UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH

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220052 - Propulsion

Coordinating unit: 205 - ESEIAAT - Terrassa School of Industrial, Aerospace and Audiovisual Engineering
Teaching unit: 220 - ETSEIAT - Terrassa School of Industrial and Aeronautical Engineering
Academic year: 2019
Degree: BACHELOR'S DEGREE IN AEROSPACE TECHNOLOGY ENGINEERING (Syllabus 2010). (Teaching unit Compulsory)
ECTS credits: 6 Teaching languages: Catalan, Spanish, English

Teaching staff

Coordinator: JOSEP ORIOL LIZANDRA DALMASES

Opening hours

Timetable: By agreement between teacher and student.

Prior skills

Physics, Chemistry, Thermodynamics, Mechanics, Fluid Mechanics, Propulsive Systems, Heat Transfer

Degree competences to which the subject contributes

Specific:

1. GrETA - An adequate understanding of the following, as applied to engineering: calculation and development methods for the installation of propulsion systems; regulation and control of the installation of propulsion systems; familiarity with the experimental techniques, equipment and measuring instruments used in the discipline; fuels and lubricants used in aircraft and automobile engines; numerical simulation of the most important physical and mathematical processes; maintenance and certification systems for aerospace engines.
2. GrETA - Applied knowledge of internal aerodynamics, propulsion theory, performance of aircraft and jet engines; engineering of propulsion systems; mechanics and thermodynamics.

Teaching methodology

The working methodology is divided into:
- Attendance lessons of theoretical contents, taught with the help of presentations and other documents that are uploaded to Atenea previously.
- Attendance lessons of practical exercises, as a direct application of the theoretical contents. The teacher proposes exercises, and give indications to the students in order to let them, autonomously, finish their resolution. Before the class ends, the teacher will present the solution with the final results so the students can compare with theirs.
- Practical works, where a project is proposed and the students have to develop them during non-school hours.

Learning objectives of the subject

1. Explain with certain detail the performance and limitations of different kind of rockets and jet engines.

2. Train the student for the execution of preliminary designs of these engines.

3. Train the students for a critic analysis of existent engines and their features.

4. Promote an appreciation of the determinant role of external drivers (mission requirements, economical issues,

environmental regulations, etc) on tdesign decisions.

Study load

Total learning time: 150h	Hours large group:	46h	30.67%
	Hours medium group:	14h	9.33%
	Self study:	90h	60.00%

220052 - Propulsion

Content

MODULE 1: JET ENGINES	Learning time: 75h Theory classes: 23h Practical classes: 7h Self study : 45h

Description:

Lecture 1. Global analysis of an engine for a commercial airplane.
1.1. The mission and its requirements.
1.2. Equation of uninstalled thrust of a simple flow turbojet. Extrapolation to a two flow turbojet (turbofan).
1.3. Cycles for turbojet engines. Efficiency of components y properties of the gas. Definitions of propulsive efficiency, thermal efficiency and overall efficiency.
1.4. Parametric analysis used in jet engine design (simple turbojet and turbofan). Election of optimal parameters for maximum thrust and maximum specific impulse.
Lecture 2. Components of a jet engine for a commercial airplane.
2.1. Static components.
2.1.1. Subsonic air inlets. Efect of the air inlet on installed thrust.
2.1.2. Nozzles. Mission of the nozzle. Effect of exit flow conditions on thrust: matched nozzle, under-expanded nozzle and over-expanded nozzle.
2.1.3. Combustion chambers. Concepts of combustion. Sizing of combustion chambers. Emissions and regulation. Physical and technological limitations.
2.2. Rotary components.
2.2.1. Euler equation for compressors and turbines. Blade cascade model. Triangles of velocities. Loss coefficients.
2.2.2. Efficiency of a stage from losses data.
2.2.3. Approximated design of a multistage compressor.
2.2.4. Radial distributions. Free vortex design. Variations.
2.2.5. Determination of the turn velocity and the number of stages.
2.2.6. Compressor Maps.
2.2.7. Compression limitations. Rotary stall and surge.
2.3.1. Turbines. Typical characteristics. Degree of reaction (R). Design for R = 0.5. Relationships for axial exit.
2.3.2. Use of loss factors
2.3.3. Computation of a turbine stage with losses.
2.3.4. Stress of rotors.
2.3.5. Turbine cooling.
Lecture 3. Off-design performace.
3.1. Determination of the system of equations and their variables, that give off-design performance. Solution algorithms.
3.1.1. Application to a simple turbojet.
3.1.2. Application to a two-spool turbojet.
3.1.3. Application to a high bypass ration turbofan.
Lecture 4. Additional considerations.
4.1. elements of jet and turbo-machinery noise.
4.2. Regulation and control of noise.
4.3. Elements of rotor-dynamics of the engine.
4.4. Manufacturing and economy elements of engines.

