SYLLABUS (revised Jan1, 2018)

CDS 270-1 Introduction to Astrodynamics

Caltech, Winter Term, 2018

Class Schedule:	T-Th 9:00-10:30, 213 ANB
Instructor:	Dr. Stefano Campagnola, JPL, *scampagn@caltech.edu*
	(Guest lecturers from JPL: TBD; TA: TBD)
	Office hours by appointment, before class. Email anytime, *Piazza* anytime.
Webpage:	Moodle: https://courses.caltech.edu/course/view.php?id=2859
	Piazza: https://piazza.com/caltech/winter2018/cds2701/home
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 a*pplied 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

Below is the current list of the course topics. This is a first offering so the list of topics will change! (we might not be able to cover all of them)

- 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, Poisson brackets, constants and integrals of motion
  - Numerical integration schemes, Newton's method, IVP and shooting methods
- Orbital Mechanics I
  - 2-body problem: orbital elements, Kepler's problem (IVP)
  - Lambert problem (BVP), rocket equation and orbital maneuvering
  - Perturbations (drag, solar radiation pressure, low-thrust, n-body problem, spherical harmonics), patched conics
- Orbital mechanics II
  - Equinoctial elements, Universal functions
  - Lagrange coefficients, 2BP State Transition Matrix
  - Variation of parameters, Gauss equations
- 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 (JPL GUEST LECTURE)
- 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, Optimal control primitives
- Space trajectory optimization II, Direct methods
  - Shooting-based, collocation, pseudo-spectral
- Space trajectory optimization III
  - Differential Dynamic Programming and SDDP

- Approximate feedback solution, global and multi-objective optimization
  - (Q-Law JPL GUEST LECTURE)
- Restricted three-body problem
  - Equation of motion, Lagrange points, Poincare' sections, Tisserand-Poincare'
  - Period orbits, stability, invariant manifolds, interplanetary highways

HW policy and grading

HW are due every second Tuesday at 17:00, and should be uploaded on Moodle unless specified otherwise. This course is Pass/Fail.

I encourage the student to work in group, also through the Piazza platform. Eventually, however, I expect each student to code her/his own tools and submit her/his own solutions.

Suggested Textbook

- Battin, R. H., An Introduction to the Mathematics and Methods of Astrodynamics , AIAA, New York, 1987
- Vallado, Fundamentals of Astrodynamics and Applications , McGraw-Hill, 1997.
- Szebehely, V., Theory of Orbits. The Restricted Problem of Three Bodies , Academic Press, New York, 1967.
- (*) Bate, Mueller, White, Fundamentals of Astrodynamics , Dover 1973
- (*) Marsden, J.E., Ratiu T., Introduction to Mechanics and Symmetry, Springer
- (*) Koon, W.S., Lo, M. W., Marsden, J.E., Ross, S.D. Dynamical Systems, the Three-Body Problem and Space Mission Design
- Betts, J. T., Practical Methods for Optimal Control and Estimation Using Nonlinear Programming
- Liberzon, D., Calculus of Variations and Optimal Control Theory
- Bryson, Y.C, Ho, A.E. Applied optimal control : optimization, estimation, and control
- Labunsky, A.V, Papkov, O.V., Sukhanov, K.G. Multiple Gravity Assist Interplanetary Trajectories - CRC Press Book.

NOTE: No formal textbook is required. The references in red, are the ones I used the most for this class. The reference with (*) are inexpensive or free online.

Course notes

Some material will be distributed via the Moodle website. My lecture notes will only include main points and formula. Some extracts from reference above may be added to Moodle too.