820762 - TFSA - Turbulence: Phenomenology, Simulation, Aerodynamics

Coordinating unit: 240 - ETSEIB - Barcelona School of Industrial Engineering
Teaching unit: 724 - MMT - Department of Heat Engines
Academic year: 2019
Degree: MASTER'S DEGREE IN ENERGY ENGINEERING (Syllabus 2013). (Teaching unit Optional)
MASTER'S DEGREE IN ENERGY ENGINEERING (Syllabus 2013). (Teaching unit Optional)
ECTS credits: 5 Teaching languages: Catalan, Spanish, English

Teaching staff

Coordinator: Xavier Trias i Carlos-David Pérez Segarra

Others: Ivette Rodríguez, Aleix Baez, Jordi Ventosa

Opening hours

Timetable: The specific timetable is personally agreed on with the student according to his/her availability.

Prior skills

Fundamentals of thermodynamics, fluid mechanics and heat transfer necessary to understand the operation of the motor thermal machines.

Requirements

Knowledge equivalent to having completed the course of levelling of the Master's

Degree competences to which the subject contributes

Specific:

CEMT-7. Analyse the performance of equipment and facilities in operation to carry out a diagnostic assessment of the use system and establish measures to improve their energy efficiency.
CEMT-5. Employ technical and economic criteria to select the most appropriate thermal equipment for a given application, dimension thermal equipment and facilities, and recognise and evaluate the newest technological applications in the production, transportation, distribution, storage and use of thermal energy.

Transversal:

CT3. TEAMWORK: Being able to work in an interdisciplinary team, whether as a member or as a leader, with the aim of contributing to projects pragmatically and responsibly and making commitments in view of the resources that are available.
CT4. EFFECTIVE USE OF INFORMATION RESOURCES: Managing the acquisition, structuring, analysis and display of data and information in the chosen area of specialisation and critically assessing the results obtained.

Teaching methodology

Teaching methodology:

The course teaching methodologies are as follows:

- Lectures and conferences: presentation of knowledge by lecturers or guest speakers.
- Participatory sessions: collective resolution of exercises, debates and group dynamics, with the lecturer and other students in the classroom; classroom presentation of an activity individually or in small groups.
- Theoretical/practical supervised work (TD): classroom activity carried out individually or in small groups, with the advice and supervision of the teacher.
- Homework assignment of reduced extension: carry out homework of reduced extension, individually or in groups.
- Homework assignment of broad extension: design, planning and implementation of a project or homework of broad extension by a group of students, and writing a report that should include the approach, results and conclusions.
- Evaluation activities (EV).

Training activities:

The course training activities are as follows:

- Face to face activities
o Lectures and conferences: learning based on understanding and synthesizing the knowledge presented by the teacher or by invited speakers.
o Participatory sessions: learning based on participating in the collective resolution of exercises, as well as in discussions and group dynamics, with the lecturer and other students in the classroom.
o Presentations (PS): learning based on presenting in the classroom an activity individually or in small groups.
o Theoretical/practical supervised work (TD): learning based on performing an activity in the classroom, or a theoretical or practical exercise, individually or in small groups, with the advice of the teacher.

- Study activities
o Homework assignment of reduced extension (PR): learning based on applying knowledge and presenting results.
o Homework assignment of broad extension (PA): learning based on applying and extending knowledge.
o Self-study (EA): learning based on studying or expanding the contents of the learning material, individually or in groups, understanding, assimilating, analysing and synthesizing knowledge.

o Homework assignment of broad extension (PA): learning based on applying and extending knowledge.
o Self-study (EA): learning based on studying or expanding the contents of the learning material, individually or in groups, understanding, assimilating, analysing and synthesizing knowledge.

Learning objectives of the subject

Goals:
Know and understand the phenomenology of turbulent flows.
Understand and correctly interpret statistical tools for turbulent flows.
Learn the basics of modelling turbulence.
Performing various practical number to better understand the theoretical aspects of the course.

Learning Outcomes:
At the end of the course, the student:
Will have basic knowledge of turbulence and its energy spectrum.
Statistical treatment of turbulent flows.
Modelling and resolution of turbulent flows.

