Course guide
300516 - MO - Orbital Mechanics

Last modified: 14/01/2026

Unit in charge: Castelldefels School of Telecommunications and Aerospace Engineering
Teaching unit: 748 - FIS - Department of Physics.

Degree: BACHELOR'S DEGREE IN SATELLITE ENGINEERING (Syllabus 2024). (Compulsory subject).

Academic year: 2025 **ECTS Credits:** 5.0 **Languages:** Catalan, Spanish, English

LECTURER

Coordinating lecturer: Definit a la infoweb de l'assignatura.

Others: Definit a la infoweb de l'assignatura.

PRIOR SKILLS

• Solid operational knowledge of the fundamentals of vector and matrix calculus, as well as differential and integral calculus, applied to physical problems in multiple dimensions.
• Familiarity with the use of coordinate systems, reference frame transformations, and vector representation of physical quantities.
• Understanding of the fundamental concepts of force, work, energy, gravitational field and potential, as well as the principles of conservation of energy, linear momentum, and angular momentum, applied to mechanical systems.
• Basic knowledge of particle dynamics and motion under central forces.
• Ability to follow mathematical and physical reasoning of intermediate complexity and to interpret analytical expressions, as well as to obtain solutions using numerical methods.
• Familiarity with the use of MATLAB and Python software.
• It is recommended to have passed Classical Mechanics and Advanced Mathematics.
• It is recommended to have passed or to be concurrently enrolled in Numerical Methods.

REQUIREMENTS

None

TEACHING METHODOLOGY

The course will be delivered through a combination of expository lectures (theoretical and problem-solving sessions) and practical sessions. In the theoretical lectures, the instructor will introduce the concepts and laws required to subsequently apply them to the solution of problems corresponding to each topic. Active student participation during classes will be encouraged.
Examples will be selected according to pedagogical criteria (to clarify the introduced concepts) and thematic relevance (ensuring they are related to the degree program), with the aim of promoting student motivation and engagement. Likewise, the use of specialized software will be encouraged to solve and apply the theoretical content.
The use of multimedia resources will form the basis of expression in both theoretical and practical classes, allowing the proposed examples to be presented in a visual and more intuitive manner.
Practical sessions will be oriented toward fostering an active role for students, enabling them to develop and apply, individually and/or in small groups, the content addressed in theoretical and problem-solving classes. Most practical sessions will be computational in nature, since solving real-world problems in orbital mechanics necessarily involves the use of numerical techniques.
During practical sessions, discussion, analysis, and public presentation of results will also be encouraged, as an essential part of the communication process in scientific and technical fields.

LEARNING OBJECTIVES OF THE SUBJECT

• To formulate and apply the fundamental principles of orbital mechanics to describe and analyze the motion of artificial satellites and celestial bodies under the action of the gravitational field, primarily within the framework of Newtonian mechanics.
• To understand and use the basic concepts of the two-body problem, Kepler's laws, and the main orbital parameters, as well as the classification of orbits and the relationship between state vectors and orbital elements.
• To formulate and solve orbital propagation problems using analytical formulations and elementary numerical methods, including the solution of Kepler's equation and the determination of time of flight.
• To analyze the effect of the main orbital perturbations (Earth's non-sphericity, atmospheric drag, third-body perturbations) and to evaluate their impact on the temporal evolution of orbits.
• To define and apply the concept of orbital manoeuvre, identify and compute transfer orbits and coplanar and non-coplanar orbital changes, and analyze basic orbital transfer strategies.
• To formulate and solve Lambert's problem, understand its classical and modern solutions, and interpret pork-chop plots for trajectory planning.
• To understand and apply the patched conics approximation for the analysis of lunar and interplanetary trajectories, including the definition and use of the sphere of influence.
• To introduce the fundamentals of the restricted three-body problem, identify and analyze Lagrange points and the Jacobi constant, and understand their role in trajectory design.
• To analyze and understand the principle of gravity assists and their application in interplanetary missions.
• To develop the ability to interpret and analyze real space mission trajectories, using simplified orbital models and engineering criteria.

STUDY LOAD

Type	Hours	Percentage
Hours small group	8,0	6.40
Hours large group	47,0	37.60
Self study	70,0	56.00

Total learning time: 125 h

CONTENTS

Introduction. General Framework

Description:
• Newtonian space-time vs. relativistic framework. Analytical mechanics.
• Central-force mechanics refresher: Kepler's and Newton's laws.
• Inertial vs. non-inertial reference frames.

Specific objectives:
• To understand the physical and mathematical framework of orbital mechanics.
• To identify the basic assumptions and limitations of the Newtonian formulation.
• To recognize the role of Kepler's and Newton's laws as the foundation of orbital motion.
• To distinguish between inertial and non-inertial reference frames in orbital contexts.

