Course guide
220341 - 220341 - Internal Aerodynamics and Aeroelasticity of Turbomachines

Last modified: 30/04/2024

Unit in charge: Terrassa School of Industrial, Aerospace and Audiovisual Engineering
Teaching unit: 220 - ETSEIAT - Terrassa School of Industrial and Aeronautical Engineering.

Degree: MASTER'S DEGREE IN AERONAUTICAL ENGINEERING (Syllabus 2014). (Optional subject).
MASTER'S DEGREE IN SPACE AND AERONAUTICAL ENGINEERING (Syllabus 2016). (Optional subject).
MASTER'S DEGREE IN MECHANICAL ENGINEERING RESEARCH (Syllabus 2024). (Optional subject).

Academic year: 2024 **ECTS Credits:** 5.0 **Languages:** English

LECTURER

Coordinating lecturer: Perez Segarra, Carlos David

Others: Schillaci, Eugenio

PRIOR SKILLS

Basic knowledge of solid dynamics, fluid dynamics, heat, computational methods, as well as a programming language (C, C++, matlab, etc.).

DEGREE COMPETENCES TO WHICH THE SUBJECT CONTRIBUTES

Specific:
CEEPROP1. MUEA/MASE: Sufficient applied knowledge of aspects of measurement, calculation and numerical resolution in experimental and computational aerodynamics (specific competency for the specialisation in Propulsion).

TEACHING METHODOLOGY

During the development of the course will use the following teaching methods:

Lecture or conference (EXP): presentation from teachers through lectures or by outsiders through invited lectures.
Participatory classes (parts): collective decision exercises, discussions and group dynamics with the teacher and other students in the classroom; Classroom presentation of an activity carried out individually or in small groups.
Presentations (PS): present in the classroom an activity conducted individually or in small groups (in person).
Theoretical and practical work directed (TD): completion of a classroom activity or theoretical/practical exercise, individually or in small groups with the teacher's guidance.
Project activity or reduced work scope (PR): Based Learning conducting individual or group of work of limited complexity or length, applying knowledge and presenting results.
Project or work of broader scope (PA): 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.
Activities Evaluation (EV).

LEARNING OBJECTIVES OF THE SUBJECT

The course aims at describing the fundamental laws governing flows within turbomachinery, together with basic and advanced techniques to study them. In the course, several important topics related to rotating turbomachinery are described: turbulence, compressible description of flows, boundary layer analysis, shock waves, rotating flows, etc. Transient effects usually encountered are also detailed, such as stall and surge. The interaction between fluid flow and turbomachinery structure, together with aeroelastic effects, are studied and described in detail.

A two-level analysis of the phenomena of interest will be presented at the course. Analysis of the general equations under restrictive assumptions is made to evidence the general behaviour of the flow, which also serves to perform initial estimations and analysis. The second level of analysis uses advanced modelling approaches, such as Computational Fluid Dynamics (CFD) techniques and Computational Solid Dynamics (CSD).

The reduced analysis level serves the student to understand the underlying physical effects in the studied case. With this background advanced techniques are presented for the student to apply this knowledge using state-of-the-art techniques. Due to the effort required to solve the physical equations, computational techniques are usually needed. Hence, in the course extensive descriptions of CFD and CSD techniques are presented.

Due to the focus on computational methods, students are expected to use and develop computational codes. Specific lectures during the course cover different aspects of computational methods.

Objectives of the learning process:

- Understand the physical phenomena that govern the flow within turbomachinery.
- Acquiring knowledge of basic aeroelasticity physics and unsteady modelling of turbomachinery.
- Acquiring a first practical experience in turbomachinery blade design, programing an own C++ code for preliminary aerodynamic design of turbomachines.
- Become familiar with advanced CFD methods applied to turbomachinery by means of open-source and/or own developed CFD packages.
- Become familiar with advanced unsteady coupled CFD and CSD methods applied to turbomachinery by means of open-source and/or own developed CFD packages.

STUDY LOAD

Type	Hours	Percentage
Hours small group	15,0	12.00
Self study	80,0	64.00
Hours large group	30,0	24.00

Total learning time: 125 h

CONTENTS

Introduction to unsteady rotating blade physics and fluttering

Description:
Different types of turbomachinery will be covered and discussed. Review of the different key components of turbomachineries will be carried out. DIn addition, steady and unsteady physics at the airfoil, cascade and rotating blade level will be covered.

Related activities:
Individual meetings with the students in order to choose and define the practical work to be carried out.

Full-or-part-time: 10h
Theory classes: 4h
Self study : 6h

Internal aerodynamic methods for turbomachinery

Description:
Two dimensional and three-dimensional methods for the design of different types of turbomachines will be reviewed in detail. The design methods will cover axial-flow turbines, axial-flow compressors, fans and radial flow gas turbines. Methods to be covered:

Reduced models for blade design
- Work and energy conservation
- Stage characterisation: degree of reaction, work coefficient, flow coefficient.
- Stage flow pattern: velocity triangles
- Stage losses
- Bi- and tri-dimensional effects.

