UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH

Course guide
220103 - MF - Fluid Mechanics

Last modified: 11/07/2024

Unit in charge: Terrassa School of Industrial, Aerospace and Audiovisual Engineering
Teaching unit: 729 - MF - Department of Fluid Mechanics.

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

Academic year: 2024 **ECTS Credits:** 4.5 **Languages:** Catalan

LECTURER

Coordinating lecturer: Castilla Lopez, Roberto

Others: Raush Alviach, Gustavo Adolfo
García Vílchez, Mercedes

PRIOR SKILLS

It is recommended that students have a sufficient level of math and physics. Basic concepts such as integration, derivation and solution of simple differential equations are recommended to properly follow the subject.

DEGREE COMPETENCES TO WHICH THE SUBJECT CONTRIBUTES

Specific:
CE08-INDUS. Knowledge of the basic principles of fluid mechanics and their application to solving problems in the field of engineering. Calculation of pipes, channels, and fluid systems. (Common module for industrial engineering)

TEACHING METHODOLOGY

Teaching methodology will be based on classes of theory and problems given by the professor, students will have to solve problems in class and they will also need to solve some exercises at home, the exercises shall be done in groups of two or three students.

LEARNING OBJECTIVES OF THE SUBJECT

At the end of the course the student must be able to:
Levels 1 and 2 (knowledge and understanding):
• Define the basic properties of fluids
• Discuss the fundamental concepts of the phenomena associated with fluids.
Level 3 (application):
• Solve Industrial Engineering problems related to Newtonian fluid flow
• Use the theoretical, experimental and numerical tools appropriate to each problem.

STUDY LOAD

Type	Hours	Percentage
Hours large group	31,0	27.56
Self study	67,5	60.00
Hours medium group	14,0	12.44

Total learning time: 112.5 h

CONTENTS

Introduction to fluid mechanics / Statics.

Description:
Fluid under microscopic, macroscopic and thermodynamic points of view. Continuum theory, and local thermodynamic equilibrium. Mechanical and thermodynamic properties of fluids, fluid rheological equations. Basic differential equation of fluid statics, differential equation of a fluid under constant acceleration.
This description can be summarized as:
1.1 Mechanical and thermodynamic properties of fluids, properties variation with the thermodynamic state of the fluid.
1.2 Differential equation for fluid statics.
1.3 Differential equation of a fluid under constant acceleration and for Cartesian and cylindrical coordinates.

Specific objectives:
At the end of this content the student must be able to:
• Define the concept of fluid.
• Name the main mechanical properties of fluids.
• Explain the compressibility criteria and give some examples.
• Name the main thermodynamic properties of fluids.
• Perform numerical calculations based on the mechanical and thermodynamic properties of fluids
• Define surface, mass and linear force.
• Define normal and tangential effort.
• Define tension tensor and relate it to surface forces.
• Define surface tension.
• Perform calculations related to forms of contact interfaces between fluids.
• Define static equilibrium of a fluid
• Write the fundamental equation of fluid statics
• Calculate air density and pressure as a function of height for an isothermal atmosphere and for an adiabatic atmosphere.
• Define standard atmosphere and calculate the density and pressure of the air as a function of the height for it
• Calculate the force exerted by a fluid at rest on a flat surface and its point of application.
• Calculate the force exerted by a fluid at rest on a curved surface and its point of application.
• Calculate the force exerted by a laminated fluid on a flat surface and its point of application.
• Interpret the two laws of floating Archimedes
• Calculate the buoyancy in bodies totally or partially submerged in a fluid.

Related activities:
ACTIVITY 1
ACTIVITY 4

Full-or-part-time: 10h
Theory classes: 4h
Practical classes: 2h
Self study : 4h

Kinematics of fluids.