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Application of basic numerical methods and turbulence to improve energy efficiency by means of efficient aerodynamic designs.

Study load

Total learning time: 125h 03m	Hours large group:	0h	0.00%
	Hours medium group:	0h	0.00%
	Hours small group:	30h	23.99%
	Guided activities:	1h 42m	1.36%
	Self study:	93h 21m	74.65%

Content

Content 1. Introduction-review of the governing equations: Navier-Stokes and energy conservation. Basic concepts. Theory of boundary layer	Learning time: 11h Theory classes: 3h Self study : 8h

Description:
General review of the Navier-Stokes equations. Basic principles, symmetries and invariants. Brief introduction to the theory of the boundary layer.

Related activities:
Theory class

Specific objectives:
Know the basic principles of the Navier-Stokes equations and the physical meaning of each of its terms.
Learn the relationship between symmetry operators and invariants.
Know the basic concepts about the theory of the boundary layer needed to perform numerical simulations.

Content 2. Introduction to turbulence. Energy spectrum. Averaged Navier-Stokes equations. Average flow and Reynolds tensor terms. Statistical treatment: autocorrelations, PDF ...	Learning time: 35h Theory classes: 9h Guided activities: 3h Self study : 23h

Description:
From the Navier-Stokes equations the phenomenology of turbulence and its statistical treatment is introduced.
Introduction of the concept of energy spectrum from a simple practical exercise.

Related activities:
Theory class

Specific objectives:
Review of basic statistical concepts. Introduction of statistical treatment of the Navier-Stokes equations.
Introduction of the concept of energy spectrum and its link with everyday reality.
Introduction to turbulence and its mathematical complexity.

Content 3. Numerical methods for solving the governing equations. Conservative discretisation. Temporary integration of equations. Solvers.	Learning time: 31h Theory classes: 8h Guided activities: 2h Self study : 21h

Description:
Introduction to numerical methods for the resolution of turbulent flows. Analysis of the conservative properties of discrete equations and deduction of which properties must meet the numerical schemes to be consistent.

Related activities:
Theory class
Practical class
Broad scope work

Specific objectives:
Be able to represent in an algebraic way a system of discrete equations.
Understand the link between the symmetries of discrete and continuous operators.
Be able to deduce the properties of discrete operators in order to maintain the same invariants continuous.
Implement it in their own code and verify their conservative properties.

Content 4. Direct turbulence resolution (DNS). Different forms of modelling turbulence: LES and models of regularisation	Learning time: 21h Theory classes: 5h Guided activities: 2h Self study : 14h

Description:
Introduction to direct simulation of turbulence. Understand its potential and its limitations. Introduction to modelling techniques of turbulence of Large-Eddy Simulation (LES) types and the models of regularisation of convective heat.

Related activities:
Theory class
Practical class
Reduced scope work
Broad scope work

Specific objectives:
Know what direct simulations of turbulence involve. What is its usefulness and what are its limitations.
Know the basic principles behind the modelling techniques or Large-Eddy Simulation (LES) types of turbulence.
Brief explanation of the models used today.
Know the basic principles behind the turbulence modelling techniques based on regularisation of convective heat.

Content 5. Application of simulation techniques in the study of flows around obstacles, around a cylinder, around an aerodynamic profile and around a simplified car	Learning time: 27h Theory classes: 5h Guided activities: 8h Self study : 14h

Description:
Apply knowledge to some practical cases.

Related activities:
Theory class
Practical class
Broad scope work

Specific objectives:
Know the different technologies used depending on the working temperature range.
Know the different medio-environmental aspects and regulations related to solar thermal installations such as low and high temperature.
Know the different methods and software for calculating solar thermal installations.
Be able to perform the calculation and dimensioning of different types of solar thermal installations such as facilities for sanitary water heating, absorption cooling facilities, thermo-solar plants.

Planning of activities

Theory sessions	Hours: 93h Guided activities: 5h Theory classes: 28h Self study: 60h

Description:
Methodology in large group. The content of the course will follow a model of exhibition class and participation. The material is organised into 5 subject areas or themes.

