lmeca2660

2021

Numerical methods in fluid mechanics

5.00 credits	30.0 h + 30.0 h	Q2

Teacher(s)

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)

Learning outcomes

At the end of this learning unit, the student is able to :

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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.

Evaluation methods

Notes of the reports of the homework (to be done alone) and of the final project (that can be done in team of two), and notes of the written final exam (with the course notes and the student personal notes allowed).

The homework and the final project are essential to this course on numerical methods in fluid mechanics, and they count for typically 2/3 of the final note, the exam counting for the remaining.

However, a minimal note of 8/20 must be obtained at the first session exam for the note of the homework and project to be also counted in the computation of the final note reported to the faculty for that first session. It is thus important to also study and work the course material.

In case the exam note is below 8/20: only that exam note is reported to the faculty as final note for that first session. The notes obtained for the homework and project are of course acquired by the student; they will be used, together with the note obtained at the second session exam (if that note is larger or equal to 8/20), to compute the final note reported to the faculty for that second session. In case that second exam note is still below 8/20, it is that note which is reported as final note to the faculty.

Teaching methods

Typically 13 lectures (each of 2 hours) in class, sessions of practical exercices in class, one homework, and one final project.

The homework and the project each have a starting date and a limiting date for the due report. It is thus not possible to do the homework or the project outside of the quadrimester.

Besides its own interest in relation to the material covers in class, the homework also serves the purpose of getting the student back to programing in C language, here through producing a simple code.

The final project must also be done in C language. It can be done in team of two students.

The presentation of the obtained results (graphs, iso-contours, etc.) can be done using any adequate tool (such as Python or Matlab).

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	• 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.
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 Biomedical Engineering	GBIO2M	5		
Master [120] in Mathematical Engineering	MAP2M	5		