220015 - TERMO - Thermodynamics

Coordinating unit: 205 - ESEIAAT - Terrassa School of Industrial, Aerospace and Audiovisual Engineering
Teaching unit: 724 - MMT - Department of Heat Engines
Academic year: 2019
Degree: BACHELOR'S DEGREE IN AEROSPACE TECHNOLOGY ENGINEERING (Syllabus 2010). (Teaching unit Compulsory)
BACHELOR'S DEGREE IN AEROSPACE VEHICLE ENGINEERING (Syllabus 2010). (Teaching unit Compulsory)
ECTS credits: 6
Teaching languages: Catalan

Teaching staff
Coordinator: Joaquim Rigola Serrano
Others: Yolanda Calventus, John Hutchinson, Frida Roman, Carles Oliet

Prior skills
Students must have acquired the basic knowledge of differential and integral calculus. Must know the concepts of temperature and pressure, work, heat capacities. Understand the concept of ideal gas and know how to work with the ideal gas model. Solve elementary problems of 1st and 2nd principles applied to closed systems.

Degree competences to which the subject contributes

Specific:
1. GrETA/GrEVA - An understanding of the thermodynamic cycles of generators of mechanical power and thrust

5. Understanding and mastery of basic concepts about the general laws of mechanics, thermodynamics and electromagnetism fields and waves and their application to solving problems in engineering.

Transversal:
2. EFFECTIVE USE OF INFORMATION RESOURCES - Level 2. Designing and executing a good strategy for advanced searches using specialized information resources, once the various parts of an academic document have been identified and bibliographical references provided. Choosing suitable information based on its relevance and quality.
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**Teaching methodology**

The subject is divided in:
1- Big group lessons: in these lessons are developed the theory lessons and part of the problem lessons, as well as the evaluation that belongs to the first and second midterms and the level tests. The model will be fixed by the teacher, being it the one that he considers more suitable to the objectives of the subject.
2- Medium group lessons: These lessons correspond to problems lessons. The problems can be fixed by the teacher, or proposed by the students to be solved if they are part of the autonomous learning. If it is considered appropriate there can be guided activities during these hours.
3- Little group lessons: In these hours the laboratory practices take place, as well as the generic competence CG6 “Solvent use of the information resources”

The Atenea platform will be used in order to support the three types of lessons detailed above. It will be used as a way of communication between teachers and students.
A) Teacher-Student:
1) Schedule of activities and information
2) Learning material
3) Grades
B) Student-Teacher
1) Task delivery
2) Questions, comments and suggestions about the development of the subject and it apprenticeship.
C) Student-Student
1) Use of the forum as place to find information and discuss topics.

**Learning objectives of the subject**

- Acquiring the basic knowledge for later studies in heat transfer, fluid mechanics and thermic motors.
- Acquiring the ability of applying the thermodynamics to related subjects.
- Acquiring the ability of making hypothesis in real systems.
- Learning the use of laboratory instruments.
- Improve the use of different units and magnitudes, as well as tables and equations. Using of software for the calculation of thermo-physic properties.
- Learning how to perform an efficient use of bibliography

**Study load**

<table>
<thead>
<tr>
<th>Total learning time: 150h</th>
<th>Hours large group:</th>
<th>32h</th>
<th>21.33%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hours medium group:</td>
<td>14h</td>
<td>9.33%</td>
</tr>
<tr>
<td></td>
<td>Hours small group:</td>
<td>14h</td>
<td>9.33%</td>
</tr>
<tr>
<td></td>
<td>Self study:</td>
<td>90h</td>
<td>60.00%</td>
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</table>
## Content

### 1. Previous concepts about the approach of Thermodynamics

**Description:**
- Previous concepts on the approach of Thermodynamics
  1.1. Objectives and method of the classical thermodynamics of equilibrium.
  1.2. Thermodynamic system and types of systems.
  1.3. State of a system and state variables. State postulate.
  1.4. Equations of state.
  1.5. Thermodynamic equilibrium.
  1.6. Processes in thermodynamic systems. Quasi-static, reversible and irreversible processes.
  1.7. Cyclic processes.
  1.8. Thermal coefficients: isothermal compressibility, isobaric expansion and piezothermal.

