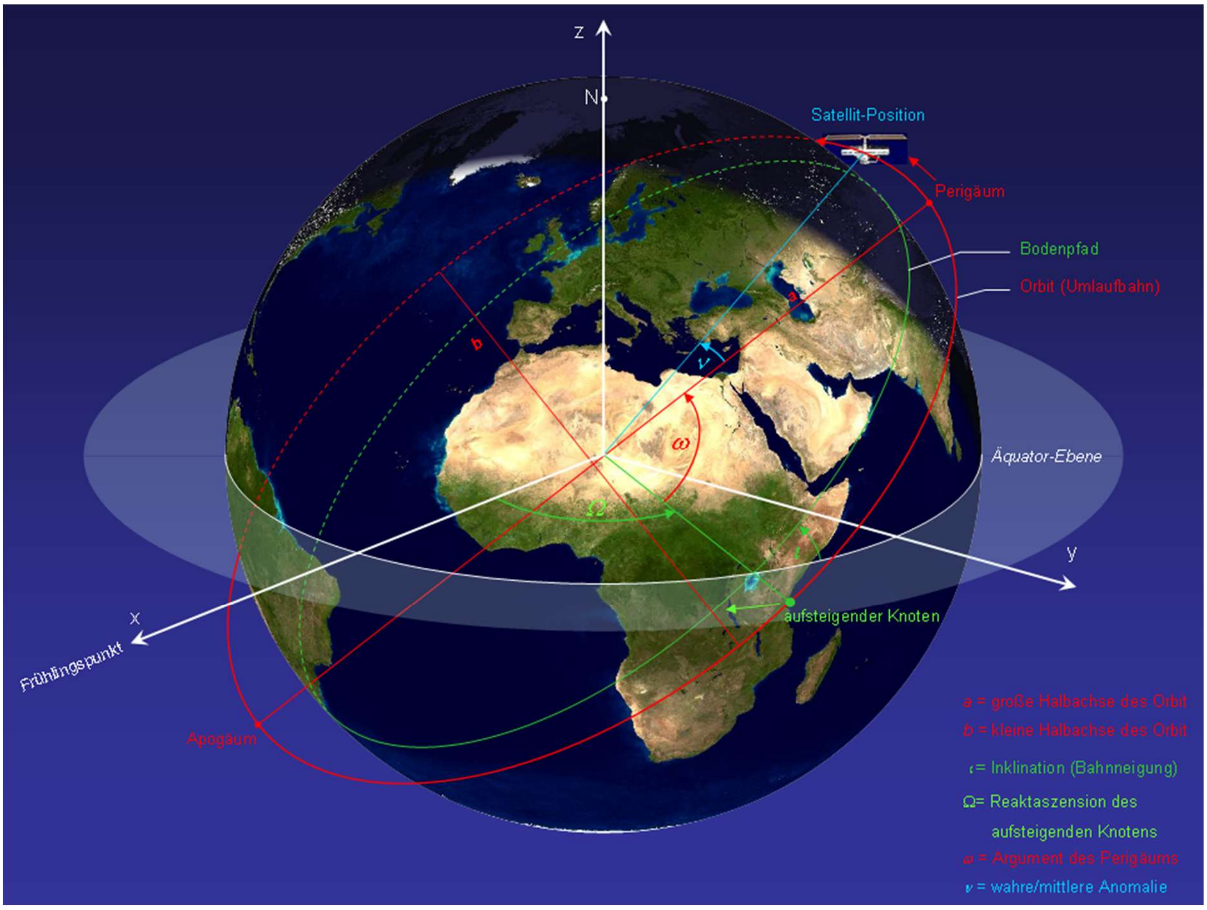
Understanding Orbits and Spaceflight: An Introduction to Astromechanics

Riley M. Fitzgerald, Virginia Tech

Wahlpflichtmodul – Seminar 2



This elective online class is designed to provide an introduction to the main concepts, intuition, and mathematics governing orbital mechanics and spaceflight, both in Earth orbit and beyond. It is intended as an introductory course for those with no background in astromechanics, and aims to provide a working knowledge base for future discussion and learning about astronautics.

The course will consist of weekly asynchronous online lectures, followed by synchronous discussion and example sessions to practice working with the material.

Prerequisites. Students are expected to have completed courses in introductory physics and/or dynamics. The class will be taught in English and students are expected to have good knowledge of the English language to be able to participate successfully.

The class will be recognized as "Seminar 2" (2 ECTS) for Bachelor students in aerospace engineering. Students need to register for the class in advance and must have completed the prerequisites for "Seminar 2" (all courses for Year 1 of aeronautical engineering including *Vorpraxis* must be successfully completed). Students can also not take the class for credit. All students will receive a certificate for successful participation.