Pseudo 2D CFD methods for the simulation of turbomachinery profiles:
- Numerical methods for incompressible and compressible CFD
- Turbulence modelling adaptation (RANS, RANS/LES and LES)
- Boundary conditions
- Best-user guides for meshing
- Post-processing methodologies

Stator-rotor interaction using dynamic meshes methods
- Arbitrary Lagrangian Eulerian (ALE) formulation for incompressible and compressible NS equations
- Reference frame methods vs dynamic mesh methods for the simulation of turbomachines rotors.
- Sliding mesh methods for cascade and 3D stator-rotor simulations

Multi-scale methods for the simulation of complex systems (Blade Element Method integration with 3D NS solvers)

Related activities:
- A design code (in C, C++, etc.) for a specific turbomachinery application is expected to be developed by the student within this module and using global models.
- 2D airfoil simulations in a periodic arrangement employing RANS techniques will be carried out using existing CFD packages or student-developed CFD tools.

Full-or-part-time: 62h
Theory classes: 14h
Laboratory classes: 8h
Self study : 40h

Aeroelasticity methods for turbomachinery

Description:
A methodology for the coupled simulation of the fluid-structure turbomachinery problems with high-fidelity models will be given. First, basic CFD methodologies using the ALE formulation, including turbulence modelling, will be covered. After that, dynamic mesh methods will be reviewed and tested using open CFD packages or student developed CFD codes. Finally, CFD coupling algorithms and simplified CSD models will be shown.

The following topics will be presented and discussed:
- Space Conservation Law for moving boundaries CFD problems.
- Moving mesh methods:
- Radial basis interpolation methods
- Spring analogy algorithms
- Approximate CSD solvers approach
- Modal methods for the CSD modelling of turbine blades
- Coupling algorithms for Fluid Structure methods:
- Monotonic approaches
- Semi-implicit coupling
- Loosely coupled algorithms

Related activities:
The students will apply the different studied techniques, simulating simplified aeroelasticity problems using an existing CFD package or an own developed CFD package.

Full-or-part-time: 53h
Theory classes: 12h
Laboratory classes: 7h
Self study : 34h

GRADING SYSTEM

Partial exam (including assignment regarding gas turbine cycles): 30%
Final exam: 25%
Computational works carried out individually and/or in groups throughout the course in internal aerodynamics (CFD, Computational Fluid Dynamics) and aeroelasticity (FSI, Fluid Solid Interaction): 45%

For those students who meet the requirements and submit to the reevaluation examination, the grade of the reevaluation exam will replace the grades of all the on-site written evaluation acts (partial and final exams). The grades obtained during the course for lab practices, works, projects and presentations will be kept.
If the final grade after reevaluation is lower than 5.0, it will replace the initial one only if it is higher. If the final grade after reevaluation is greater or equal to 5.0, the final grade of the subject will be pass 5.0

EXAMINATION RULES.

Students must follow the instructions explained in class and contained in the file with the activities to develop in practice. As a result of these activities, the student must submit a report (preferably in pdf format) to the teacher, following his instructions and deadline for each activity. The assessment will involve both its accomplishment, as well as their defense.
Practices:
Practical exercises can begin during the class schedule planned for this activity and will be completed (if necessary) as autonomous activity, following the instructions given in class. The results of practical exercises will be given to the teacher by following the instructions given in class. The evaluation of the practice can lead to both its implementation, as well as their defense.
Exams:
There will be a final exam for the course. Students must complete both theoretical questions and problems related to theoretical and practical content of the course.
Reviews and / or claims with reference to the exams are conducted according to the dates and times established in the academic calendar.

BIBLIOGRAPHY

Basic:

- Saravanamuttoo, H.I.H. [et al.]. Gas turbine theory. 6th ed. Harlow, England; New York: Prentice Hall, 2009. ISBN 9780132224376.
- Ferziger, J.H.; Peric, M. Computational methods for fluid dynamics. 3rd, rev. ed. Berlin: Springer, 2002. ISBN 3540420746.
- Dowell, E.H. [et al.]. A modern course in aeroelasticity [on line]. 4th rev. and enl. ed. Dordrecht; Boston: Kluwer Academic Publishers, 2004 [Consultation: 03/05/2022]. Available on: https://link-springer-com.recursos.biblioteca.upc.edu/book/10.1007/1-4020-2106-2. ISBN 1402020392.
- Kerrebrock, J.L. Aircraft engines and gas turbines. 2nd ed. Cambridge, Mass: MIT Press, 1992. ISBN 0262111624.

Complementary:

- Pope, S.B. Turbulent flows. Cambridge: Cambridge University Press, 2000. ISBN 0521591252.
- Dixon, S.L.; Sydney, L.; Hall, C.A. Fluid mechanics and thermodynamics of turbomachinery [on line]. 7th ed. Oxford: Butterworth-Heinemann, 2014 [Consultation: 27/07/2022]. Available on: https://www-sciencedirect-com.recursos.biblioteca.upc.edu/book/9780124159549/fluid-mechanics-and-thermodynamics-of-turbomachinery. ISBN 9780124159549.
- Bazilevs, Y.; Takizawa, K.; Tezduyar, T.E. Computational fluid-structure interaction: methods and applications. Chichester, West Sussex, United Kingdom: Wiley, 2013. ISBN 9780470978771.
- Mattingly, Jack D. Elements of gas turbine propulsion. New York: American Institute of Aeronautics and Astronautics, 2005. ISBN 1563477785.

RESOURCES

Other resources:

Material prepared by the lectures.