**Related activities:**
- Theory classes, problems and laboratory practices.
- Individual test of previous knowledge related to Thermodynamics (not evaluable).

**Specific objectives:**
- Identify the specific vocabulary related to Thermodynamics through the precise definition of basic concepts to feel the language of Thermodynamics. Master the concepts of: system, border, environment, state, state variables, independent variable, thermodynamic equilibrium, process.
- To know how to classify a system according to its walls, know how to find its independent variables.
- Define the concept of state equation and state thermal equation.
- Define the concepts of coefficient of expansion, compressibility, piezo-thermal, its sign, its dependence on the thermodynamic variables, units and the relationship between them.
- Calculate variations in temperature, pressure, volume and find the thermal equation of state from the coefficients. Thermals

### 2. Volumetric properties of a pure substance, simple and compressible.

**Description:**
- Phenomenological study of the PVT behavior of a pure, simple and compressible substance.
  2.1. Concept of pure substance.
  2.2. Definition of phase and phase change.
  2.3. Description of the surface PVT. Projections P-T, P-v and T-v. Identification of the stable phases and triple point.
  2.4. Study of the liquid-vapor region: gas condensation and critical properties. Title of a wet steam.
  2.5. Tabulated data of PVT properties of some pure substances.
  2.6. Equations of state.

**Related activities:**
- Theory classes, problems and laboratory practices.
- Laboratory Practice: PVT behavior of a pure substance. Critical point.
### 3. The first law of thermodynamics

#### Description:

3.1. - The First Principle of Thermodynamics in closed systems
3.1.1. - Energy interactions. 3.1.2. - Work in Thermodynamics. 3.1.3. - Definition of heat. 3.1.4. - Formulation of the First Principle in closed systems. 3.1.5. - Energy analysis of a cycle. 3.1.6. - Enthalpy function. 3.1.7. - Thermal effects. Heat capacity at constant volume and constant pressure. Meyer's relationship. 3.1.8. - Variations of internal energy and enthalpy in ideal gases. 3.1.9. - Definition of perfect gas. 3.1.10. - Model of incompressible substance. 3.1.11. - Latent heat of transformation or phase change. Clapeyron equation. 3.1.12. - Sensitive heat. 3.1.13. - Free expansion of a gas in a vacuum. 3.1.14. - Adiabatic processes: PVT equations for perfect gas reversible adiabatic processes. 3.1.15. - Polytopic processes.

3.2. - The first principle of Thermodynamics in open systems.
3.2.1. - Definition of continuous system and volume of control. 3.2.2. - Conservation of mass and energy in a control volume. 3.2.3. - Development of the term work. 3.2.2. - Balance of mass and energy in a control volume. 3.2.5. - Processes with perfect gases in open systems of stationary flow.

3.3. - Application of energy analysis to control volumes.
3.3.1. - Description of stationary flow devices

#### Related activities:

Theory classes, problems and laboratory practices.
Laboratory practice: Determination of the vapor pressure of a liquid. Latent heat of vaporization.
Laboratory practice: Determination of the heat power of a gas. Gas junker.
Oral presentation of a laboratory practice
Activity 6. Level test of contents 1 and 2
1st partial exam. Contents 1, 2 and 3

#### Specific objectives:

- Define the concept of thermodynamic work and apply it to any thermodynamic system
- Formulate the first principle of Thermodynamics as a statement of the principle of conservation of energy for closed systems (mass of control)
- Define the concept of heat
- Define the specific heat at constant pressure and volume and relate them to the calculation of the internal energy and enthalpy of an ideal gas.
- Define perfect gas
- Understand the equations of the reversible adiabatic of a perfect gas and of the polytropic processes.
- Solve energy balance problems in closed systems.
- Know how to deduce the equations of conservation of mass and energy in a control volume
- Interpret each one of the terms that appear in it. Develop the term work
- Define steady state
- Formulate the equations of conservation of mass and energy in a volume of control in a stationary flow
- Describe the processes of perfect gases in open systems of stationary flow