Specific objectives:

This module is focused on the global analysis of jet engines and the working principles of their components, aiming at a depth understanding, with as less as possible empiricism, of engine design, its possibilities and limitations. The objective is that students be able of carrying out a preliminary design, and, if desired, to access to methods for a detailed design, either numerical or experimental.

MODULE 2: ROCKETS	Learning time: 75h Theory classes: 23h Practical classes: 7h Self study : 45h

Description:
Lecture 1. Introduction
1.1.1. Classification according to gas acceleration mechanism / force on the vehicle.
1.1.2. Classification according to the energy source.
1.1.3. Classification according to the thrust level.
1.2. Performance measures.
1.2.1. Specific impulse.
1.2.2. Thermal efficiency.
1.2.3. Thrust/weight ratio.
1.3. Rocket selection guide (according to the mission).
Lecture 2. Rockets nozzles and Thrust.
2.1. Thrust equation.
2.2. Thrust losses due to non-uniformities of direction at the exit.
2.3. Relationship between total enthalpy and exit velocity: nozzle efficiency.
2.4. Thrust losses due to non-uniformities of total enthalpy. Efficiency of non-uniformities of total enthalpy.
Lecture 3. Ideal nozzles fluid dynamics, according to the quasi one-dimensional model.
3.1. Quasi one-dimensional nozzles without flow separation.
3.1.1. Characteristic velocity and thrust coefficient.
3.1.2. Choice of the optimum expansion ratio for an ascent flight through the atmosphere.
3.2. Effects of flow separation. Summerfield criterion.
Lecture 4. Convective heat transfer in rocket nozzles. Reynolds analogy.
4.1. Convective heat transfer. Boundary layer equations.
4.2. Turbulent viscosity and thermal conductivity coefficients.
4.3. Approximated model for unity Prandtl number and zero pressure gradient. Reynolds Analogy.
4.4. Corrections for Pr less than 1.
4.5. Bartz formula for the heat flux at the wall.
Lecture 5. Effect of heat losses on rocket performance.
5.1. Total heat loss.
5.2. Effect on rocket performance.
Lecture 6. Nozzle cooling of liquid propellant rockets.
6.1. Design considerations.
6.2. Mechanical stresses on cooled nozzle walls.

Specific objectives:
This module is not focused on design, but rather on the fundamentals of propulsion, however some methods for the preliminary design are also studied. It aims at training the student to approach innovations and other different types of rockets, what is found to occur more often in this area, rather than in the more mature one of jet engines.

Planning of activities

LARGE GROUPS/ THEORY	Hours: 86h Theory classes: 42h Self study: 44h

Description:
Attendance lessons, in which the professor teaches theoretical knowledges and guide the students so they can develope autonomous learning.

Support materials:
Notes available on Atenea.
Basic and complementary bibliography of the subject.

Specific objectives:
The objective of these sessions is that the student acquire the necessary knowledges, so as to apply them to exercises and assignments, by developing the autonomous learning.

MEDIUM GROUPS/PROBLEMS	Hours: 40h Practical classes: 14h Self study: 26h

Description:
The professor poses exercises to be solved in class, as direct application of theory, consisting of modelling of engines and/or their components. Students are encouraged to work in small groups (2 to 3) so that they share concepts, ideas and approaches.

