lmeca2323

2024

Aerodynamics of external flows

5.00 credits	30.0 h + 30.0 h	Q2

Teacher(s)	Chatelain Philippe ;Winckelmans Grégoire ;
Language :	English > French-friendly
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 experimental laboratory sessions led by an assistant. No laboratory report will be accepted with the name of a student who did not participate in the laboratory. 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 %). It is however required to obtain at least 8/20 at the exam for that rule to apply. If the grade obtained at the exam is below 8/20, the final grade for the course is the grade of the exam.

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 4-5 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. The use of generative AI tools such as ChatGPT, Consensus, Perplexity,... to produce parts of results or reports is not allowed.
Content	1. **Reminder of conservation equation and dimensional analysis** • General reminder of the classical formulation of the Navier-Stokes equations for incompressible and compressible flows. • Dimensional analysis : Vaschy-Buckingham theorem and applications. 2. **Vortex dynamics** • Conservation equations in vorticity-velocity formulation for incompressible and compressible flows. • Vortex line and vortrex tube : theorems of Kelvin and of Helmholtz, applications. • Velocity induced by vorticity : Biot-Savart; application to 3-D vortex tubes and to 2-D vortices. • Vorticity production : at walls, baroclinic term; vorticity transport and diffusion. • 2-D irrotational flows past airfoils : panel method (using vortex sheet panels). • Prandtl model for wing of finite span: lift and induced drag, Oswald efficiency, optimal wing, application to wing of general chord distribution, to wing of general lift distrtibution. 3. **2-D supersonic flow of a perfect fluid** • Reminder about normal shock waves • Oblique shock waves • Limit of infinitely weak shocks, isentropic compression waves • Expansion fans and the Prandtl-Meyer function • Applications to supersonic airfois, e.g. diamond airfoil, computation of lift and drag, discussion and comparison with very low Mach numbers • Concept of characteristics, small perturbations and acoustic waves; method of characteristics; 4. **2-D subsonic flow of a perfect fluid** • Reminder about potential flow • Karman-Tsien expansion for the flow past a cylinder • Critical Mach number 5. **Laminar boundary layers** • Similarity solution for cases with power law external velocity (= velocity at the edge of the boundary layer): Falkner-Skan. • Case with general external velocity: Thwaites approximate integral method for evaluating the boundary layer development up to the separation point. 6. **Turbulent boundary layers** • Reminders, classical approach and global results for the case with constant external velocity: von Karman law of the wall, Coles law of the wake and Coles composite profile, Millikan's argument. • Concept of "equilibrium turbulent boundary layer" : similarity parameters of Clauser and of Coles. • Experimental results for cases with varying external velocity: Clauser, etc., and Coles composite velocity profile. • Concept of turbulent boundary layers at equilibrium : Clauser and Coles views, and comparison. • Case with general external velocity: an integral method (based on both Coles and Clauser views) for evaluating the boundary layer development up to the separation.
Inline resources	Moodle site of the course
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		
Master [120] in Energy Engineering	NRGY2M	5		