Learning time: 47h
- Theory classes: 9h
- Practical classes: 5h
- Laboratory classes: 5h
- Self study: 28h

Description:
4.1. Introduction to the Second Principle of Thermodynamics
4.2.1. Clausius inequality. 4.2.2. Entropy concept. 4.2.3. Equations Tds. 4.2.4. Calculation of entropy variations. 4.2.5. Entropy of a pure, simple and compressible substance. Tabulated data of entropy. 4.2.6. Entropic diagrams: h-s and T-s. 4.2.7. Principle of increasing entropy. 4.2.8. Thermal entropy flow and entropy production. 4.2.9. Sources of irreversibilities. 4.2.10. Production of entropy and degradation of energy. 4.2.11. Entropy balance in closed systems and control volumes.
4.3.1. Isentropic process. 4.3.2. Isentropic performance of some stationary flow devices: turbines, compressors, nozzles, diffusers and pumps. 4.3.3. Comparison between reversible and irreversible work interactions in turbines, compressors and pumps. 4.3.4. Comparison between the kinetic energy in the isentropic process and the actual nozzle process.

Related activities:
- Theory classes, problems and laboratory practices.
- Laboratory practice: Study of a refrigeration cycle. Heat pump
- Laboratory practice: Joule-Thompson coefficient of a gas
- Oral presentation of a laboratory practice

Specific objectives:
Identify the limitations of the First Principle
Remember the classical statements of the Second Principle of Thermodynamics. Define heat focus
Define reversible and irreversible process
Define the concept of thermal performance and COP
Analyze direct heat machines and refrigerators and heat pumps.
Give examples of thermodynamic cycles such as Rankine, Brayton, and cooling cycles.
Describe the Carnot cycle
Remember and demonstrate the Carnot corollaries
Deduce and interpret Clausius inequality
Define the concept of entropy from Clausius inequality.
Formulate equations for the calculation of entropy variations of ideal and perfect gases, incompressible
substances, phase changes, heat sources
Calculate entropy and entropy variations with the equations in the previous section and using the tables.
Describe T-s and h-s diagrams and represent processes and cycles
Formulate the principle of increasing entropy
Formulate the entropy balance in a closed system. Interpret the terms that appear in the equation.
Classify irreversibilities and give examples
Deduce the entropy balance equation in control volumes
Apply entropy balance equations to closed systems and control volumes to solve problems
Define a special class of idealized processes called isentropic.
Compare isentropic processes with real (irreversible adiabatic) processes using real work and isentropic work.
Define the isentropic performance of an expansion and a compression.
5. Thermodynamic cycles.

**Description:**
5.1.- Power cycles.
5.1.1.- Basic Rankine cycle. 5.1.2.- Modifications of the Rankine cycle. 5.1.3.-Applications of the Rankine cycle. 5.1.4.-Simple Brayton cycle. 5.1.5.- Modifications of the Brayton cycle. 5.1.6.- Applications of the Brayton cycle.
5.2.- Refrigeration cycles.
5.2.1.- Steam compression cycles (reverse Rankine). Applications. 5.2.2.- Reverse Brayton refrigeration cycles and applications.

