Preface

The purpose of this book is to provide an introduction to space mechanics for undergraduate engineering students. It is not directed toward graduate students, researchers, and experienced practitioners, who may nevertheless find useful review material within the book's contents. The intended readers are those who are studying the subject for the first time and have completed courses in physics, dynamics, and mathematics through differential equations and applied linear algebra. I have tried my best to make the text readable and understandable to that audience. In pursuit of that objective I have included a large number of example problems that are explained and solved in detail. Their purpose is not to overwhelm but to elucidate. I find that students like the "teach by example" method. I always assume that the material is being seen for the first time and, wherever possible, I provide solution details so as to leave little to the reader's imagination. The numerous figures throughout the book are also intended to aid comprehension. All of the more labor-intensive computational procedures are accompanied by MATLAB® code.

For this, the fourth edition, I have retained the content and style of the previous editions and corrected all the errors discovered by me or reported to me by readers. Except for the new Chapter 9 on basic lunar trajectories and an expanded discussion of quaternions in Chapter 11 the book remains essentially the same. Adding the new chapter required the following reshuffling:

Topic	***This edition***	***Previous edition***
Lunar trajectories	Chapter 9	Absent
Introduction to orbital perturbations	Chapter 10	Chapter 12
Rigid body dynamics	Chapter 11	Chapter 9
Satellite attitude dynamics	Chapter 12	Chapter 10
Rocket vehicle dynamics	Chapter 13	Chapter 11

The organization of the book remains the same as that of the third edition. Chapter 1 is a review of vector kinematics in three dimensions and of Newton's laws of motion and gravitation. It also focuses on the issue of relative motion, crucial to the topics of rendezvous and satellite attitude dynamics. The material on ordinary differential equation solvers will be useful for students who are expected to code numerical simulations in MATLAB or other programming languages. Chapter 2 presents the vector-based solution of the classical two-body problem, resulting in a host of practical formulas for the analysis of orbits and trajectories of elliptical, parabolic, and hyperbolic shape. The restricted three-body problem is covered to introduce the notion of Lagrange points and to present the numerical solution of a lunar trajectory problem. Chapter 3 derives Kepler's equations, which relate position to time for the different kinds of orbits. The universal variable formulation is also presented. Chapter 4 is devoted to describing orbits in three dimensions. Coordinate transformations and the Euler elementary rotation sequences are defined. Procedures for transforming back and forth between the state vector and the classical orbital elements are addressed. The effect of the earth's oblateness on the motion of an orbit's ascending node and eccentricity vector is described, pending a more detailed explanation in Chapter 10. Chapter 5 is an introduction to preliminary orbit determination, including Gibbs' and Gauss' methods and the solution of Lambert's problem. Auxiliary topics include topocentric coordinate systems, Julian day numbering, and sidereal time. Chapter 6 presents the common means of transferring from one orbit to another by impulsive delta-v maneuvers, including Hohmann transfers, phasing orbits, and plane changes. Chapter 7 is a brief introduction to relative motion in general and to the two-impulse rendezvous problem in particular. The latter is analyzed using the Clohessy-Wiltshire equations, which are derived in this chapter. Chapter 8 is an introduction to interplanetary mission design using patched conics. Chapter 9 extends the patched conic method and the restricted three-body approach to lunar trajectory analysis. Chapter 10 is an introduction to common orbital perturbations: drag, nonspherical gravitational field, solar radiation pressure, and lunar and solar gravity. Chapter 11 presents those elements of rigid body dynamics required to characterize the attitude of a space vehicle. Euler's equations of rotational motion are derived and applied in a number of example problems. Euler angles, yaw-pitch-roll angles, and quaternions are presented as ways to describe the attitude of rigid body. Chapter 12 describes the methods of controlling, changing, and stabilizing the attitude of spacecraft by means of thrusters, gyros, and other devices. Chapter 13 is a brief introduction to the characteristics and design of multistage launch vehicles.

Chapters 1 through 4 form the core of a first orbital mechanics course. The time devoted to Chapter 1 depends on the background of the student. It might be surveyed briefly and used thereafter simply as a reference. What follows Chapter 4 depends on the objectives of the course.

Chapters 5 through 10 carry on with the subject of orbital mechanics. Chapter 6 on orbital maneuvers should be included in any case. Coverage of Chapters 5, 7, 8, and 9 is optional. However, if Chapters 8 and 9 on interplanetary and lunar missions is to form a part of the course, then the solution of Lambert's problem (Section 5.3) must be studied beforehand.

Chapter 10 is appropriate for a course devoted exclusively to orbital mechanics with an introduction to perturbations, which is a whole topic unto itself.

Chapters 11 and 12 must be covered if the course objectives include an introduction to spacecraft dynamics. In that case Chapters 5, 7, 8, and 9 would probably not be studied in depth.

Chapter 13 is optional if the engineering curriculum requires a separate course in propulsion including rocket dynamics.

The important topic of spacecraft control systems is omitted. However, the material in this book and a course in control theory provide the basis for the study of spacecraft attitude control.

To understand the material and to solve problems requires using a lot of undergraduate mathematics. Mathematics, of course, is the language of engineering. Students must not forget that the English mathematician and physicist Sir Isaac Newton (1642–1727) had to invent calculus so he could solve orbital mechanics problems in more than just a heuristic way. Newton's 1687 publication *Mathematical Principles of Natural Philosophy* ("the *Principia*") is one of the most influential scientific works of all time. It must be noted that his contemporary, the German mathematician Gottfried Wilhelm von Leibnitz (1646–1716) is credited with inventing infinitesimal calculus independently of Newton in the 1670s.

In addition to honing their math skills, students are urged to take advantage of computers (which, incidentally, use the binary numeral system developed by Leibnitz). There are many commercially available mathematics software packages for personal computers. Wherever possible they should be used to relieve the burden of repetitive and tedious calculations. Computer-programming skills can and should be put to good use in the study of orbital mechanics. The elementary MATLAB programs referred to in Appendix D of this book illustrate how many of the procedures developed in the text can be implemented in software. All the scripts were developed and tested using MATLAB version 9.2 (release 2017a). Information about MATLAB, which is a registered trademark of The MathWorks, Inc., may be obtained from

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Appendix A presents some tables of physical data and conversion factors. Appendix B is a road map through the first three chapters, showing how the most fundamental equations of orbital mechanics are related. Appendix C shows how to set up the n-body equations of motion and program them in MATLAB. Appendix D contains listings of all the MATLAB algorithms and example problems presented in the text. Appendix E shows that the gravitational field of a spherically symmetric body is the same as if the mass were concentrated at its center. Appendix F explains how to deal with a computational issue that arises in some perturbation analyses.

SUPPLEMENTS TO THE TEXT

For purchasers of the book, copies of the MATLAB M-files listed in Appendix D can be freely downloaded from this book's companion website. Also available on the companion website are a set of animations that accompany the text. To access these files, please visit https://www.elsevier.com/books-and-journals/book-companion/9780081021330.

For instructors using this book for a course, please visit www.textbooks.elsevier.com to register for access to the solutions manual, PowerPoint lecture slides, and other resources.

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