Related activities:
• Practical session 1
• Midterm exam
• Final exam

Full-or-part-time: 2h
Theory classes: 1h
Self study : 1h

The Two-Body Problem

Description:
• Simplifying assumptions.
• Equation of motion.
• Constants of motion.
• Kepler's equation.
• Conic orbits: circular, elliptical, parabolic, and hyperbolic.
• Orbit determination. Classical orbital elements and Two-Line Elements.
• Orbital position as a function of time.

Specific objectives:
• To formulate and solve the two-body problem under ideal assumptions.
• To identify and use constants of motion in central-force fields.
• To analyze and classify conic orbits based on their parameters.
• To solve Kepler's equation and determine orbital position as a function of time.
• To relate state vectors to classical orbital elements and TLEs.

Related activities:
• Practical session 1
• Midterm exam
• Final exam

Full-or-part-time: 27h
Theory classes: 10h
Laboratory classes: 2h
Self study : 15h

Orbital Perturbations

Description:
• Earth's non-sphericity. Third-body perturbations. Atmospheric drag. Solar radiation pressure. Magnetic interactions. Space debris.
• Gauss variational equations and numerical estimation methods.

Specific objectives:
• To identify the main sources of orbital perturbations in real missions.
• To analyze the effect of perturbations on the temporal evolution of orbits.
• To apply Gauss's variational equations to estimate orbital changes.
• To introduce numerical methods for the analysis of perturbed orbital dynamics.

Related activities:
• Practical session 2
• Midterm exam
• Final exam

Full-or-part-time: 18h
Theory classes: 7h
Laboratory classes: 1h
Self study : 10h

Orbital Manoeuvres

Description:
• Coplanar changes. Hohmann transfer. Bi-elliptic transfer.
• Orbital plane changes.
• Orbital rendezvous.
• Formation flying and constellation design.

Specific objectives:
• To understand the concept of orbital manoeuvre and its impact on the orbit.
• To analyze and compute coplanar and non-coplanar transfers.
• To apply the basic principles of orbital rendezvous.
• To introduce the fundamentals of formation flying and constellation design.

Related activities:
• Practical session 2
• Midterm exam
• Final exam

Full-or-part-time: 15h
Theory classes: 5h
Laboratory classes: 1h
Self study : 9h

Lambert's Problem

Description:
• Problem statement.
• Classical solutions.
• Modern solutions.
• Pork-chop plots.

Specific objectives:
• To formulate Lambert's problem as a boundary-value orbital problem.
• To understand classical and modern solutions to the problem.
• To analyze trajectories as a function of time of flight and required energy.
• To interpret pork-chop plots for mission planning

Related activities:
• Practical session 3
• Final exam

Full-or-part-time: 23h
Theory classes: 8h
Laboratory classes: 2h
Self study : 13h

Interplanetary Trajectories

Description:
- Patched conics approximation.
- Sphere of influence (SOI).
- Lunar transfer trajectories.
- Interplanetary transfers.

Specific objectives:
- To understand the patched conics approximation for interplanetary trajectories.
- To define and use the concept of sphere of influence.
- To analyze lunar and interplanetary transfer trajectories.
- To integrate orbital concepts into preliminary space mission design.

Related activities:
- Practical session 4
- Final exam

Full-or-part-time: 20h
Theory classes: 8h
Laboratory classes: 1h
Self study : 11h

The Three-Body Problem

Description:
- Circular restricted three-body problem.
- Lagrange points.
- Gravity assists in 2D and 3D.
- Jacobi constant.
- N-body problem.

Specific objectives:
- To introduce the circular restricted three-body problem.
- To identify and analyze Lagrange points and their dynamical properties.
- To understand the physical meaning of the Jacobi constant.
- To analyze the principle of gravity assists in 2D and 3D.
- To recognize the limitations of the two-body problem and the need for N-body models.

Related activities:
- Practical session 4
- Final exam

Full-or-part-time: 20h
Theory classes: 8h
Laboratory classes: 1h
Self study : 11h

ACTIVITIES

Practice 1

Description:
Computational analysis and representation of orbital motion, focusing on the relationship between state vectors and classical orbital elements for Keplerian (conic) orbits. Numerical propagation of orbits and visualization of their main characteristics.

Specific objectives:
- To compute and relate state vectors and orbital elements for conic orbits.
- To propagate orbits in time using Keplerian models.
- To visualize orbital trajectories and analyze their main parameters.
- To apply numerical methods to the solution of Kepler's equation and basic orbital analysis.

Material:
Personal computer and appropriate scientific computing tools (e.g. Python- or MATLAB-based environments and/or specialized orbital analysis software).

Delivery:
Individual or group submission of computational results, figures, and a brief technical report and/or oral exposition according to the instructor's guidelines.

Full-or-part-time: 2h
Laboratory classes: 2h

Practice 2

Description:
Computational analysis of orbital perturbations and orbital manoeuvres, focusing on the numerical estimation of perturbative effects on satellite orbits and the evaluation of â□□V requirements for basic manoeuvres.

