Solar System Navigation (ASTE589)
Fall Semester 2016

Recommended Preparation: ASTE580 or equivalent course in Orbital Mechanics

3 Lecturers (in order of presentation): Dr. Hintz, Dr. Goodson, Dr. Anderson
POC: Gerald R. Hintz (ghintz@usc.edu)

The Interplanetary Superhighway

Topics

Segment 1 – Back to the Moon, 3-Body Problem, and Lagrange Points:

- Free-Return Lunar Trajectory Analyses ("Houston, we have a problem.")
- Circular Restricted 3-Body Problem
- Lagrange Points
- Mission Applications of the Past, Present and Future

Segment 2 – Optimization and Control of Interplanetary Trajectories:

- Targeting Encounter/Flyby Conditions
- Optimization Concepts
- Trajectory Optimization Methods

Segment 3 – Mission Design Using the Interplanetary Superhighway:

- Dynamical Systems Theory for Mission Design: Introduction and Survey
- Additional Three-Body Models and the Ephemeris Model
- Libration Orbit Design and Continuation
- Stability and Invariant Manifolds
- Interplanetary Superhighway and Beyond

SOLAR SYSTEM NAVIGATION
ASTE589

Instructors

Dr. Gerald R. Hintz, POC, ghintz@usc.edu
Dr. Troy Goodson
Dr. Rodney Anderson

Course Scope and Objectives

Three research and professional engineers will teach a series of advanced topics in Orbital Mechanics (Dr. Hintz weeks 1-4, Dr. Goodson weeks 5-8, Dr. Anderson weeks 9-14). Topics include: free-return lunar trajectory analysis, Circular Restricted 3-Body Problem, Lagrange points and mission applications, spacecraft targeting encounter and flyby conditions, optimization concepts for trajectories, trajectory optimization methods, dynamical systems theory for mission design, additional 3-body models and the ephemeris model, libration orbit design and continuation, stability and invariant manifolds, and the Interplanetary Superhighway and beyond. The course will cover standard techniques beyond the undergraduate level and advanced topics.

Course Requirements

- The course assumes student familiarity with the concepts covered in Orbital Mechanics I (ASTE580) or an equivalent course in Orbital Mechanics, use of MATLAB for programming, and basic undergraduate engineering techniques.
- Textbooks:
  1. Gerald R. Hintz, *Orbital Mechanics and Astrodynamics: Techniques and Tools for Space Missions,* Springer, New York, 2015.
  2*. J. S. Parker and R. L. Anderson, *Low-Energy Lunar Trajectory Design,* Volume 12 of JPL Deep Space Communications and Navigation Series, John Wiley and Sons, Inc., Hoboken, New Jersey, 2014.
  3*. K. E. Davis and R. L. Anderson, "Libration Point Orbiters and the Three-Body Problem," *Encyclopedia of Aerospace Engineering*, Volume 5, John Wiley & Sons Ltd, 2010.
  * Free electronic copies of textbooks 2 and 3 will be provided online to the students of ASTE589.

Grading

- Each lecturer will assign homework exercises during the appropriate segment. These exercises will expand on the concepts covered in the classroom and provide practice tools for the students.
- Midterm 1 will be a take-home assignment on the material in Segment 1 due 9/21/16. Midterm 2 will be a take-home assignment on Segment 2 due 10/9/16. The final will be a take-home assignment on Segment 3 due 12/7/16 during Finals Week.
- There will be no in-class examinations.

Class Sessions: An Outline

Segment 1

- Weeks 1-2: Free-Return Lunar Trajectory Analyses: Parametric plots and application to the Apollo 13 mission ("Houston, we have a problem.")
- Weeks 3-4: Circular Restricted 3-Body Problem, Lagrange points, space mission applications – past, present and future.

Segment 2

- Week 5: Targeting Encounter and Flyby Conditions, including orbital-element targeting, singularities, Russian visual-plane targeting, and Monte-Carlo mission simulation.
- Week 6: Optimization Concepts for Trajectories, including cost functions, local versus global optimization, direct versus indirect, low-thrust versus impulsive, scaling the problem, linearization.
- Week 7: Trajectory Optimization - Lagrange multipliers, first variation, two-point boundary value problems, Lawden's primer vector, Multiple-point shooting versus simple shooting.
- Week 8: Trajectory Optimization – Direct Methods, including collocation, direct transcription, nonlinear programming, and the relationship between direct and indirect methods

Segment 3

- Weeks 9-10: Dynamical Systems Theory for mission design, chaotic dynamics and the Interplanetary Superhighway including the 3-Body Problem, periodic orbits, libration orbit design around collinear Lagrange points, and halo orbits

- Weeks 11-12: Periodic orbit families, orbital stability, variational equations, and invariant manifolds
- Week 13: Transfers via invariant manifolds, including replacing Lambert's Theorem with invariant manifolds, computing invariant manifolds, and using invariant manifolds to design transfers, heteroclinic and homoclinic connections
- Week 14: Interplanetary Superhighway and Beyond, including exploration in the Earth's neighborhood and the Petit Grand Tour of Jupiter's Icy Moons, invariant manifolds in flybys or resonant transfers, delta-V design, and topological obstructions to transfers