**Related activities:**
Theory classes and problems
Activity 6. Content level test 4
Second Partial Exam: Contents all the course material

**Specific objectives:**
Recognize the basics elements of the Rankine cycle and modifications
Recognize the basics of a simple Brayton cycle and modifications
Give examples of applications from both cycles
Perform the energy analysis of these cycles
Recognize the basic elements of a steam compression cooling cycle
Recognize the basics of a Brayton inverse cycle
Give examples of applying the latter: cooling an aircraft cabin
### Planning of activities

<table>
<thead>
<tr>
<th>ACTIVITY 1: THEORY CLASSES</th>
<th>Hours: 68h</th>
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<tbody>
<tr>
<td></td>
<td>Theory classes: 26h</td>
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<tr>
<td></td>
<td>Self study: 42h</td>
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</tbody>
</table>

**Description:**
- Methodology in large group
- Presentation of the contents of the subject following a model of participatory and expository class.
- The subject matter has been organized into 5 thematic areas or topics.
- This class will solve problems with the whole group.

**Support materials:**
- Basic bibliography
- Teacher's notes (ATENEA).
- Pure fluid thermodynamic properties table book.
- Pure fluid properties diagrams: T-s, h-s and P-h.
- Self-assessment questionnaires to be uploaded to ATENEA.

**Descriptions of the assignments due and their relation to the assessment:**
- This activity is evaluated in conjunction with activity 2 (problems) through a first partial exam and a second partial or final exam.
- Evaluations of the questionnaires will not be taken into account in the final grade. The evaluation will be indicative for the student.

**Specific objectives:**
- At the end of this activity, the student must be able to master the acquired knowledge, consolidate and apply it correctly to technical problems that involve real situations. In addition, they must be the basis for the development of other subjects in the field of Thermodynamics related to Heat Transfer, Heat Engines and Refrigeration.

<table>
<thead>
<tr>
<th>ACTIVITY 2: PROBLEM CLASSES</th>
<th>Hours: 40h</th>
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<tbody>
<tr>
<td></td>
<td>Practical classes: 14h</td>
</tr>
<tr>
<td></td>
<td>Self study: 26h</td>
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**Description:**
- Medium group methodology
- In each of the topics, there will be problems in class so that students acquire the necessary guidelines to carry out this resolution: approach, numerical resolution, simplifications, units, ...

**Support materials:**
- Basic bibliography
- Teacher's notes (ATENEA).
- Pure fluid thermodynamic properties table book.
- Pure fluid properties diagrams: T-s, h-s and P-h.
- Self-assessment questionnaires to be uploaded to ATENEA.

**Descriptions of the assignments due and their relation to the assessment:**
- This activity is evaluated in conjunction with activity 1 (theory) by means of a partial exam and a final exam. Evaluations of the questionnaires will not be taken into account in the final grade. The evaluation will be indicative for the student.
Activity 3: Laboratory Practices

Description:
This activity consists of performing 6 laboratory practices plus two exhibition sessions of two of the practices performed. The practices will be performed in groups of two students in the Thermodynamics laboratory. The structure to be followed will be:
1. Preparation of the practice through the manual of practices.
2. Resolution of a questionnaire related to the practice to be performed.
3. Practice in groups of 2 students. The maximum duration will be 2 hours.
4. Discussion of the results obtained and the problems that have arisen during the realization of the practice.
5. Writing a report on the practice made with experimental results, graphical constructions, questions and conclusions. This report will be evaluated along with the completion of the practice.
6. Oral presentation of two of the practices performed. This exhibition will be evaluated in terms of objectives, methodology, results, conclusions and questions raised at the end of the exhibition. The maximum duration is 15 minutes.

Support Materials:
- Laboratory material
- Equipment and assemblies appropriate to the objectives of the practice.
- Practice scripts and reports to be submitted.
- Pre-practice questionnaires and checking the degree of comprehension of the practice before its completion.

Description of the assignments due and their relation to the assessment:
For each practice performed, of which the corresponding report will be presented, the assessment will be:
a) Questionnaire before completion: 10%
b) Completion of the practice: 10%
c) Presentation style: 10%
d) Evaluation of the report: 70%

In the practices with oral exposure, the evaluation of the report will be equivalent to 40% of the mark of the practice and the remaining 60% of oral exposure.

