220020 - Fluid Mechanics

Coordinating unit: 205 - ESEIAAT - Terrassa School of Industrial, Aerospace and Audiovisual Engineering
Teaching unit: 729 - MF - Department of Fluid Mechanics
Academic year: 2019
Degree: BACHELOR'S DEGREE IN AEROSPACE VEHICLE ENGINEERING (Syllabus 2010). (Teaching unit Compulsory)
BACHELOR'S DEGREE IN AEROSPACE TECHNOLOGY ENGINEERING (Syllabus 2010). (Teaching unit Compulsory)
ECTS credits: 7.5
Teaching languages: Catalan, Spanish

Teaching staff
Coordinator: PEDRO JAVIER GAMEZ MONTERO - ROBERTO CASTILLA LOPEZ
Others: Raush Alviach, Gustavo Adolfo Quintana Vallmitjana, Marc

Degree competences to which the subject contributes

Specific:
4. 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 3 theory classes per week, in large groups, are mainly instructed using the expository method, although small exercises, directly related to Activity 1, are included. In addition, some examples and particular applications are worked with a more active participation of students.
The applications classes, in medium groups, are problems from the collection available in ATENEA. Some of these problems are exposed by the lecturer in the classroom, but most are solved by the students in teams of 3, and delivered as homework and in ATENEA forums. The student's resolutions are accessible by the rest of the students.
The practical classes, in small groups, are done in the laboratory and in the computer classrooms. The work is developed in teams. The objective for the student is to be able to collect data, to process, analyze and draw conclusions, comparing the results with other reference, theoretical, numerical, or experimental results.

Learning objectives of the subject
At the end of the course, the student should be able to:
Levels 1 and 2 (knowledge and compression)
- Define the basic properties of fluids
- Discuss the fundamental concepts of phenomena associated with fluids.
Level 3 (application)
- To solve problems of Aeronautical Engineering related to the flow of Newtonian fluids
- Use the theoretical, experimental and numerical tools appropriate to each problem.
## Study load

<table>
<thead>
<tr>
<th>Total learning time: 187h 30m</th>
<th>Hours large group: 47h 25.07%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hours medium group: 14h 7.47%</td>
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<tr>
<td></td>
<td>Hours small group: 14h 7.47%</td>
</tr>
<tr>
<td></td>
<td>Guided activities: 0h 0.00%</td>
</tr>
<tr>
<td></td>
<td>Self study: 112h 30m 60.00%</td>
</tr>
</tbody>
</table>
# 220020 - Fluid Mechanics

## Content

<table>
<thead>
<tr>
<th>1 - Introduction and basic concepts</th>
<th>Learning time: 4h</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Description:</strong></td>
<td>Theory classes: 2h</td>
</tr>
<tr>
<td>1.1 Definition of fluid</td>
<td>Self study: 2h</td>
</tr>
<tr>
<td>1.2 Continuum hypothesis</td>
<td></td>
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<tr>
<td>1.3 Properties of fluids</td>
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<tr>
<td><strong>Related activities:</strong></td>
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<tr>
<td>Theoretical classes</td>
<td></td>
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<tr>
<td>Activity 1</td>
<td></td>
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<tr>
<td>Activity 3 (control 1)</td>
<td></td>
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<tr>
<td>Activity 4 (first mid-semester exam)</td>
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<table>
<thead>
<tr>
<th>3 - Fluid Statics</th>
<th>Learning time: 10h 30m</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Description:</strong></td>
<td>Theory classes: 3h</td>
</tr>
<tr>
<td>2.1 Surface, mass and linear forces</td>
<td>Practical classes: 1h 30m</td>
</tr>
<tr>
<td>2.2 Fundamental equation for Fluid Statics</td>
<td>Self study: 6h</td>
</tr>
<tr>
<td>2.3 The atmosphere</td>
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<tr>
<td>2.4 Fluid statics force on a surface</td>
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<tr>
<td>2.5 Archimedes' principle</td>
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<tr>
<td>2.6 Second Law of Archimedes</td>
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<tr>
<td>2.7 Stability</td>
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<tr>
<td><strong>Related activities:</strong></td>
<td></td>
</tr>
<tr>
<td>Theoretical and problem sessions</td>
<td></td>
</tr>
<tr>
<td>Activity 1</td>
<td></td>
</tr>
<tr>
<td>Activity 2</td>
<td></td>
</tr>
<tr>
<td>Activity 3 (control 1)</td>
<td></td>
</tr>
<tr>
<td>Activity 4 (first mid-semester exam)</td>
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</tr>
</tbody>
</table>
## 3 - Kinematics

