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205017 - Numerical Methods in Heat and Mass Transfer

Coordinating unit: 205 - ESEIAAT - Terrassa School of Industrial, Aerospace and Audiovisual Engineering
Teaching unit: 724 - MMT - Department of Heat Engines
Academic year: 2018
Degree: MASTER'S DEGREE IN SPACE AND AERONAUTICAL ENGINEERING (Syllabus 2016). (Teaching unit Optional)
MASTER'S DEGREE IN AERONAUTICAL ENGINEERING (Syllabus 2014). (Teaching unit Optional)
ECTS credits: 5 Teaching languages: English

Teaching staff

Coordinator: Carlos David Perez-Segarra
Xavier Trias

Others: Assensi Oliva
Jorge Chiva

Degree competences to which the subject contributes

Specific:
CE13. MUEA/MASE: Understanding and mastery of combustion and heat and mass transfer phenomena.

Teaching methodology

A basic knowledge of fluid dynamics and heat and mass transfer, as well as a programming language, are required.
The goal of the course is to give a robust training in the numerical solution of the governing equations of fluid dynamics and heat and mass transfer. The student can acquire a practical experience in programming, and verification and validation of CFD&HT codes (Computational Fluid Dynamics and Heat Transfer). Furthermore, he/she will become familiar with the main aspects related to CFD & HT codes and acquire the ability to critically judge the quality of the numerical solutions.
Main issues of the course: i) Consolidation of basic mathematical formulations of fluid dynamics and heat and mass transfer phenomena; ii) Knowledge of different numerical integration methodologies of the Navier-Stokes equations; iii) Introduction to the resolution of turbulent flows based on methods like RANS, LES and DNS; iv) Application of code verification techniques, verification and validation of numerical solutions of mathematical formulations.
During the development of the course the following teaching methods are used:
Lecture or conference: presentation from teachers through lectures.
Participatory classes: collective decision exercises, discussions and group dynamics with the lecturer and other students in the classroom; Classroom presentation of an activity carried out individually or in small groups.
Theoretical and guided work: completion of a classroom activity or theoretical/practical exercise, individually or in small groups with the lecturer's guidance.
Project activity or reduced work scop: Based Learning conducting individual or group of work of limited complexity or length, applying knowledge and presenting results.
Project or work of broader scope: learning based on the design, planning and implementation of a group wide project or job complexity or length, applying and extending knowledge and writing a report poured approach this and the results and conclusions.

Learning objectives of the subject

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Acquire basic training in the numerical solution of the governing equations of fluid dynamics and heat and mass transfer. Acquiring a first practical experience in programming, verification and validation of CFD&HT codes (Computational Fluid Dynamics and Heat Transfer).
Become familiar with the use of CFD & HT code and acquire the ability to critically judge the quality (verification and validation of numerical solutions of the mathematical formulations used).

Learning Outcomes. At the end of the course, the student will have:
Consolidation of basic mathematical formulations of fluid dynamics and heat and mass transfer phenomena.
Knowledge of different numerical integration methodologies of the Navier-Stokes equations.
Introduction to the resolution of turbulent flows based on methods like RANS, LES and DNS.
Application of code verification techniques, verification and validation of numerical solutions of mathematical formulations.

Study load

Total learning time: 125h	Hours large group:	30h	24.00%
	Hours medium group:	0h	0.00%
	Hours small group:	15h	12.00%
	Guided activities:	0h	0.00%
	Self study:	80h	64.00%

Content

Introduction to numerical methods in fluid dynamics and heat and mass transfer	Learning time: 12h Theory classes: 2h Self study : 10h

Description:
General approach to the mathematical formulation and the problems involved in integrating the fluid dynamics and heat and mass transfer equations. General comments of the different methods of integration of equations (finite differences, finite volumes, finite elements, spectral methods, etc.).

Related activities:
Lecture
Practical class
Reduced scope of work
Broad scope of work

Specific objectives:
Review of basic mathematical formulations in fluid dynamics and heat and mass transfer.
General outline of the various methods for integration of the Navier Stokes equations.

Solving the equation of heat transfer by heat conduction. Steady and unsteady analysis.	Learning time: 24h Theory classes: 9h Self study : 15h

Description:
Extension of the methodology explained in basic courses of heat and mass transfer, based on finite volume method and for structured mesh, orthogonal mesh and adaptable domain.
Finite volume techniques will be used in the resolution of conduction heat transfer problems. Complex geometries are solved using blocking-off techniques and unstructured meshes with non-orthogonal finite volume and variety of shapes (i.e. tetrahedra). Explanation of the techniques of data processing and connectivity tables.
At this stage solving equations systems of discretization is carried out with the methods already known of previous courses (Gauss-Seidel, line-by-line and sub/over relaxation techniques).