Support materials:
Notes available on Atenea.
Basic and complementary bibliography of the subject.

Specific objectives:
By doing these exercises the student is expected to familiarise with the modelling of engines and components, so that he/she will be in conditions to satisfactorily solve the exam exercises.

PRACTICAL WORKS	Hours: 20h Self study: 20h

Description:
A practical work is planned, and it may be about either a laboratory practice or a computer simulation assignment, in teams of up to 3 students. In the case of a laboratory practice, a report will be required. The practical work may deal issues as the following:
1. Design and computation of performance of a jet engine by means of numerical models.
2. Design and computation of performance of engine components.
3. Performance measures of Internal parameters (thrust, flows, pressures, temperatures, turn speed) of a laboratory jet engine, an later data analysis, and determination of unknown engine parameters,
4. Design and computation of performance of a rocket engine.

Support materials:
Notes available on Atenea.
Basic and complementary bibliography of the subject, and web links.
Laptop and a variety of computer tools, to write and execute computer codes.

Descriptions of the assignments due and their relation to the assessment:
The assignment weighs a 16% on the global grade of the subject. The deadline to submit it will be indicated via Atenea.

Specific objectives:
One expects that the student will consolidate his/her concepts by doing this practical works, since this is not only a tool to complement class exercises, bu also, because the submit deadline is further away, and the assignment is carried out by means of computer codes, a much more realistic simulations is possible, what in turn permits much more reliable comparisons with real engines.

PARTIAL EXAM	Hours: 2h Theory classes: 2h

Description:
Individual written test, corresponding to module 1.

Support materials:
One formula sheet, written by both sides, and a non-programmable calculator.

Descriptions of the assignments due and their relation to the assessment:
The exam weighs a 42% on the global grade of the subject.

Specific objectives:
With this exam the student must demonstrate that he/she has assimilated the concepts of module 1.

FINAL EXAM	Hours: 2h Theory classes: 2h

Description:
Individual and written test, corresponing to module 2.

Support materials:
One formula sheet, written by both sides, and a non-programmable calculator.

Descriptions of the assignments due and their relation to the assessment:
The exam weighs a 42% on the global grade of the subject.

Specific objectives:
With this exam the student must demonstrate that he/she has assimilated the concepts of module 2.

220052 - Propulsion

Qualification system

42% Mid-term exam.
42% Final exam.
16% Practical assignment.

All those students who fail, want to improve their mark or cannot attend the partial exam, they will have the opportunity to examine the same day of the final exam. If due to the circumstances it is not viable to do it the same day of the final examination, the responsible teacher of the subject will propose, via the platform Atenea, that the mentioned recovery exam will be carried out another day, in class schedule.
The new mark of the recovery exam will substitute the previous one, just in the case that it is higher.

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 (tests, midterm and final exams) and 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.

Regulations for carrying out activities

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Bibliography

Basic:

Cumpsty, N. A. Jet propulsion: a simple guide to the aerodynamic and thermodynamic design and performance of jet engines. 2nd ed. New York: Cambridge University Press, 2003. ISBN 0521541441.

Mattingly, J. D. Elements of propulsion: gas turbines and rockets. Reston: American Institute of Aeronautics and Astronautics, 2006. ISBN 1563477793.

Complementary:

Kerrebrock, J. L. Aircraft engines and gas turbines. 2nd ed. Cambridge: MIT Press, 1992. ISBN 0-262-11162-4.

Sutton, G. P.; Biblarz, O. Rocket propulsion elements. 7th ed. New York: John Wiley & Sons, 2001. ISBN 0471326429.

Hill, P. G.; Peterson, C. R. Mechanics and thermodynamics of propulsion. 2nd ed. Massachusetts: Addison-Wesley, 1992. ISBN 0201146592.

Cohen, H.; Rogers, G.F.C.; Saravanamuttoo, H.I.H. Gas turbine theory. 4th ed. Harlow; Essex: Longman: Addison-Wesley, 1996. ISBN 0582236320.

Others resources:

Hyperlink

http://www.ocw.mit.edu/index.html