### Description:
- 3.1 Eulerian and Lagrangian description
- 3.2 Streamlines, pathlines and streaklines.
- 3.3 Substantial derivative
- 3.4 Circulation, flux and vorticity
- 3.5 Relative movement around a point

### Related activities:
- Theoretical and problem sessions
- Activity 1
- Activity 2
- Activity 3 (control 1)
- Activity 4 (first mid-semester exam)

### Learning time: 3h 30m
- Theory classes: 1h
- Practical classes: 0h 30m
- Self study: 2h

## 4 - Dynamics and General Equations

### Description:
- 4.1 Conservation equations
- 4.2 Reynolds' Transport Theorem
- 4.3 Differential and integral formulation
- 4.4 Conservation of mass
- 4.5 Conservation of momentum
- 4.6 Navier-Stokes Equations
- 4.7 Conservation of energy
- 4.8 Conservation of momentum of momentum

### Related activities:
- Theoretical and problem sessions
- Activity 1
- Activity 2
- Activity 3 (control 1)
- Activity 4 (first mid-semester exam)
- Activity 7 (Lab practice 1: Introduction to CFD)
- Activity 8 (Lab practice 2: Flow in a fan)

### Learning time: 45h
- Theory classes: 12h
- Practical classes: 5h
- Laboratory classes: 4h
- Self study: 24h
5 - Dimensional analysis and theory of model

<table>
<thead>
<tr>
<th>Description:</th>
<th>Learning time: 28h</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.1 Buckingham's Pi Theorem</td>
<td>Theory classes: 7h</td>
</tr>
<tr>
<td>5.2 Basic dimensionless numbers</td>
<td>Practical classes: 1h 30m</td>
</tr>
<tr>
<td>5.3 Nondimensionalization of equations</td>
<td>Self study : 19h 30m</td>
</tr>
<tr>
<td>5.4 Similitude</td>
<td></td>
</tr>
</tbody>
</table>

Related activities:
- Theretical and problem sessions
- Activity 1
- Activity 2
- Activity 3 (control 1)
- Activity 4 (first mid-semester exam)
- Activity 7 to 13 (Lab practice)

6 - Viscous flows

<table>
<thead>
<tr>
<th>Description:</th>
<th>Learning time: 14h</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.1 Introduction to viscous flows</td>
<td>Theory classes: 3h</td>
</tr>
<tr>
<td>6.2 Equations an boundary conditions</td>
<td>Practical classes: 1h</td>
</tr>
<tr>
<td>6.3 Flow between two parallel plates</td>
<td>Laboratory classes: 2h</td>
</tr>
<tr>
<td>6.4 Continuity and Navier-Stokes equations in cylindrical coordinates</td>
<td>Self study : 8h</td>
</tr>
<tr>
<td>6.5 Hagen-Poiseuille flow</td>
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<tr>
<td>6.6 Flow between two concentric cylinders</td>
<td></td>
</tr>
</tbody>
</table>

Related activities:
- Theretical and problem sessions
- Activity 1
- Activity 2
- Activity 5 (control 2)
- Activity 6 (second mid-semester exam)
- Activitat 9 (Lab practice 3: Viscous flow / CFD)
## 7 - Turbulent flows

**Learning time:** 6h  
- Theory classes: 1h  
- Laboratory classes: 2h  
- Self study: 3h

**Description:**  
- 7.1 Introduction to turbulence. Reynolds Average.  
- 7.2 Physical interpretation of Reynolds' tensor  
- 7.3 Law of the wall and turbulent boundary layer  

**Related activities:**  
- Theoretical and problem sessions  
- Activity 1  
- Activity 2  
- Activity 5 (control 2)  
- Activity 6 (second mid-semester exam)  
- Activity 10 (Lab practice: Measurement of turbulence with CTA)

## 8 - Boundary layer

**Learning time:** 10h 30m  
- Theory classes: 3h  
- Practical classes: 0h 30m  
- Laboratory classes: 2h  
- Self study: 5h

**Description:**  
- 8.1 Introduction to boundary layer  
- 8.2 Laminar boundary layer. Blasius' equation  
- 8.3 Momentum-integral equations for the boundary layer  
- 8.4 Turbulent boundary layer  
- 8.5 Boundary layer with pressure gradient. Flow separation.