Description:
The basic concepts will be defined for the mathematical evaluation of a moving fluid, without viscosity and defined by a vector field. The complete kinematic analysis of the motion of a fluid particle will be performed.
2.1 Eulerian and Lagrangian description
2.2 Current lines, trajectories and trace lines
2.3 Substantial derivative
2.4 Circulation, flow and vorticity
2.5 Movement relative to the environment of a point

Specific objectives:
At the end of this content the student must be able to:
• Distinguish between Lagrangian and Eulerian descriptions of a physical variable.
• Define and give some examples of current line, trajectory and trace line.
• Define local, convective and substantial derivative.
• Perform calculations of derivatives of variables associated with a fluid.
• Define circulation, flow and vorticity.
• State Stokes' theorem.
• Decompose the velocity divergence tensor into a symmetrical part and an antisymmetric part and relate both to the deformation of a fluid element and to the rotation.

Related activities:
ACTIVITY 1
ACTIVITY 4

Full-or-part-time: 5h 30m
Theory classes: 2h
Practical classes: 1h
Self study : 2h 30m

Fundamental equations.

Description:
This is the basic topic of the course, here all the basic equations of fluid mechanics will be posed, both in integral and differential mode. Extensive application of the same will be done in both inertial and non-inertial reference systems.
3.1 Conservation equations
3.2 Reynolds Transport Theorem
3.3 Integral and differential formulation
3.4 Conservation of the dough
3.5 Conservation of the amount of movement
3.6 Navier-Stokes equations
3.7 Energy conservation
3.8 Conservation of the kinetic moment
3.9 Bernoulli equation. Flowmeters

Specific objectives:
At the end of this content the student must be able to:
• State the basic laws of conservation of mass, momentum and energy.
• Distinguish between integral and differential formulation and list the most important characteristics of both.
• Distinguish between control system and control volume.
• State and prove Reynolds' Transport theorem.
• State the integral form of conservation of the mass in general.
• Simplify the integral form of mass conservation for cases of stationary and / or incompressible flows.
• Define and calculate the average velocity of a flow through a surface.
• Derive the mass conservation differential equation
• Define current function and current lines
• Calculate and draw the current lines of a two-dimensional flow.
• Calculate the flow through a surface of a two-dimensional flow from the current lines.

• Define and interpret the integral form of the theorem of conservation of momentum.
• Solve problems related to the conservation of momentum, from an inertial reference system.
• Solve problems related to the conservation of momentum, from a non-inertial reference system
• Identify and interpret the amount of movement flow correction factor.
• Calculate the momentum flow correction factor for different types of flow in a pipe.
• Derive and interpret the differential form of conservation of momentum
• Write the tension tensor for Newtonian fluids and introduce it in the differential form of conservation of momentum
• Derive and interpret the Navier-Stokes equation
• Simplify the Navier-Stokes equation for cases of incompressible fluid and / or uniform viscosity
• Define and interpret the integral form of the kinetic moment conservation theorem
• Solve problems related to the conservation of kinetic momentum,
from an inertial reference system.
• Solve problems related to the conservation of kinetic momentum, from a non-inertial reference system
• Derive and interpret the integral form of energy conservation
• Derive the Bernoulli equation from the integral form of energy conservation
• Derive the differential law of conservation of energy
• Solve problems related to the energy conservation theorem
• Deduce the Bernoulli Equation from the Euler Equation
• Use the Bernoulli Equation for calculations with incompressible flows
• Define static, dynamic and total pressure
• Calculate the flow or velocity of a flow from measurements obtained in a Pitot Tube, a Prandtl Tube a Venturi Tube, or a diaphragm
• Calculate the discharge time of a tank through a hole

Related activities:
ACTIVITY 2
ACTIVITY 4

Full-or-part-time: 30h
Theory classes: 6h
Practical classes: 4h
Self study : 20h

Flow with dominant viscosity.