Course Outline and Structure

The course will be organized by week, and will cover the topics outlined below.

Week	Starting Date	Topic
Week 1	October 13th	Introduction and the Two-Body Problem
Week 2	October 20th	Constants of Motion and Kepler's First Law
Week 3	October 27th	Keplerian Orbits and Time of Flight
Week 4	November 3rd	Coordinates and Orbital Elements
Week 5	November 10th	Rockets and Basic Orbital Maneuvers
Week 6	November 17th	General Orbital Maneuvers and Phasing
Week 7	November 24th	Patched Conics and Spheres of Influence
Week 8	December 1st	Interplanetary Transfers and Gravity Assists

Each week will be structured as follows: Two lecture videos (roughly 50 minutes each) will be posted at the beginning of the week for asynchronous viewing, along with a short assignment summarizing the material. At the end of the week, there will be a synchronous online discussion and example problem session wherein we can discuss the material, answer any questions you may have, and go over some practice problems relevant to the assignment. Finally, assignment solutions will be due by the beginning of the next week.

Student Evaluation and Grading

Students will be evaluated using two metrics:

1. **Weekly Problem Sets (70%).** Students will submit solutions to the weekly assignments. These will be graded, and solutions will be discussed at weekly synchronous sessions.
2. **Final Project (30%).** There will be one "final project" for the class, due at the end of the term. This will take the form of a given set of problems outlining the orbital computations necessary for the preliminary design of a space mission. The outline will be released early on, and students will have the opportunity to work on the relevant pieces of the project throughout the term.

Detailed Summary of Course Material

Week 1 will consist of a short course introduction, as well as a summary of the relevant history of astronomy and astromechanics. It will introduce Kepler's laws in a historical context, and then introduce Newton's laws of motion and universal gravitation as a foundation upon which to construct an understanding of orbital motion. Finally, we will introduce the N-body problem, and simplify as necessary to reach the restricted two-body problem as the basis for rederiving Kepler's laws.

Week 2 will start from the equations of motion derived for the restricted two-body problem, and will show how energy and angular momentum are conserved, as well as their specific forms in the context of orbital mechanics. We will then use these to approach the proof of Kepler's first law from the physical basis of Newtonian mechanics. This will introduce the concept of conic section orbits and their geometry.

Week 3 will further explore the geometry and properties of Keplerian orbits, developing an understanding of the many descriptors and measures of two-body trajectories. The many types of orbits—circles, ellipses, parabolas, and hyperbolas—and their defining relationships will be developed. We will then prove Kepler's second and third laws, before continuing onward to an examination of how the swept-area rule provides a means of calculating the time of flight between known positions in a Keplerian orbit.

Week 4 will introduce the many coordinate systems that are used to express positions, velocities, and other vectors relevant to astromechanics and orbits, including Earth-Centered Inertial, Earth-Centered Earth-Fixed, Perifocal, Topocentric Horizon, Radial In-Track Cross-Track, and Normal Tangential Cross-Track coordinates. We will then introduce the classical orbital elements as a standard descriptor of orbit geometry, and show how they can be computed from position and velocity vectors.

Week 5 will focus on an introduction to orbital maneuvering, that is, how a spacecraft may use impulses to change its trajectory and move from one orbit to another. We will start with a recap of the Tsiolkovsky rocket equation, and introduce the concept of Delta-V. Finally, we will examine some basic maneuvers (e.g. tangential burns for perigee/apogee adjustments), and develop intuition for how maneuvers affect spacecraft motion. The Hohmann and bi-elliptic transfers will be introduced.

Week 6 will continue our examination of orbital maneuvering with discussions of more general maneuvers: non-tangent burns, plane changes, and combined maneuvers. We will also expand from a purely geometric picture of transfers into one that includes the dynamics and timing of spacecraft traversing transfer trajectories; this will include an introduction to phasing maneuvers and orbital rendezvous computations.

Week 7 will allow us to move beyond Earth's orbit and begin a consideration of interplanetary trajectories, i.e. those that depart Earth, move through the solar system, and arrive at another planet or other gravitating body. As these are fundamentally more-than-two-body problems, we will introduce the concept of spheres of influence, and use this to develop the patched-conics approximation for interplanetary trajectories. We will show how the velocity requirements transfer between frames, and how the tools of transfer design can be applied at interplanetary scale.

Week 8 will tie everything together by actually executing computations of complete interplanetary patched-conics transfers, synthesizing our analyses of Keplerian orbits, maneuvering, transfers, patched conics, and phasing. We will end with a discussion of gravity assist ("slingshot") maneuvers, and how they can be used to achieve large-scale trajectory changes for interplanetary travel.