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Book Review

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Review of Orbital Mechanics for Engineering Students

Edited by Howard D. Curtis, Elsevier, 2005, 673 pp., $83.95, ISBN 0-7506-6169-0
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Professor Curtis has successfully created a foundational text in astronautics that is suitable for undergraduates, while also including an admirable amount of depth and rigor. The author concentrates the majority of the text on orbital mechanics, but also devotes several chapters to space applications of rigid-body dynamics. There are more than enough topics included to develop several solid undergraduate courses. The text is written assuming students have no formal experience in the subject and are prepared with typical undergraduate courses in physics, dynamics, and mathematics through differential equations and linear algebra. Undergraduate students will benefit from the approachable treatment of the topics as well as from the numerous detailed examples found throughout each chapter. First-year graduate students may also find the text useful as an introduction to the subject which will prepare them for more advanced study.

The text includes 11 chapters and 5 appendices. Online materials are also available, including MATLAB code for orbital and rigid-body dynamics projects. The many end-of-chapter exercises will challenge students and provide instructors with many options. Chapters 1–4 include a review of particle dynamics and development of mathematics necessary to describe two-body orbits. The first chapter, *Dynamics of Point Masses*, is a review of particle dynamics. It is not exhaustive, nor is it intended to be. It is an entirely suitable review of kinematics, force, and Newton's laws, and relative motion, although the kinematics discussion would benefit from a review of the appropriate rectilinear and curvilinear coordinate systems. The chapter is particularly detailed in describing time derivatives of moving vectors and their application to relative motion. The notation differences between relative and absolute velocities and accelerations are clear and distinct when introduced, but the author possibly invites confusion by quickly dropping the more precise terminology in the following section on relative motion. However, the chapter is an effective dynamics review for the intended audience.

Chapter 2, *The Two-Body Problem*, develops the classic orbital equations of motion in a thorough, general manner. The author initially derives the two-body motion equations using the system mass center as the inertial reference frame origin. The motion of one mass relative to the second is ultimately developed, demonstrating that the equations of motion of either body, relative to the mass center, take the same form as the relative motion of either one of the bodies. Along the way, energy and momentum concepts are defined and applied to the orbital equation. Lagrange coefficients are also derived and applied in several examples. The chapter concludes with sections on the restricted three-body problem, Lagrange points, and the Jacobi constant.

Chapter 3, *Orbital Position as a Function of Time*, presents Kepler's equation and uses Newton's method to solve the transcendental equation. Several excellent examples illustrate the concepts in detail. The author proceeds from elliptical orbits to parabolic and hyperbolic trajectories by developing and applying universal variables. The next chapter, *Orbits in Three Dimensions*, presents typical orbital coordinate systems and definitions for orbital orientation in three-dimensions. This material may more logically appear before Chapter 3, but the material may be presented in an alternate order without affecting the value of either chapter. Included in Chapter 4 is a section on coordinate transformation, which is immediately applied to transformation between geocentric-equatorial and perifocal coordinate frames. A separate course in spacecraft attitude dynamics should cover this section in conjunction with the kinematics material in Chapter 9. Knowledge of direction cosines is assumed, which may not be appropriate for all undergraduates, but the illustrations and examples help create an excellent introduction to the material.

The next four chapters continue the subject with standard topics of orbit determination, maneuvers, relative motion, and interplanetary trajectories. This material could extend the first course in orbital mechanics or form a second course, depending on the depth of coverage and background of the students. Chapter 5, *Preliminary Orbit Determination*, presents most standard, important topics including Lambert's problem and several approaches to the orbit determination problem: Gibbs's, angles-only, and Gauss's methods. Maneuvering to different orbits using impulsive maneuvers is covered in Chapter 6, *Orbital Maneuvers*. Hohmann transfers are presented first, followed by more general transfers, phasing maneuvers, and plane changes. Chapter 7, *Relative Motion and Rendezvous*, develops and then linearizes the equations of relative motion for two objects. The Clohessy–Wiltshire equations are produced and applied to the rendezvous problem. The examples are excellent, although more illustrations of relative motion solutions in the Clohessy–Wiltshire frame would improve an already fine chapter. Chapter 8, *Interplanetary Trajectories*, extends the orbital maneuvering topics to interplanetary missions. In addition to Hohmann transfers and rendezvous, the chapter presents the patched-conic method in detail with extensive examples.

Chapter 9, *Rigid-Body Dynamics*, introduces the topic and provides the foundation for satellite attitude dynamics, presented in Chapter 10. Chapter 9 is presented as a review of dynamics and it provides a detailed, complete development of concepts. The development of rigid-body kinematics and kinetics goes beyond many undergraduate dynamics texts in depth and detail. Topics include angular momentum and the inertia tensor, as well as transformation of the tensor to principal axes. Euler's equations are developed and applied to the motion of a spinning top. The author introduces Euler angles in a classic 3-1-3 rotation sequence, as well as an alternate 3-2-1 sequence. Although the book strives to be general throughout, the treatment of attitude parameterization is more limited than other aspects of the text. The author refers to "the three Euler angles..." in the 3-1-3 sequence, and the "yaw, pitch, and roll angles" of the 3-2-1 sequence, but does not put these two different sequences in the context of the 12 possible rotation sequences and angles that are also Euler angles. The singularity in Euler rates is mentioned, and the yaw, pitch, and roll angles are presented as an alternative to avoid the singularity. However, the author does not discuss Euler's theorem, quaternions, or other alternate attitude parameters. The chapter nevertheless provides an outstanding introduction to the material and provides the foundation for the following chapter on satellite attitude dynamics.

Chapter 10, *Satellite Attitude Dynamics*, is a rich collection of spacecraft attitude dynamics topics that range from standard torque-free motion to more challenging subjects such as stability of dual-spin spacecraft using energy-sink methods. An undergraduate course in space dynamics may not need to cover every topic, as some material will challenge even the most adept undergraduates. Some of the subjects covered include nutation dampers, coning maneuvers, attitude control thrusters, yo–yo despin mechanisms, gyroscopic control, and gravity gradient stabilization. The last two sections provide some insight into attitude control and prepare the student for applying feedback control methods.

The final chapter, *Rocket Vehicle Dynamics*, is an introduction to the subject including the equations of motion, thrust equation, ideal rocket equation, and staging. However, this introductory chapter seems an odd place to conclude the book given the more thorough treatment of the first ten chapters. However, this chapter would work well as a block within a space dynamics course. For a more complete rocket dynamics course, other rocket propulsion or dynamics texts would be preferable. The chapter does include similar outstanding examples as previous chapters and students would undoubtedly benefit from the presented material.

Overall, Professor Curtis has crafted a text remarkably complete in detail and rigor for an introductory book. He communicates clearly using text, illustration, and exhaustive examples. These subjects typically challenge students, particularly during their initial exposure to the material. The superb examples will be extremely valuable to undergraduates and distinguishes this text from many others. This book should be given serious consideration for any undergraduate course in orbital mechanics or spacecraft dynamics.

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