**Related activities:**  
- Theoretical and problem sessions  
- Activity 1  
- Activity 2  
- Activity 5 (control 2)  
- Activity 6 (second mid-semester exam)  
- Activitat 11 (Lab practice 3: Viscous flow / CFD)
### 9 - Ideal and potential flows

**Learning time:** 16h
- Theory classes: 4h
- Practical classes: 1h
- Self study: 11h

**Description:**
- 9.1 Euler's equations
- 9.2 Stream function
- 9.3 Vorticity equation
- 9.4 Elementary potential flows
- 9.5 Circulation

**Related activities:**
- Theretical and problem sessions
- Activity 1
- Activity 2
- Activity 6 (second mid-semester exam)

### 10 - External Flow

**Learning time:** 11h
- Theory classes: 2h
- Practical classes: 1h
- Laboratory classes: 2h
- Self study: 6h

**Description:**
- 10.1 Introduction to Aerodynamics
- 10.2 Friction and pressure drag forces
- 10.3 Aerodynamic coefficients
- 10.4 Airfoils

**Related activities:**
- Theretical and problem sessions
- Activity 1
- Activity 2
- Activity 6 (second mid-semester exam)
- Activity 12 (Lab practice 6: Aerodynamics)
## 11 - Compressible flow

**Description:**
- 11.1 Introduction to compressible flow. Review of thermodynamics
- 11.2 Speed of sound
- 11.3 Adiabatic flow
- 11.4 Sonic values
- 11.5 Diffusers and injectors
- 11.6 Normal shock waves
- 11.7 Nozzles
- 11.8 Mach's conus
- 11.9 Oblique shock waves

**Related activities:**
- Theoretical and problem sessions
- Activity 1
- Activity 2
- Activity 6 (second mid-semester exam)
- Activity 13 (Lab practice 7: Compressible flow)

<table>
<thead>
<tr>
<th>Learning time</th>
<th>39h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theory classes</td>
<td>9h</td>
</tr>
<tr>
<td>Practical classes</td>
<td>2h</td>
</tr>
<tr>
<td>Laboratory classes</td>
<td>2h</td>
</tr>
<tr>
<td>Self study</td>
<td>26h</td>
</tr>
</tbody>
</table>
# Planning of activities

| 1 - SIMPLE EXERCISES PRESENTED IN THE THEORETICAL DOCUMENTATION OF THE SUBJECT | Hours: 70h  
Theory classes: 37h  
Self study: 33h |
|---|---|
| **Description:**  
Simple exercises of application of the theoretical concepts presented in the documentation. They are made and weekly delivered on the digital campus. |  |
| **Support materials:**  
Notes of the subject in ATENEA |  |
| **Descriptions of the assignments due and their relation to the assessment:**  
Exercises are weekly delivered. They can be handmade and scanned or photographed. The delivery is part of the 10% of the global mark corresponding to the class grade. |  |
| **Specific objectives:**  
At the end of this activity the student should be able to:  
- Apply the concepts acquired in the theoretical sessions to solve simple problems |  |

| 2 - PROBLEMS | Hours: 45h 30m  
Practical classes: 14h  
Self study: 31h 30m |
|---|---|
| **Description:**  
Problems solved in teams of 3 students. Problems are discussed in class. |  |
| **Support materials:**  
Subject notes  
Collection of problems |  |
| **Specific objectives:**  
At the end of this activity the student should be able to:  
- Find and analyze technical documentation in the biography and / or on Internet related to the proposed problems  
- Work in teams and distribute tasks in order to efficiently solve problems. |  |

| 4 - CONTROL 1 | Hours: 4h  
Theory classes: 1h  
Self study: 3h |
|---|---|
| **Description:**  
Test type control solved by couples in the classroom |  |
| **Support materials:**  
A sheet with handwritten formulae. |  |
| **Descriptions of the assignments due and their relation to the assessment:**  
The mark is part of the 10% of the global mark corresponding to controls grade. |  |
| **Specific objectives:**  
At the end of this activity the student must be able to:  
- Show the achievement of the specific objectives associated with contents 1, 2, 3 and first half of 4. |  |
### 4 - FIRST MID-SEMESTER EXAM