Support materials:
Recommended references. Notes and transparencies. Magazine articles related to the topic.

Descriptions of the assignments due and their relation to the assessment:
This activity is evaluated together with the rest of the course work and written test.

Specific objectives:
At the end of this activity, students should be able to master the knowledge, consolidate them and apply them correctly to various technical problems. The acquired knowledge will be applied to other activities/guided problems.

2. Numerical resolution of Burgers equation in Fourier space	Hours: 7h Theory classes: 1h Guided activities: 2h Self study: 4h

Description:
Broad scope work where students put into practice the knowledge acquired. The problem consists in solving numerically the Burgers equation in Fourier space.

Support materials:
Recommended references. Notes and transparencies. Magazine articles related to the topic.

Descriptions of the assignments due and their relation to the assessment:
Report with the results and their analysis.

Specific objectives:
Be able to numerically solve the problem.
Consolidate the theoretical knowledge acquired by means of the practical problems posed: energy spectrum, statistical analysis of the results, conservative properties of equations...
Understand the physical and numerical dependence of different parameters present in the posed problem.

3. Implementing a structured two-dimensional code to solve the incompressible Navier-Stokes	Hours: 6h Guided activities: 2h Self study: 4h

Description:
Broad scope work where students put into practice the knowledge acquired. The problem consists in implementing a code of their own to solve the Navier-Stokes equations for incompressible flows. It will be limited to Cartesian mesh structures and two-dimensional flows. At least a couple of problems to solve will be posed: one for forced convection and one for natural convection.

Support materials:

Recommended references. Notes and transparencies. Magazine articles related to the topic.

Descriptions of the assignments due and their relation to the assessment:

Report with the results and their analysis. Delivery of source code.

Specific objectives:

Be able to implement a code of their own to solve the incompressible Navier-Stokes equations.
Understand the role played by different types of spatial discretisations. In particular, it is asked to verify different conservative properties: mass, momentum, kinetic energy...
Implement at least one linear solver to solve the Poisson equation for the pressure.
Verify the tools given during the course of the different parts of the code.
Consolidate the theoretical knowledge acquired by means of the practical problems posed: discrete symmetry operators, linear solvers, temporary discretisations...
Understand the dependence of physical and numerical parameters present in the posed problems.

4. Direct simulation of turbulence (DNS) in their own code

Hours: 6h
Guided activities: 2h
Self study: 4h

Description:

Broad scope work where students put into practice the knowledge acquired. The problem consists in performing a direct simulation of a turbulent case (DNS), make the appropriate statistical analysis and compare it with the reference solutions provided. This will be based on the code that the student must have previously implemented.

Support materials:

Recommended references. Notes and transparencies. Magazine articles related to the topic.

Descriptions of the assignments due and their relation to the assessment:

Report with the results and their analysis.

Specific objectives:

Based on numerical simulation code of the Navier-Stokes equations for two-dimensional flow to be able to perform a DNS simulation of a turbulent case.
Improve the efficiency of the code; probably improve the efficiency of the linear solver for the Poisson equation for the pressure.
Be able to implement statistical analysis tools required to extract the requested results.
Consolidate the theoretical knowledge acquired by means of the practical problems posed: the results of the statistical analysis, boundary layer theory, calculation of Reynolds tensor elements...
Understand the dependence of physical and numerical parameters present in the posed problem.

5. Numerical resolution of a case of LES modelling for Burgers equation in Fourier space

Hours: 5h
Guided activities: 2h
Self study: 3h

Description:

Broad scope work where students put into practice the knowledge acquired. The problem consists in solving numerically Burgers equation in Fourier space using a Large-Eddy Simulation (LES) turbulence model. This simulation will be implemented based on the previous code.

Support materials:
Recommended references. Notes and transparencies. Magazine articles related to the topic.

Descriptions of the assignments due and their relation to the assessment:
Report with the results and their analysis.

Specific objectives:
Be able to numerically solve the problem.
Consolidate the theoretical knowledge acquired by means of the practical problems posed: energy spectrum, statistical analysis of the results, conservative properties of equations, turbulence modelling, the Large-Eddy Simulation (LES) concept,...
Understand the dependence of physical and numerical parameters present in the posed problem. In particular, the constant present in the LES turbulence model.

