., 1991. • P. A. Thompson, "Compressible-fluid dynamics", advanced engineering series, Maple Press, 1984. • H. Lamb, "Hydrodynamics", sixth edition, Cambridge University Press 1932, Dover Publications. • L. Rosenhead, "Laminar boundary layers", Oxford University Press 1963, Dover Publications. • P. G. Drazin and W. H. Reid, "Hydrodynamic stability", Cambridge University Press 1985. • M. Van Dyke, "An album of fluid motion", The Parabolic Press, 1982. • H. Schlichting, "Boundary-layer theory", Mc Graw-Hill, NY, 1968. • H.W. Liepmann and A. Roshko, « Elements of gasdynamics », Dover Publications, 2001. • D. J. Tritton, « Physical Fluid Dynamics », Clarendon Press, 1988.
Faculty or entity in charge	MECA

Programmes containing this learning unit (UE)

Program title	Acronym	Credits	Prerequisite	Learning outcomes
Master [120] in Mechanical Engineering	MECA2M	5		
Master [120] in Electro-mechanical Engineering	ELME2M	5		