Related activities:
Lecture
Practical class
Reduced scope of work
Broad scope of work

Specific objectives:
Numerical solution of the equations of heat transfer by conduction in irregular domains.
Review of the basic techniques of solving large systems of algebraic equations resulting from discretisation.

Solving convection-diffusion equations.	Learning time: 26h 30m Theory classes: 5h Laboratory classes: 3h 30m Self study : 18h

Description:
Unlike the equations presented on the topic before, here comes the generic form of the transport equations with convective terms. Explains the different techniques of integration of the equation and accuracy problems (numerical diffusion) and/or convergence (stability) that can appear according to the scheme. Different benchmark problems with given velocity fields are proposed (i.e. inclined uniform flow, Smith-Hutton problem, etc.).

Related activities:
Lecture
Practical class
Practical work
Reduced scope of work

Specific objectives:
Presentation of the convection-diffusion equation (generic transport equation) and the method of numerical integration.
Presentation of different schemes for the convective term.
Introducing different benchmark cases for the verification of the codes developed by the students.

Technical verification of codes and numerical solutions and review of the most appropriate solvers.	Learning time: 28h 30m Theory classes: 7h Laboratory classes: 3h 30m Self study : 18h

Description:

This topic addresses two fundamental aspects in the methodology of the numerical solution. The first concerns the verification of the code and verification of numerical solutions. The second concerns the solution techniques for large systems of algebraic equations.
Regarding the first point, we present different techniques for verification of codes, such as comparison with known analytical solution of simplified cases, verification of global mass balance, momentum and / or energy, creation of ad hoc numerical solutions (known as MMS or Method of Manufactured Solutions). Once the code is sufficiently verified, some techniques will be explained to ensure the quality of the numerical solution (i.e. the results can not be conditional on the generated mesh discretization or numerical parameters used or the number of significant digits (precision-used for the computer).
In the second part iterative solvers are presented (Gauss-Seidel or line-by-line). In particular, preconditioner for Krylov methods (CG, GMRES, BiCGSTAB) and multimesh-multilevel methods. In 3D cases with a periodic direction, Fourier diagonalisation methods are explained.

Related activities:

Lecture
Practical class
Practical work
Reduced scope of work

Specific objectives:

Presentation of techniques for code verification and verification techniques of numerical solutions.
Presentation of new solvers more efficient for the treatment of large algebraic equations systems resulting from the discretisation of the convection-diffusion equations.

Solving the Navier-Stokes equations.	Learning time: 34h Theory classes: 7h Laboratory classes: 8h Self study : 19h

Description:
Description of the issues to solve these equations, from a physical and numerical point of view. Different properties are discussed about the conservation of the discretisation equations and how these properties are introduced in the numerical treatment. The methodology is explained based on techniques such as explicit and spectro-consistent discretisation schemes. The global algorithm is based on the Fractional-step method. Different benchmark cases are proposed (driven cavity, differentially cavity, backward-facing step, etc.). This approach allows students to address situations of turbulent flows with standard models like DNS (Direct Numerical Simulation) and LES (Large Eddy Simulation). We discuss phenomenological aspects related to turbulence (energy cascade, filtering equations, initial and boundary conditions) and statistical treatment of data.

Related activities:
Lecture
Practical class
Reduced scope of work
Broad scope of work

Specific objectives:
Methodology for solving the Navier-Stokes equations (partial differential equations system like the convection-diffusion euqations , nonlinear and strongly coupled).
Introducing different benchmark cases for verification of the codes developed by the students.
Introduction to turbulence and numerical techniques based on DNS and LES models.

Qualification system

Final exam: 35%
Works done individually and/or in groups throughout the course (TR): 65%

There are methods to recover unsatisfactory results.

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Bibliography

Basic:

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Patankar, S.V. Numerical heat transfer and fluid flow. Washington: New York: Hemisphere; McGraw-Hill, cop. 1980. ISBN 0070487405.

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Versteeg, H. K; Malalasekera, W. An introduction to computational fluid dynamics: the finite volume method. 2nd ed. Harlow, Essex: New York: Pearson Education, 2007. ISBN 9780131274983.

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Complementary:

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Shyy, W. [et al.]. Computational fluid dynamics with moving boundaries. Philadelphia [etc.]: Taylor & Francis, cop. 1996. ISBN 1560324589.

Others resources:

Computer material

Apunts

Notes made by professors of the subject.