In developing practices, a system will be developed to develop and evaluate generic competence. The assessment of Generic Competence will be 5% of the subject.
The mark of laboratory practices (NL) will be 20% of the overall mark of the subject. 15% will correspond to the evaluation of practices and the remaining 5% will be the evaluation of generic competence (CG).

Specific objectives:
At the end of this activity, the student should be able to: a) Know how to describe the experimental tasks performed; b) Process the experimental data obtained and draw conclusions; c) Correctly prepare the report of the work done; d) Know how to present this report correctly, clearly and in a timely manner, and correctly answer the questions that arise.
### ACTIVITY 4: PART 1 EXAMINATION

**Description:**
- Development of the partial exam of the subject.
- It includes theoretical aspects and problem development.
- This partial does not eliminate matter.

**Support materials:**
- Book of charts and graphs of thermodynamic properties.
- The form provided by the teacher is allowed.

**Descriptions of the assignments due and their relation to the assessment:**
- The exam is resolved on the fold of sheets delivered at the beginning of the test by the theoretical part and / or on additional sheets due to the problems. The extra sheets, if any, are attached to the theory sheets at the end of the test.
- At the beginning of the test will indicate the score of each exercise, theory and problems, and the evaluation criteria.
- The rating of this activity N1P is worth 30% of the final overall rating.
- This first partial does not eliminate matter.

**Specific objectives:**
- Show the level of knowledge reached in the theoretical and problem activities.

**Hours:**
- Theory classes: 2h

### ACTIVITY 5: 2nd PARTIAL EXAM (FINAL)

**Description:**
- Development of the final exam of the subject. This test includes all the content of the subject.
- This test will establish the mechanism for redirecting students who have not passed the first semester exam.
- It includes theoretical aspects and problem development.

**Support materials:**
- Book of charts and graphs of thermodynamic properties.
- The form provided by the teacher is allowed.

**Descriptions of the assignments due and their relation to the assessment:**
- The exam is resolved on the fold of sheets delivered at the beginning of the test by the theoretical part and / or on additional sheets due to the problems. The extra sheets, if any, are attached to the theory sheets at the end of the test.
- At the beginning of the test will indicate the score of each exercise, theory and problems, and the evaluation criteria.
- The rating of this activity N2P is worth 40% of the final overall rating.

**Specific objectives:**
- Show the level of knowledge reached in the theoretical and problem activities.

**Hours:**
- Theory classes: 2h

### ACTIVITY 6: PARTIAL LEVEL TESTS

**Hours:**
- Theory classes: 2h
Description:
Development of a partial level test of the syllabus already studied.
During the course there will be 2 evaluable level tests

Support materials:
Book of charts and graphs of thermodynamic properties.
It is allowed to use the form provided by the teacher.

Descriptions of the assignments due and their relation to the assessment:
The test is settled on the sheet of paper delivered at the beginning.
At the beginning of the test the score of each exercise and the evaluation criterion will be indicated.
The average rating of the 2 level tests, Nc, will be equivalent to 10% of the final overall rating.

Specific objectives:
Show the level of knowledge reached in the theoretical and problem activities.

Qualification system
First midterm exam "N1P" : weigh 30%
Second midterm exam: "N2P" : weigh 40%
Laboratory practices: "NL" : weigh 20%
Level tests "Nc": weigh 10%

The course will provide for procedures to recover unsatisfactory results obtained in the first evaluation, inside the final exam (for students with a mark lower than 5 with a degree between 0 and 5).

Regulations for carrying out activities
1) The self-evaluation questionnaires won't be used in order to fix a grade.
2) The lack of assistance to a laboratory session would lead to a mark of zero without the possibility of doing it at other moment. A tardiness of more than 15 min would lead to the same. The laboratories inform can be made by group or individually and would be delivered the next session. There would be an exposition session. If a student doesn't attend the exposition the mark would be a zero too.
3) The exams must be made without the use of external material, except the book "Taules I Gràfics" y the formula sheet.
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Bibliography

Basic:


Complementary:


Others resources:

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