Course guide
220026 - DGTCM - Gas Dynamics and Heat and Mass Transfer

Last modified: 19/04/2023

Unit in charge: Terrassa School of Industrial, Aerospace and Audiovisual Engineering
Teaching unit: 724 - MMT - Department of Heat Engines.

Degree: BACHELOR'S DEGREE IN AEROSPACE TECHNOLOGY ENGINEERING (Syllabus 2010). (Compulsory subject).
BACHELOR'S DEGREE IN AEROSPACE VEHICLE ENGINEERING (Syllabus 2010). (Compulsory subject).

Academic year: 2023 **ECTS Credits:** 6.0 **Languages:** Catalan, Spanish

LECTURER

Coordinating lecturer: Carlos David Pérez Segarra

Others: Oliva Llena, Asensio
Trias Miquel, Francesc Xavier
Castro Gonzalez, Jesus
Balcázar Arciniega, Néstor Vinicio
Torras Ortiz, Santiago
Ablanque Mejia, Nicolas

PRIOR SKILLS

Basic knowledge of previous courses: mathematics (specially differential and integral calculus), physics, mechanics of continuous media, fluid mechanics, thermodynamics.

DEGREE COMPETENCES TO WHICH THE SUBJECT CONTRIBUTES

Specific:
1. GrETA/GrEVA - An adequate understanding of the following, as applied to engineering: concepts and laws that govern the processes of energy transfer, the movement of fluids, the mechanisms of heat transfer and phase transition, and their role in analysis of the main aerospace propulsion systems.

TEACHING METHODOLOGY

The language use in the lectures is principally Catalan. Spanish is also used.

LEARNING OBJECTIVES OF THE SUBJECT

- Basic knowledge in gas dynamics and heat and mass transfer, both in aspects related to the physiscal phenomena involved ad their mathematical formulation.
- Development of analytical and numerical methods of resolution of heat transfer phenomena by conduction, convection and radiation. Approach to the problem of convection and gas dynamics at different levels: Navier-Stokes equations, zonal models based on boundary layers / viscous zone, one-dimensional analysis, etc.
- Presentation of various technological applications in the field of aeronautics: turbines, heat exchangers, combustors, cooling of electrical and electronic components, thermal loads in aircraft cabins, flow in nozzles and diffusers, etc. All this in order to optimize these thermal systems and equipment, increasing their energy efficiency and reducing their environmental impact.
- Contribute to the consolidation of those aspects of Thermodynamics and Heat Transfer and Gas Dynamics.

STUDY LOAD

Type	Hours	Percentage
Hours large group	46,0	30.67
Hours medium group	14,0	9.33
Self study	90,0	60.00

Total learning time: 150 h

CONTENTS

1. Introduction. Heat transfer by conduction in solids

Description:
Lesson1. Introduction. Review of the first principle of thermodynamics for open systems. Description of the different forms of heat transfer: conduction, convection and radiation. Fourier's law. Definition of the convection heat transfer coefficient ("Newton's law"). Review of macroscopic concepts such as pressure and temperature (a brief look at the molecular world using the kinetic theory of gases). Relevance of gas dynamics and heat and mass transfer in aeronautical engineering.

Specific objectives:
Heat flux concept and its vector character. Fourier's law. Derivation of the general equation of heat transfer by conduction. Resolution of cases with analytical solution (steady and unsteady). Analysis of the particular case of finned surfaces (two-dimensional heat flow with a one-dimensional temperature distribution hypothesis). Introduction to numerical methods of finite volumes. Application of general cases (1D, 2D or 3D in permanent or transitory regime) of heat transfer by conduction.

Related activities:
Sessions of theory, problems and numerical simulation practical works.

Full-or-part-time: 40h
Theory classes: 17h
Practical classes: 3h
Self study : 20h

2. Heat transfer by radiation

Description:
Electromagnetic radiation, basic concepts. Thermal radiation. Specific radiant intensity. Integro-differential equation of heat transfer by radiation.

Radiation between surfaces; reflection and absorption phenomena. Radiant flux on or from a surface. Specific, total and/or hemispherical radiant properties (absorptivity, reflectivity, transmissivity). Black body radiation: basic characteristics and emissive power. Emissivity concept. Kirchhoff's law of radiation. Non-black surfaces. Radiant properties of real surfaces.