Description:
Under dominant viscosity it is understood that the movement of the fluid is directed by the viscous forces, the forces of inertia play an irrelevant role. This chapter will focus on the use of the equation of continuity and amount of motion in differential form.
4.1 Introduction to flow with dominant viscosity
4.2 Equations and boundary conditions
4.3 Flow between parallel flat plates
4.4 Continuity and Navier-Stokes equations in cylindrical coordinates
4.5 Hagen-Poiseuille flow
4.6 Flow between two concentric cylinders

Specific objectives:
At the end of this content the student must be able to:
- Define Dirichlet boundary condition and Neumann boundary condition.
- Calculate the speed profile and the derived dynamic quantities for the two-dimensional flow between two flat layers parallels.
- Use the continuity and Navier-Stokes equations in cylindrical coordinates to calculate the velocity profile and the associated dynamic magnitudes in two-dimensional axisymmetric flows.
- Calculate the relationship between flow and pressure difference for a laminar flow in a straight circular pipe.
- Calculate the relative moment between two concentric cylinders with different angular velocities, with a fluid determined in space
interior.

Related activities:
ACTIVITY 3
ACTIVITY 4

Full-or-part-time: 16h
Theory classes: 4h
Practical classes: 2h
Self study : 10h

Dimensional analysis / Theory of models.

Description:
This chapter presents the basics for optimally performing any experimental measurement in fluid mechanics. The key is the characterization of the physical phenomenon to be studied using dimensionless groups. The use of dimensionless groups to extrapolate results between models and prototypes, will be the second part of this chapter, where we will see what problems appear when performing this extrapolation.
5.1 Buckingham's theorem Π
5.2 Basic dimensionless numbers
5.3 Dimensionalization of equations
5.4 Similarity

Specific objectives:
At the end of this content the student must be able to:
• Explain the basics of Dimensional Analysis and give examples of its applications.
• Give the basic units of physical quantities used in Fluid Mechanics.
• State the Theorem | of Buckingham.
• Calculate the dimensionless groups involved in a given physical law.
• Identify important dimension groups in Fluid Mechanics.
• Dimensionize an equation.
• Calculate the scale of a model based on kinematic and dynamic similarity.
• Calculate the relationship of physical quantities between prototype and model.

Related activities:
ACTIVITY 5
ACTIVITY 8

Full-or-part-time: 6h
Theory classes: 3h
Self study : 3h

Boundary layer / External flow.

Description:
The explanation of why the fundamental equations in integral form are not applicable to a great majority of external flows, resides in the understanding of what happens in the regions of the fluid near the body, regions where the denominated limit layer appears. In this chapter we will study the equations that characterize the boundary layer in both the laminar and turbulent zone on flat plates.
6.1 Prandtl differential equation for the laminar boundary layer, Blasius solution. Von Karman's integral equation.
6.2 application of the Von Karman equation to the laminar and turbulent zones of the boundary layer. Obtaining the algebraic equations that characterize the different parameters of the boundary layer, both in the laminar and turbulent zone.
6.3 Dimensional groups characteristic of external flow.

Specific objectives:
At the end of this content the student must be able to:
• Define boundary layer, local Reynolds number, boundary layer thickness, displacement thickness, amount of movement thickness, wall surface stress coefficient, and drag coefficient.
• Explain how the Blasius equation arises from the Navier-Stokes equation.
• Calculate the thickness of a laminar boundary layer and the surface stress and drag coefficients.
• Derive the integral equation of momentum for a boundary layer.
• Calculate the thickness of a laminar boundary layer and the coefficients of surface stress and drag considering a certain speed profile.
• Calculate thickness and drag for a turbulent boundary layer.
• Define favorable and adverse pressure gradient.
• Define flow separation and explain the conditions for it to pass. Calculate the separation point for a laminar boundary layer with known adverse pressure gradient.
• Solve problems with aerodynamic forces on bodies

Related activities:
ACTIVITY 5
ACTIVITY 8

Full-or-part-time: 7h
Theory classes: 3h
Self study : 4h

Internal flow.