6. Resolution of the Navier-Stokes equations for the flow around an obstacle

Hours: 6h
Guided activities: 2h
Self study: 4h

Description:
Broad scope work where students put into practice the knowledge acquired. The problem consists in solving flow around obstacles. This work will be based on the code implemented previously.

Support materials:
Recommended references. Notes and transparencies. Magazine articles related to the topic.

Descriptions of the assignments due and their relation to the assessment:
Report with the results and their analysis. Delivery of source code.

Specific objectives:
Be able to numerically solve the problem.
Based on teh developed code and verified previously, the necessary calculation tools for the specific problem will be implemented: calculation of drag and lift coefficients, frequency analysis of the signals to different parts of the physical domain...
Consolidate the theoretical knowledge acquired by means of the practical problems raised.
Understand the dependence of physical and numerical parameters present in the posed problems. In particular stationary transitions to non-stationary and the transition to turbulence.

7. Written test

Hours: 2h
Theory classes: 2h

Description:
Development of a written test of the course contents 1 and 2. It includes theoretical aspects and development problems.

Support materials:
Recommended references. Notes and transparencies. Magazine articles related to the topic.

Descriptions of the assignments due and their relation to the assessment:
The exam will be held freely and the statement delivered along with the statement duly filled in with the data required.

Specific objectives:
Demonstrate the level of knowledge achieved in theoretical activities and problems.

Qualification system

Written test: 35%
Work performed individually or in groups: 55%
Attendance and participation in guided works: 10%

Regulations for carrying out activities

There will be a final exam for the course. Students must complete both theoretical questions and problems related to the theoretical and practical content of the course. Reviews and/or claims regarding the examinations will be conducted according to the dates and times established in the academic calendar.

Work done individually or in groups along the course (TR).

Students must follow the instructions explained in class and contained in the file for the work that will be proposed to the student in relation to different teaching content of the course. As a result of these activities, students must submit a report (preferably in PDF format) to the professor, with the deadline to be fixed for each activity. The evaluation work will involve both its realisation and a possible defense.

Attendance and participation in classes and laboratories (AP).

The labs will be assessed both in their implementation and in the implementation of practical exercises that will be proposed; they can begin during the class schedule planned for this type of activity to be completed (if applicable) as an autonomous activity, following the instructions given in class. The results of practical exercises delivered to the teacher must follow the instructions given in class.

The evaluation of the practice will involve both its realisation and a possible defense.

Quality and performance of group work (TG).

The reports of practices and/or group work will be assessed individually on the oral defense if necessary or of any single group on the report.

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Bibliography

Basic:

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Berselli, Luigi Carlo; Iliescu, T.; Layton, W. J. Mathematics of large eddy simulation of turbulent flows [on line]. Berlin: Springer, cop. 2006Available on: <http://dx.doi.org/10.1007/b137408>. ISBN 3540263160.

Patankar, Suhas V. Numerical heat transfer and fluid flow. New York: McGraw-Hill, cop. 1980. ISBN 0891165223.

Sagaut, Pierre. Large eddy simulation for incompressible flows : an introduction. 3rd ed. Berlin [etc.]: Springer, cop. 2006. ISBN 3540263446.

Complementary:

Saad, Yousef. Iterative methods for sparse linear systems. 2nd ed. Philadelphia: SIAM, cop. 2003. ISBN 0898715342.

Foias, Ciprian [et al.]. Navier-Stokes equations and turbulence. Cambridge: Cambridge University Press, 2001. ISBN 0521360323.

Frisch, Uriel. Turbulence : the legacy of A.N. Kolmogórov. Cambridge: Cambridge University Press, cop. 1995. ISBN 0521457130.

Wendt, John F.; Anderson, John David. Computational fluid dynamics : an introduction. 2nd ed. Berlin ; New York: Springer, 1996. ISBN 354059471X.

Others resources:

Audiovisual material

Transparencies, proposed problems to be used in class

Resource

Notes made by the professor of the course

Resource