Introduction to Astrodynamics

Caltech, Winter Term, 2019

Class Schedule:	[TBD]
Instructor:	Dr. Stefano Campagnola, JPL, *scampagn@caltech.edu*
	Office hours by appointment, before class. Email anytime, *Piazza* anytime.
Webpage:	Moodle: [TBD]
	Piazza: [TBD]
Prerequisite:	None formally. However, the scope and pace will assume students know about dynamical systems, ODE, and programming.
Programming:	MATLAB. Need SPICE/MICE toolbox and kernels (instructions provided in the early classes).

Course overview

This course covers several topics in astrodynamics, i.e. the mathematical modeling and optimization of spacecraft trajectories. This class focus in particular on interplanetary trajectories for space exploration. Astrodynamics is an exciting field for students from multiple disciplines, from those interested in applied mathematics and computer science, to those interested in space sciences and engineering.

We review basic orbital mechanics and several topics in applied mathematics relevant to astrodynamics, such as dynamical systems, numerical methods, Hamiltonian mechanics, optimal control theory, etc. Then we discuss advance astrodynamics topics to bring the students to pace with the state of the art in interplanetary trajectory design and optimization.

Programming is an important part of the course, since the most interesting problems can only be solved numerically. For this reason, students are expected to have some programming experience, and will be asked to program in MATLAB. By the end of the course, students will have developed their own astrodynamics toolbox.

The course promotes the "*Caltech-JPL connection*", and wants to be a catalyst for new collaborations in the astrodynamics field between JPL navigators and mission designers, and Caltech students and faculty.

Course topics

- Intro to astrodynamics and space exploration; astrodynamics times and frames
  - Example missions and trajectories
  - TAI, TDB, UTC, ET, JD // EME, EMO, IAU // SPICE kernels and MICE
- Background
  - Dynamical system, flow map, linearized system and STM, Lagrangian and Hamiltonian mechanics, symplectic maps, constants and integrals of motion
  - Numerical integration schemes, Newton's method, IVP and shooting methods
  - Optimization: with equality and inequality constraint, line search and thrust region methods, QP and NLP, global and multi-objective optimization
- Orbital Mechanics
  - 2-body problem: orbital elements, Kepler's problem (IVP), Equinoctial elements
  - Lambert problem (BVP), rocket equation and orbital maneuvering
  - Perturbations (drag, low-thrust), patched conics
- Interplanetary trajectories
  - Launch, launch window/periods, Orbit insertion and landing, porkchop plot
  - Gravity assist vs flybys, Vinfinity sphere
  - Resonant, non-resonant, and Vinfinity-leveraging transfer; Tisserand graph
  - Moon tour trajectory design
- Space trajectory optimization I, Indirect methods
  - Review of optimal control theory with variational approach: necessary conditions, costate equations
  - Limitation of variational approach; the geometric approach: Pontryagin Maximum Principle, proof and discussion
  - Application to space trajectory optimization: primer vector theory
- Space trajectory optimization II, Direct methods
  - Shooting-based, collocation, pseudo-spectral

About the instructor

Stefano Campagnola is an astrodynamics researcher and mission designer at JPL, Outer Planet Mission Analysis Group, currently working at the Europa Clipper and Lander projects. I am also Principal Investigator for the Orbit Control Experiment for EQUULEUS, the Japanese lunar CubeSat to be launched by SLS' Exploration Mission 1 in 2018. Stefano Campagnola has more than 10-year experience in the field at JPL, the European Space Agency, and the Japanese Space Agency. He received his MS from Politecnico di Milano in 2002, and his PhD from University of Southern California in 2010.