Advanced Spacecraft Dynamics

Academic year 22/23

Instructor Prof. Mauro Pontani

COURSE PROGRAM

- **Chapter 1. Eulerian attitude dynamics**
  - Vectors, vectrices, dyads, and vector kinematics
  - Overview on attitude kinematics
  - Spacecraft modeled as a rigid body
  - Alternate forms of the dynamics equations
  - Spacecraft with a single wheel
  - Dual-spin spacecraft
  - Spacecraft with damper
  - Spacecraft with wheel and damper
  - Spacecraft with multiple wheels
  - Spacecraft with single-gimbal gyroscope

- **Chapter 2. Attitude dynamics of multibody spacecraft (Kane's method)**
  - Constraints
  - Multibody tree structures
  - Two bodies and a joint: velocities and partial velocities
  - Generalized forces
  - Kane's dynamical equations
  - Two bodies and a joint: accelerations and dynamics equations
  - Kane's equations for multibody spacecraft with tree structure
  - Methodology for simulations
  - Application: dynamics of a spacecraft with two appendages

- **Chapter 3. Nonlinear attitude control using momentum exchange devices**
  - Introduction
  - An overview on momentum exchange devices
  - Common architectures for momentum devices arrays
  - Steering laws for spacecraft equipped with SG-CMGs
  - Steering law for spacecraft equipped with RWs
  - Attitude tracking via nonlinear feedback
  - Application: attitude tracking for a geostationary satellite
  - Attitude pointing via nonlinear feedback
  - Application: pointing maneuver

❖ **Chapter 4. Nonlinear orbit control using continuous thrust**

- Introduction
- Orbit dynamics
- Variable-thrust nonlinear orbit control
- Nonlinear control on semimajor axis, eccentricity, and inclination
- Application: nonlinear orbit control in medium Earth orbit
- Application: nonlinear orbit control in low Earth orbit

❖ **Chapter 5. Finite-thrust orbit transfers**

- Types of finite-thrust engines
- Equations of motion
- Minimum-time orbit transfers using CSI-low-thrust
- Minimum-fuel orbit transfers using CSI-finite-thrust
- Minimum-fuel orbit transfers using VSI-low-thrust
- Spacecraft attitude along orbit transfers
- Concluding remarks

❖ **Chapter 6. Planetary entry**

- Introduction
- Reference frames for trajectory and attitude
- General flight equations
- Entry heating
- Ballistic entry
- Gliding entry
- Overview of the Shuttle reentry trajectory (transatmospheric phase)
- Concluding remarks

❖ **Chapter 7. An introduction to satellite constellations**

- Introduction
- Repeating-ground-track orbits
- Multisynchronous constellations
- Concluding remarks

❖ **Appendix A. Elements of stability theory**

- Stability definitions
- Lyapunov's method
- LaSalle's invariance principle

- **Appendix B. Lagrange planetary equations**
  - Equations for orbit elements
  - Modified equinoctial elements
  - Gauss equations for modified equinoctial elements

- **Appendix C. Fundamentals of optimal control theory**
  - Formulation of the problem
  - Optimality conditions

DIDACTIC MATERIAL

The topics of the course are addressed in the textbook

M. Pontani, *Advanced Spacecraft Dynamics*, Efesto, Rome, 2023

FINAL EXAM INFO (UNTIL A.Y. 22/23)

During the lectures, several homeworks are proposed. They must be returned by the due date in order to be evaluated. Homeworks are *not* mandatory.

The final exam consists of an oral session, articulated in three questions.

(1) a topic chosen by the student among those treated in the course or any research topic related to the course contents and developed with the Instructor's approval;
(2) a topic chosen by the Instructor;
(3) a topic chosen by the Instructor *or* comments and clarifications on the homeworks, if the student chose to solve and send the homeworks for their evaluation.

FINAL EXAM INFO (STARTING FROM A.Y. 23/24)

During the lectures, several homeworks are proposed. They must be returned by the due date in order to be evaluated. Homeworks are *not* mandatory.

The final exam consists of an oral session, articulated in three questions. Depending on the number of homeworks returned by the due date, 3 different modalities are defined:

(1) The student returned ***less than half of the homeworks***

a. No homework is evaluated.

b. The exam is composed of 3 questions, chosen by the Instructor.

(2) The student returned ***more than half of the homeworks, but not all the homeworks***

a. Homeworks are evaluated.

b. The exam is composed of 3 questions:

- question 1 chosen by the Instructor,
- question 2 chosen by the Instructor,
- question 3 focused on homeworks (comments and/or clarifications).

(3) The student returned ***all the homeworks***

a. Homeworks are evaluated.

b. The exam is composed of 3 questions:

- question 1 chosen by the student among the topics treated in the course,
- question 2 chosen by the Instructor,
- question 3 focused on homeworks (comments and/or clarifications).