**Description:**
Individual mid-semester exam

**Support materials:**
Formulae used in controls

**Descriptions of the assignments due and their relation to the assessment:**
The exam is the 30% of final course mark

**Specific objectives:**
At the end of this activity the student should be able to:
- Show the achievement of the specific objectives associated with contents 1, 2, 3, 4 and 5

**Hours:** 11h
- Theory classes: 3h
- Self study: 8h

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### 5 - CONTROL 2

**Description:**
Test type control solved by couples in the classroom

**Support materials:**
A sheet with handwritten formulae.

**Descriptions of the assignments due and their relation to the assessment:**
The mark is part of the 10% of the global mark corresponding to controls grade.

**Specific objectives:**
At the end of this activity the student must be able to:
- Show the achievement of the specific objectives associated with contents 6, 7, 8 and first half of 8.

**Hours:** 4h
- Theory classes: 1h
- Self study: 3h

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### 6 - SECOND MID-SEMESTER EXAM

**Description:**
Individual mid-semester exam. It includes an activity for recovery of activity 4 (first mid-semester exam)

**Support materials:**
Handwritten formulae used in controls

**Descriptions of the assignments due and their relation to the assessment:**
The exam is the 40% of the course global grade.

**Specific objectives:**
At the end of this activity the student should be able to:
- Show the achievement of the specific objectives associated with content 6, 7, 8, 9, 10 and 11.

**Hours:** 11h
- Theory classes: 3h
- Self study: 8h
<table>
<thead>
<tr>
<th>7 - LAB PRACTICE 1. INTRODUCTION TO CFD</th>
<th>Hours: 4h</th>
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</thead>
<tbody>
<tr>
<td><strong>Description:</strong></td>
<td></td>
</tr>
<tr>
<td>Lab practice with a very basic introduction to CFD tools that will be used in computer practices</td>
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<tr>
<td><strong>Support materials:</strong></td>
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<tr>
<td>CFD software</td>
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<tr>
<td>Desktop in computer classroom</td>
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<tr>
<td>Subject notes</td>
<td></td>
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<tr>
<td>Lab practices guide.</td>
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<tr>
<td><strong>Descriptions of the assignments due and their relation to the assessment:</strong></td>
<td></td>
</tr>
<tr>
<td>Report by teams.</td>
<td></td>
</tr>
<tr>
<td>The correct delivery of the report is part of the 10% of the overall course grade, corresponding to the laboratory grade</td>
<td></td>
</tr>
<tr>
<td><strong>Specific objectives:</strong></td>
<td></td>
</tr>
<tr>
<td>At the end of this activity the student should be able to:</td>
<td></td>
</tr>
<tr>
<td>- Find information on the Internet, books, articles on numerical methods using CFD</td>
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<tr>
<td>- Describe in generic form what is a CFD program</td>
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<tr>
<td>- Perform a simulation with simple geometry, a laminar flow with standard contour conditions.</td>
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</tr>
<tr>
<td>- Interpret the results obtained from a CFD simulation</td>
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</tbody>
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<table>
<thead>
<tr>
<th>8 - LAB PRACTICE 2. FLOW RATE MEASUREMENT IN A FAN</th>
<th>Hours: 4h</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Laboratory classes:</strong></td>
<td></td>
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<tr>
<td>2h</td>
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<thead>
<tr>
<th>9 - LAB PRACTICE 3. VISCOUS FLOW</th>
<th>Hours: 4h</th>
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<tbody>
<tr>
<td><strong>Laboratory classes:</strong></td>
<td></td>
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<tr>
<td>2h</td>
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<thead>
<tr>
<th>10 - LAB PRACTICE. MEASUREMENT OF TURBULENCE WITH CTA</th>
<th>Hours: 4h</th>
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</thead>
<tbody>
<tr>
<td><strong>Laboratory classes:</strong></td>
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<tr>
<td>2h</td>
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<table>
<thead>
<tr>
<th>11 - LAB PRACTICE. BOUNDARY LAYER</th>
<th>Hours: 4h</th>
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<tbody>
<tr>
<td><strong>Laboratory classes:</strong></td>
<td></td>
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<tr>
<td>2h</td>
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</tbody>
</table>
### 12 - LABORATORY PRACTICE 6. EXTERNAL FLOW - AERODYNAMIC BALANCE

