UCLouvain

lmeca2660

2019

Numerical methods in fluid mechanics

In view of the health context linked to the spread of the coronavirus, the methods of organisation and evaluation of the learning units could be adapted in different situations; these possible new methods have been - or will be - communicated by the teachers to the students.

5 credits	30.0 h + 30.0 h	Q2

Teacher(s)	Bricteux Laurent (compensates Winckelmans Grégoire) ;Winckelmans Grégoire ;
Language :	English
Place of the course	Louvain-la-Neuve
Main themes	• Reminder of the conservation equations in fluid mechanics; Reminder of the differents types of PDEs and of their classification. • Finite differences et numerical schemes for ODEs and discretized PDEs : consistency, stability, convergence, explicit and implicit schemes. • Case of 2-D and of 3-D flows, steady and unsteady. • Incompressible flows : formulation in velocity-pressure and formulation in vorticity-velocity (streamfunction) . • Compressible flows, including capture of discontinuities. • Structured grids, also with mapping from physical to computational space. Introduction to finite volumes approaches, and to unstructured grids. • Lagrangian vortex element method (VEM) eventually combined with the boundary element method (BEM)
Aims	1 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 • AA2.3, AA2.4, AA2.5 • AA3.1, AA3.3 • AA5.1, AA5.2, AA5.6 • AA6.2, AA6.4 Enlarge the knowledge and skills of the students in numerical methods and initiate them to the numerical simulation in fluid mechanics (Computational Fluid Dynamics, CFD), the path followed focusing on the understanding of the physical problems and on their mathematical and numerical modelisation in an adequate formalism. Develop the aptitude of the student to realize numerical programs (codes) that "put to work" some of the numerical schemes presented in the course, in order to produce a complete numerical simulation of a physical problem. - - - - *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".*
Evaluation methods	**Due to the COVID-19 crisis, the information in this section is particularly likely to change.** Reports of homework(s) and of final project, and written exam (with course notes and personal notes allowed). The homework(s) and the final project are essential and they count for 60% of the final note, the examn counting for the remaining 40%. However, a minimal note of 9/20 must be obtained at the exam for the note of the homerk(s) and project to be used in the final note; otherwise, only the exam note is reported as the final note; the note for the homework(s) and the project are still acquired by the student and they will be used, together with the note of an exam in the next session, to compute the new final note).
Teaching methods	**Due to the COVID-19 crisis, the information in this section is particularly likely to change.** Typically 13 courses (26 hours), practical exercices (homework(s)) and a final project.
Content	Reminder of the different types of partial differential equations (PDE) : hyperbolic, parabolic, elliptic. Systems of PDEs. Method of characteristics for hyperbolic cases and applications in simple compressible flows. Discretisation using explicit finite differences, centered and decentered: obtention by Taylor series, truncation error and order. Definition of fundamental operators and obtention of finite difference stencils using operators. Implicit finite differences and compact schemes. Model convection equation in 1-D: discretisation of the convective term using centered finite differences, explicit and implicit, modal analysis and modified wavenumber: phase error (= numerical dispersion); decentered finite differences (upwinding) and amplitude error (= numerical diffusion).

	Model diffusion equation in 1-D: discretisation of the diffusion term using centered finite differences, explicit and implicit, modal analysis and modified wavenumber: amplitude error. Temporal integration schemes for discretized problems: numerical integration of ODE and system of ODEs; reminder of basic schemes and new schemes, stability analysis : explicit Euler, implicit Euler, Crank-Nicolson (= trapezoid rule), multi substeps schemes (Runge-Kutta), multi step schemes (Leap Frog, Adams-Bashforth, Adams-Moulton), predictor-corrector schemes, Hyman scheme, 3BDF scheme. Equations of convection and/or diffusion : mesh Reynolds number, Fourier number and CFL (Courant-Friedrichs-Lewy) number, linear and non linear cases, integration schemes and stability, decentered finite differences for the convection (upwinding), ADI schemes for multi-dimensional problems. Numerical methods for incompressible flows : velocity-presure formulation : discretisation (MAC mesh), imposition of boundary conditions, method of artificial evolution for steady flows, methods for unsteady flows, stability, Brinkman penalization method for case with an immersed body. Vorticity-velocity formulation: discretisation, obtention of the velocoty field from the vorticity field, obtention of an approximate boundary condition on the vorticity, method or artifical evolution for steady flows, methods for unsteady flows (also introduction to the method of vortex particles). Hyperbolic systems in conservative form : model non-linear equation (Burgers), Euler equations for compressible flows and boundary conditions (based on the characteristics) ; explicit integation schemes (Lax, Lax-Wendroff, Richtmeyer, MacCormack), implicit integration schemes; numerical capture of discontinuities. Transformation of a computational structured domain (block) in a physical domain, and obtention of equations in a conservative form in the computational domain ; multi-blocks approach. Delta form of the discretized equations for multi-dimensionanl domains and generalized ADI schemes (Beam-Warming). Introduction to the method of finite volumes for unstructured grids: treatment of the convective and diffusive fluxes.
Inline resources	http://moodleucl.uclouvain.be/enrol/index.php?id=5623
Bibliography	• Notes du titulaire • Transparents, documentation et notes du titulaire. • R.W. Hamming, « Numerical Methods for Scientists and Engineers », second ed., Dover, 1986. • J.H. Ferziger, « Numerical Methods for Engineering Applications », Wiley, 1981. • J. H. Ferziger and M. Peric, « Computational Methods for Fluid Dynamics », Springer, 1996. • R. Peyret and T.D. Taylor, « Computational Methods for Fluid Flow », Springer, 1986. • C.A. J. Fletcher, « Computational Techniques for Fluid Dynamics 1, Fundamental and General Techniques », second ed., Springer 1991. • C.A. J. Fletcher, « Computational Techniques for Fluid Dynamics 2, Specific Techniques for Different Flow Categories » second ed., Springer, 1991. • K. Srinivas and C.A.J Fletcher, « Computational Techniques for Fluid Dynamics, A Solutions Manual », Springer, 1991. • D.A. Anderson, J.C. Tannehill, R.H. Pletcher, « Computational Fluid Mechanics and Heat Transfer », Hemisphere Publishing, 1984. • D. Drikakis and W. Rider, « High-Resolution Methods for Incompressible and Low-Speed Flows », Springer, 2005. • G. Winckelmans, « Vortex Methods » : Chapter 5 in « Encyclopedia of Computational Mechanics, Volume 3 Fluids », Editors E. Stein, R. de Borst, T. J.R. Hughes, Wiley, 2004.
Faculty or entity in charge	MECA

Programmes containing this learning unit (UE)				
Program title	Acronym	Credits	Prerequisite	Aims
Master [120] in Biomedical Engineering	GBIO2M	5		
Master [120] in Mechanical Engineering	MECA2M	5		
Master [120] in Mathematical Engineering	MAP2M	5		
Master [120] in Electro-mechanical Engineering	ELME2M	5		