Specific objectives:
- To compute and analyze the effects of orbital perturbations on satellite motion using numerical methods.
- To analyze historical TLE data from real satellites to estimate rates of change of classical orbital elements.
- To assess orbital decay and re-entry scenarios using simplified models and available tools.
- To compute the â□□V requirements associated with basic orbital manoeuvres and transfers.
- To relate perturbative effects and manoeuvre strategies to real satellite mission constraints.

Material:
Personal computer and appropriate scientific computing tools (e.g. Python- or MATLAB-based environments and/or specialized orbital analysis software and databases).

Delivery:
Individual or group submission of computational results, figures, and a brief technical report and/or oral exposition, according to the instructor's guidelines.

Full-or-part-time: 2h
Laboratory classes: 2h

Practice 3

Description:
Computational analysis of Lambert’s problem for orbital transfer design. Numerical solution of boundary-value orbital problems connecting two position vectors within a prescribed time of flight, and evaluation of transfer feasibility and energy requirements.

Specific objectives:
- To formulate Lambert’s problem from given initial and final position vectors and a specified time of flight.
- To compute orbital transfer solutions using classical and modern Lambert solvers.
- To analyze transfer trajectories in terms of â□□V requirements, geometry, and time of flight.
- To generate and interpret pork-chop plots for preliminary mission and transfer window analysis.
- To assess the suitability of different transfer options for mission planning purposes.

Material:
Personal computer and appropriate scientific computing tools (e.g. Python- or MATLAB-based environments and/or specialized orbital analysis software).

Delivery:
Individual or group submission of computational results, figures, and a brief technical report, according to the instructor’s guidelines.

Full-or-part-time: 2h
Laboratory classes: 2h

Practice 4

Description:
Computational analysis of space mission navigation data using basic SPICE routines. Retrieval, processing, and interpretation of ephemeris and trajectory information for historical space missions, with emphasis on understanding real spacecraft motion from flight data.

Specific objectives:
- To retrieve spacecraft and planetary ephemerides using basic SPICE routines.
- To obtain and process navigation and trajectory data for historical missions (e.g. Voyager, Cassini, New Horizons).
- To represent and analyze spacecraft trajectories in different reference frames.
- To interpret real mission data in the context of orbital and interplanetary dynamics.
- To become familiar with professional navigation tools used in space mission analysis.

Material:
Personal computer and appropriate scientific computing tools (e.g. MATLAB-based environments), access to SPICE kernels, and basic SPICE libraries for trajectory and ephemeris handling.

Delivery:
Individual or group submission of computational results, figures, and a brief technical report, according to the instructor’s guidelines.

Full-or-part-time: 2h
Laboratory classes: 2h

Mid-term exam

Description:
During the midterm examination week, an individual exam will be conducted, covering theoretical concepts and problem-solving related to the content addressed up to that point.

Specific objectives:
To assess the knowledge acquired on the covered topics by both instructors and students. To develop the ability to communicate clearly and effectively in written form, justifying problem solutions and answering theoretical and practical questions.

Material:
Printed exam statement, calculator, and formula sheet.

Delivery:
The completed exam will be submitted individually for evaluation.

Full-or-part-time: 1h 30m
Guided activities: 1h 30m

End-of-term exam

Description:
During the end-of-term examination week, an individual exam will be conducted, covering theoretical concepts and problem-solving related to all the content addressed in the course.

Specific objectives:
To assess the knowledge acquired on the covered topics by both instructors and students. To develop the ability to communicate clearly and effectively in written form, justifying problem solutions and answering theoretical and practical questions.

Material:
Printed exam statement, calculator, and formula sheet.

Delivery:
The completed exam will be submitted individually for evaluation.

Full-or-part-time: 1h 30m
Guided activities: 1h 30m

GRADING SYSTEM

The final grade will be calculated based on:
Two partial exams (midterm and end-of-term): 50%
Practical work and deliverables (problem sets and codes): 40%
Project: 10%

EXAMINATION RULES.

All proposed assessment activities are mandatory. Any exam, practical session, assignment, or project not submitted will be graded with a score of zero. Examinations will be conducted on an individual basis. Assignments, practical work, and the project may be completed in groups, in accordance with the instructor’s guidelines.

BIBLIOGRAPHY

Basic:

- Curtis, Howard D. Orbital mechanics for engineering students . Fourth edition. ISBN 978-0128240250.
- Bate, Roger R; Mueller, Donald D; White, Jerry E. Fundamentals of astrodynamics . New York : Dover, cop. 1971. ISBN 0486600610.
- Vallado, David A; McClain, Wayne D. Fundamentals of astrodynamics and applications . 4a ed. Hawthorne : Microcosm Press, cop. 2013. ISBN 978- 1881883180.

Complementary:

- Roy, A. E. Orbital motion . 4th ed. Bristol [etc.] : Institute of Physics, 2005. ISBN 978-0750310154.