View factor concept for diffuse radiation. Radiosity method for opaque, gray and diffuse surfaces. Application exercises with a brief introduction to atmospheric radiation and solar energy.

Specific objectives:
Introduction to the radiation heat transfer. Basic approach and application to radiation between opaque, gray and diffuse surfaces in non-participating media. Introduction to solar energy and atmospheric radiation.

Related activities:
Sessions of theory, problems and numerical simulation practical works.

Full-or-part-time: 22h
Theory classes: 8h
Practical classes: 2h
Self study : 12h

3. Convection phenomena. Gas dynamics.

Description:
Review of the basic integral formulation of convection: equations of conservation of mass, linear momentum, angular momentum and energy. The second principle of thermodynamics. Application exercises.

Limitations of continuum treatment. Review of the basic constitutive equations: Stokes' law of viscosity and Fourier's law of conduction heat transfer. Deduction of the differential formulation: equations of continuity, momentum, kinetic energy, total energy, thermal energy and entropy transport. Boundary conditions and general approach to the mathematical formulation in specific cases. Laminar flow vs. turbulent flow. Validity of the Navier-Stokes equations in the resolution of turbulent flows and presentation of illustrative cases of direct numerical simulation (DNS).

Statistical treatment of turbulence: Reynolds equations. Turbulence closure problem. A brief introduction to the linear models of turbulent viscosity of two equations (k-e and k-w).

Zonal resolution of flows by dividing the domain into the non-viscous zone and boundary layers (hydrodynamic and thermal). Simplified Navier-Stokes equations for the viscous zone (Euler equations). Simplified Navier-Stokes equations for laminar boundary layers (order-of-magnitude analysis). Coupling of the inviscid zone with the boundary layers (concept of displacement thickness). Analytical solutions of the equations of the laminar boundary layers in isothermal plates. Integral methods.

Simplified Navier-Stokes equations for turbulent boundary layers. Algebraic models of turbulence (Prandtl mixing length, Baldwin-Lomax…). Resolution of turbulent boundary layers (hydrodynamic and thermal) in isothermal plates. Integral methods.

Buckingham's pi theorem. Interest of dimensional analysis. Obtaining the characteristic dimensionless groups in specific cases of flows in natural and forced convection. Physical meaning of the non-dimensional groups. Deduction of the Nusselt number and systematic calculation of superficial heat transfer coefficients in internal and external flows. Application exercises.

One-dimensional analysis of compressible flows in ducts of constant and variable section (nozzle-diffuser), and with consideration of friction and heat transfer effects. Step-by-step method for the case of subsonic and supersonic flows. Analysis of boundary conditions. Application exercises in cases of subsonic and supersonic flows. Shock wave prediction.

Specific objectives:
Study of convection phenomena and gas dynamics by means of a basic and rigorous approach to the phenomena and their mathematical formulation: Navier-Stokes equations, treatment of turbulent flows, zonal treatment based on the division of the domain into boundary layers and non-viscous zone.

Dimensionless analysis and semi-empirical approach to different problems. Dimensionless analysis. Compressible flows: phenomenological aspects (subsonic, transonic, supersonic flows, shock waves, etc.). Introduction to numerical methods in convection.

Related activities:
Sessions of theory, problems and numerical simulation practical works.

Full-or-part-time: 38h
Theory classes: 16h
Practical classes: 2h
Self study : 20h

4. Combined problems

Description:
Different exercises that combine convection, conduction and radiation phenomena and that may be of interest in the field of aeronautics: heat exchangers, turbine blade cooling, etc.

Specific objectives:
Application of the knowledge acquired in the previous modules to applied cases of interest in the field of aeronautics (heat exchangers, turbine blade cooling, balance of thermal loads in aircraft cabins, flow in nozzles and diffusers, heat transfer in electrical and electronic components, etc.).

Related activities:
Sessions of theory, problems and numerical simulation practical works.

Full-or-part-time: 50h
Theory classes: 5h
Laboratory classes: 7h
Self study : 38h

ACTIVITIES

THEORY LECTURERS

Description:
Large group methodology.
Presentation of the contents of the subject following an expository and participatory lecture model.
The subject has been organized into four thematic areas: heat transfer by conduction, convection, radiation and conjugated heatv transfer problems.
In these lecturers, the theoretical aspects are presented and different problems are solved to facilitate learning.

