UCL Université catholique de Louvain

LMECA2323

2012-2013

Aerodyamics of external flows.

5.0 credits	30.0 h + 30.0 h	2q

Teacher(s) :	Dupret François ; Winckelmans Grégoire ;
Language :	Français
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.
Aims :	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 outils 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. *The contribution of this Teaching Unit to the development and command of the skills and learning outcomes of the programme(s) can be accessed at the end of this sheet, in the section entitled “Programmes/courses offering this Teaching Unit”.*
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.
Other infos :	Prerequisite : Courses of "fluid mechanics and transfers I and II" Practical exercices and laboratories : The practical exercices will be, in part, done in class sessions (roughly 12 hrs, to further develop concepts and applications partially covered during the courses). Students will also have to work on exercices outside of class sessions (roughly 8 hrs), this work leading to a written and graded report. The students must also participate to the laboratories (roughly 8 hrs), this work also leading to a written and graded report. Some references : 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 (paperback). L. Rosenhead, "Laminar boundary layers", Oxford University Press 1963, Dover Publications (paperback). 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.
Cycle and year of study :	> Master [120] in Mechanical Engineering
Faculty or entity in charge:	MECA