Description:
This topic is one of the classics in industrial engineering. Here the fluid will be treated as incompressible and therefore the equations to be used are especially simple. However, it is a subject of enormous practical application, since the transport of all types of fluid (incompressible) using ducts and pumping groups will be defined in this chapter.
7.1 Application of the energy equation to conduits, concept of linear and singular losses, Moody's diagram.
7.2 Various types of problems that may appear in the study of incompressible flow in ducts.
7.3 Series and parallel duct systems, concept of hydraulic diameter and equivalent length.

Specific objectives:
At the end of this content the student must be able to:
- Identify main and secondary losses
- Interpret the coefficient of friction
- Describe the Poiseuille and Darcy-Weisbach equation
- Calculate the coefficient of friction, main and secondary losses in ducts
- Manipulate the Moody chart
- Calculate the coefficient of friction, main and secondary losses in ducts

Related activities:
ACTIVITY 6
ACTIVITY 8

Full-or-part-time: 13h
Theory classes: 3h
Practical classes: 2h
Self study : 8h

Compressible flow.

Description:
If the fluid is a gas, and evolves through the interior of a conduit, it is very likely that the study of the fluid as incompressible does not obey reality. It will be necessary to treat the fluid as compressible.
8.1 Introduction to compressible flow. Thermodynamic review
8.2 The speed of sound
8.3 Adiabatic flow
8.4 Sonic values
8.5 Diffusers and injectors
8.6 Normal shock waves
8.7 Nozzles

Specific objectives:
At the end of this content the student must be able to:
• Define the concept of sound and deduce the expression for its speed.
• Define the stagnation values of the thermodynamic variables.
• Define the sonic or critical values of thermodynamic variables.
• Perform calculations of adiabatic flows in a duct.
• Calculate the dynamic and thermodynamic magnitudes of an isoentropic compressible flow at a point in a conduit known at any other point.
• Deduce Rankine-Hugoniot expression for flow through a shock wave.
• Perform calculations with adiabatic compressible flows through one-dimensional shock waves.

Related activities:
ACTIVITY 7
ACTIVITY 8

Full-or-part-time: 25h
Theory classes: 6h
Practical classes: 3h
Self study : 16h

ACTIVITIES

ACTIVITY 1

Description:
Students in groups of two or three people, will need to do at home several exercises in order to get a deeper understanding of the theory presented in class. The exercises in this first activity will be related with the first and second chapter of the subject.

Specific objectives:
The objective of the various works that will be carried out during the course is to establish knowledge of each of the topics. Students will also learn to look for information that will help them solve the proposed exercises and will also improve their skills for teamwork.

Material:
To do the homework, students shall use all existing information, books, articles, web pages etc.

Delivery:
The work will need to be presented in a given date and before the first examination date. The work will be presented in digital form and using ATENEA.

Full-or-part-time: 26h
Theory classes: 6h
Practical classes: 3h 30m
Self study: 16h 30m

ACTIVITY 2

Description:
Students in small groups will do at home several exercises to improve their understanding of each chapter of the subject.

Specific objectives:
The objective of the various works that will be carried out during the course is to establish knowledge of each of the topics. Students will also learn to look for information that will help them solve the proposed exercises and will also improve their skills for teamwork.

Material:
Students are allowed to use all information of any source to perform the work.

Delivery:
The work will need to be given until a fixed date, which will always be before the date of the first exam. Work shall be presented in digital format and using ATENEA.

Full-or-part-time: 26h 30m
Theory classes: 6h
Practical classes: 3h 30m
Self study: 17h

ACTIVITY 3 - FIRST EXAM

Description:
This is the first partial exam of the subject.

Specific objectives:
Evaluate the proper understanding of the concepts explained during this first part of the course.

Material:
Students shall bring a sheet with mathematical expressions used during this first part of the subject.

Delivery:
In paper format at the end of the exam or scanned and delivered in digital format to Atenea.