**Hours:** 4h  
Laboratory classes: 2h  
Self study: 2h

**Description:**  
Aerodynamic coefficients of a body are measured and compared with reference values.

### 13 - LABORATORY PRACTICE 7. COMPRRESSIBLE FLOW

**Hours:** 4h  
Laboratory classes: 2h  
Self study: 2h

**Description:**  
Practice with Computational Fluid Dynamics software. A compressible flow is simulated and the results are compared with the estimations calculated made in problem sessions.

**Support materials:**  
CFD software  
Desktop in classroom  
Subject notes  
Guide of the practice in ATENEA

**Descriptions of the assignments due and their relation to the assessment:**  
Report in a group of three students.  
The correct delivery of the report is part of the 10% of the overall course grade, corresponding to the laboratory grade.

**Specific objectives:**  
At the end of this activity the student should be able to:  
- Design a compressible flow simulation with a simple geometry.  
- Interpret the results obtained from the simulation and compare them with the analytical results.

### 14 - ARTICLES READING

**Hours:** 6h  
Self study: 6h

**Description:**  
The student has to read an article or chapter of a book, in English, Spanish or Catalan, and make a small report/summary.

**Support materials:**  
Article

**Descriptions of the assignments due and their relation to the assessment:**  
The assessment of the report is part of the 10% of the overall course mark, corresponding to the class grade.

**Specific objectives:**  
At the end of this activity the student should be able to:  
- Extract from a scientific paper on Fluid Mechanics the most significant features  
- Criticize and comment on a scientific article on Fluid Mechanics
Qualification system

<table>
<thead>
<tr>
<th>Activity</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st mid-semester</td>
<td>30%</td>
</tr>
<tr>
<td>2nd mid-semester weight</td>
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</tr>
<tr>
<td>Class grade</td>
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<tr>
<td>Control tests</td>
<td>10%</td>
</tr>
<tr>
<td>Lab practices</td>
<td>10%</td>
</tr>
</tbody>
</table>

In the case of unsatisfactory results in the first mid-semester, and whenever the grade is less than 5, the second mid-semester will be replaced by a final exam with the content of the whole subject. The final grade corresponding to the partial marks (70%) will be the highest value between the final exam and the weighting between the 1st mid-term and the second part in the final exam.

Regulations for carrying out activities

The controls are test type and they will be written in couples with an approximate duration of 30 minutes. Students can have a handmade collection of formulae.

The mid-semester exams ones consist of:
- Two problems. 2 hours duration. They may include evaluation of theoretical concepts. With formulae and calculator. Each problem is 50% of the total mid-semester mark.

The exams have be written with pen.

Theoretical tasks must be presented every week in ATENEA. They can be made by hand, scanned or photographed. The problems must be presented in ATENEA, made with a word processor, with the format available in ATENEA, and always with pdf format.

The reports of the practices must be presented in ATENEA, made with a word processor, with the format available in ATENEA, and always with pdf format.
Bibliography

Basic:


Complementary:


**Others resources:**
Notes and slides in Atenea

**Hyperlink**

- [www.efluids.com](http://www.efluids.com)
  Portal de recursos en internet sobre Mecánica de Fluids

- [www.cfd-online.com](http://www.cfd-online.com)
  Portal sobre Computational Fluid Dynamics

- [www.potto.org](http://www.potto.org)
  Projecte per la publicació de material docent de forma oberta i gratuita. Llibre sobre Flux Compressible.