Specific objectives:
At the end of this activity, the student must be able to master the knowledge acquired, consolidate it and apply it correctly to technical problems. In addition, since Gas Dynamics and Heat and Mass Transfer are basic technological subjects, the theory classes must serve as a basis for the development of other more technical subjects in the thermal field related to Turbomachines, Refrigeration, Thermal Load Balances, Solar Energy, etc.

Material:
Basic bibliography (available at the Campus Library).
Teachers' notes (all this material is available at ATENEA).

Delivery:
This activity is evaluated jointly with activity 2 (problems) through the partial and final exam and the control test.

Full-or-part-time: 65h
Theory classes: 25h
Self study: 40h

EXERCISES SESSIONS

Full-or-part-time: 68h
Theory classes: 14h
Practical classes: 7h
Laboratory classes: 7h
Self study: 40h

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PROJECT

Full-or-part-time: 10h
Self study: 10h

GRADING SYSTEM

The partial exam accounts for 40% of the final grade.
The control test accounts for 10% of the final grade.
The final exam accounts for 50% of the final grade.

If the mark of the partial exam is less than 5, there will be the possibility of improving this mark at the end of the course. The mark of the re-evaluation will substitute the previous one as long as it is higher, with a maximum of 5 points. This exam is carried out on the same day scheduled for the final exam.

The successful presentation and defense of the voluntary numerical work carried out during the course may increase the final grade obtained by the student by a maximum of 2 points, provided that the weighted grade is equal to or greater than 5.

EXAMINATION RULES.

The exams will consist of theory and problems. It is not allowed to use any extra material, except the one delivered by the lecturers. The use of mobile phones, smartwatches or similar devices, together with computers and programmable calculators, is also not allowed.

BIBLIOGRAPHY

Basic:
- Incropera, F. P.; DeWitt, D. P. Fundamentos de transferencia de calor. 4ª ed. México: Prentice Hall, 1999. ISBN 9701701704.
- Mills, A. F. Transferencia de calor. México: Irwin, 1995. ISBN 8480861940.
- Lienhard IV, J. H.; Lienhard V, J. H. A heat transfer textbook [on line]. 3rd ed. Cambridge: Phlogiston Press, 2001 [Consultation: 20/02/2023]. Available on: https://ahtt.mit.edu/.
- Patankar, S. V. Numerical heat transfer and fluid flow [on line]. New York: McGraw-Hill, 1980 [Consultation: 16/11/2022]. Available on: https://www-taylorfrancis-com.recursos.biblioteca.upc.edu/books/mono/10.1201/9781482234213/numerical-heat-transfer-fluid-flow-suhas-patankar. ISBN 9780891165224.
- Eckert, E. R. G.; Drake, R. M. Analysis of heat and mass transfer. Washington: Hemisphere, 1972. ISBN 0891165533.
- Nellis, Gregory; Klein, Sanford A. Heat transfer. Cambridge [etc.]: Cambridge University Press, 2009. ISBN 9781107671379.

Complementary:
- Anderson, J. D. Modern compressible flow: with historical perspective. 3rd ed. Boston: McGraw-Hill, 2003. ISBN 9780071241366.
- Landau, L. D.; Lifshitz, E. M. Fluid mechanics. 2nd ed. Oxford: Elsevier Butterworth Heinemann, 1987. ISBN 0750627670.
- Lakshminarayana, B. Fluid dynamics and heat transfer of turbomachinery. New York: John Wiley & Sons, 1996. ISBN 0471855464.
- Cebeci, T. [et al.]. Computational fluid dynamics for engineers: from panel to navier-stokes methods with computer programs. New York: Springer, 2005. ISBN 3540244514.
- Thompson, P. A. Compressible-fluid dynamics. New York: McGraw-Hill, 1972. ISBN 0070644055.
- Shapiro, A. H. The dynamics and thermodynamics of compressible fluid flow. New York: Ronald Press Company, 1954.

RESOURCES

Audiovisual material:
- Apunts realitzats pel professorat de l'assignatura

Other resources:
Notes developed by the lecturers of the subject.