Full-or-part-time: 3h 30m
Theory classes: 3h 30m

ACTIVITY 4

Description:
Students in small groups will undertake exercises to improve their knowledge of the subject, to be done at home. This activity is linked with chapters five and six of the subject.

Specific objectives:
The objective of the various works that will be carried out during the course is to establish knowledge of each of the topics. Students will also learn to look for information that will help them solve the proposed exercises and will also improve their skills for teamwork.

Material:
Students are allowed to use all resources they might be having at hand.

Delivery:
Work will be given until a fixed date, and always before the final exam of the subject. The assignments will be given in digital form and using ATENEA.

Full-or-part-time: 26h 30m
Theory classes: 6h
Practical classes: 3h 30m
Self study: 17h

ACTIVITY 5

Description:
In small groups students will do proposed exercises at home, this activity is linked with exercises of chapter 7 of the subject.

Specific objectives:
The objective of the various works that will be carried out during the course is to establish knowledge of each of the topics. Students will also learn to look for information that will help them solve the proposed exercises and will also improve their skills for teamwork.

Material:
Students are allowed to use all kind of resources they might feel they need.

Delivery:
Work will be presented in digital form and using ATENEA. The assignments will need to be presented before a given date.

Full-or-part-time: 26h 30m
Theory classes: 6h
Practical classes: 3h 30m
Self study: 17h

ACTIVITY 6 - FINAL EXAM

Description:
This is the second and final exam of the subject.

Specific objectives:
This activity aims to evaluate the students gathered knowledge.

Material:
Just a sheet of paper with all the mathematical expressions used in the subject can be brought.

Delivery:
In paper format at the end of the exam or scanned and delivered in digital format to Atenea.

Full-or-part-time: 3h 30m
Theory classes: 3h 30m

GRADING SYSTEM

Students will do two assignments before the first partial exam, with a joint value of 15%, the first partial exam will have a value of 35%. After the first part and before the final exam, two more works will be carried out, which will again have a joint value of 15%. Finally the final exam will be worth the remaining 35%. Each of the two midterm exams consists of two problems.

The subject provides procedures to recover unsatisfactory results. Specifically in the second partial exam there will be an extra problem that can be done by those who have had a grade lower than 5 in the first partial. The mark of this problem will replace the lower of the two marks of the problems of the first part, without ever being able to diminish the qualification of the first part. With regard to the four works carried out during the course, it will be allowed to do the recovery of all the works with lower or equal qualifications to 6.

EXAMINATION RULES.

The four works, two in the first part and two in the second part, that the students have to carry out outside the class schedule, will be done with computer and delivered via ATENEA. The teacher will be able to ask questions related to the work done.

The two exams will last about two and a half hours, where you will basically be asked to solve problems, although you can also ask some theoretical questions of concept.

BIBLIOGRAPHY

Basic:

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- Mitchell, John W; Fox, Robert W; McDonald, A.T. Introduction to fluid mechanics. 10th edition. Hoboken, N.J: Wiley, [2020]. ISBN 9781119665953.

Complementary:

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- Liñán, A. [et al.]. Mecánica de fluidos, vol. 1. Madrid: UPM. Escuela de Ingeniería Aeronáutica y del Espacio, 2005.
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- Lopez-Herrera, J. M. [et al.]. Mecánica de fluidos: problemas resueltos. Madrid: McGraw-Hill, 2005. ISBN 8448198891.
- Spurk, J. H. Fluid mechanics. Berlin: Springer, 1997. ISBN 3540616519.
- Spurk, J. H. Fluid mechanics: problems and solutions. Berlin: Springer, 1997. ISBN 3540616527.

RESOURCES

Hyperlink:

- Informació deixada a ATENEA. Power point notes of the subject and collections of solved problems.
- www.efluids.com. Web page related to fluid mechanics.
- www.cfd-online.com. Web page with information related with computational fluid mechanics.

Other resources:

Information left in ATENEA and information to be found in web pages related to fluid mechanics.