JOURNAL OF GUIDANCE, CONTROL, AND DYNAMICS
Vol. 22, No. 4, July–August 1999

Book Review

Publishers are invited to send two copies of new books for review to Dr. I. Michael Ross, Code: AA/Ro, Department of Aeronautics and Astronautics, U.S. Naval Postgraduate School, 699 Dyer Road, Monterey, CA 93943.

Space Vehicle Dynamics and Control

Bong Wie, AIAA, Reston, VA, 1998, 564 pp., $84.95, ISBN 1-56347-261-9

The unification of spacecraft orbital and attitude dynamics in a single-volume textbook is a very challenging and formidable task, which prior to this text had not been attempted to any degree of technical sophistication. Additionally, the combination of highly theoretical content with practical relevance is rare in the existing crop of technical books describing spacecraft dynamics, demanding a broad and proficient background of theoretical and industrial experience by the author. Professor Wie uses his unique capabilities and experiences as both an educator and a practicing spacecraft engineer to successfully bridge these critical gaps and provide the spacecraft community with an excellent text and reference book.

The book comprises 10 chapters divided into four parts: an introductory section on dynamic system modeling, analysis, and control; a section on orbital dynamics and control; a section on attitude dynamics and control; and a section on structural dynamics and control. Each chapter within these sections goes into extensive theoretical detail of the pertinent equations and contains many interesting and practical examples and problems. For example, in Chapter 4 the derivation and analytical solution to the Clohessy–Wiltshire equations for orbital rendezvous problems are provided, and interesting applications to a two-impulse target rendezvous maneuver and an elliptical target flyaround maneuver are presented. As another example, in Chapter 7 the equations of motion for a large space station actuated by a control-moment gyro (CMG) are provided, and practical attitude control laws with momentum management are designed in the presence of periodic environmental disturbance torques.

An introduction to modeling, analysis, and control of dynamic systems is covered in Part 1. Chapter 1 provides a review of the key mathematical preliminaries of classical vector mechanics and analytical dynamics, including interesting example applications of the problem of spacecraft solar array deployment dynamics. Also included is a review of linear and nonlinear systems analysis. Chapter 2 provides a review of dynamic systems control including classical control, digital control, state-space control, and robust control. It is my opinion that this introductory section is one of the few shortcomings of the text. Although a majority of these mathematical preliminaries are very pertinent to the subject content, about 30 pages of material on robust control is primarily of academic interest only and, hence, of little use to practicing spacecraft engineers. Additionally, the inclusion of an introductory chapter describing typical spacecraft orbit and attitude control systems and strategies, as well as commonly used sensors and actuators, would have improved this section immensely.

The dynamics and control of spacecraft orbital motion is covered in Part 2. Chapter 3 provides a review of the governing equations of spacecraft orbital dynamics, including orbital parameter variations due to Earth oblateness. Also included is a detailed discussion of the three-body problem. Orbital control strategies are covered in Chapter 4, including discussions on launch vehicle ascent and guidance, orbit injection, orbit maneuvering, interplanetary flight, orbit rendezvous, and halo orbits about the Langrangian equilibrium points. Although not commonly found in textbooks on orbital mechanics, it is clear from the depth of coverage that the halo orbit determination and control problem is a research subject of interest to Professor Wie.

The dynamics and control of rigid spacecraft attitude motion is covered in Part 3. Chapters 5 and 6 provide a standard review of rotational kinematics and rigid-body dynamics, including the equations of motion for a gyrostat in a circular orbit. Chapter 7 provides a discussion of spacecraft attitude control and maneuver strategies. The classes of spacecraft covered here are spin and dual-spin stabilized spacecraft under thruster control, and three-axis stabilized spacecraft under thruster, reaction wheel, and CMG control. Included are some elegant and useful closed-form solutions for thruster-based spin maneuvers, active nutation control, and gyrostat reorientation. Also included are detailed descriptions of time-optimal and quaternion feedback maneuver strategies, CMG-based control and momentum management, CMG steering logic, and thruster modulation strategies. The inclusion of these various strategies to the technical depth and practical usefulness that they are presented is unique to this text and demonstrates the diverse background of research and experience that Professor Wie brings to the field. In fact, the majority of these topics were relegated to technical journal articles prior to the release of this text. I believe the only shortcoming of this chapter is the exclusion of magnetic control strategies, which are widely used in practice for both control and momentum management.

The diverse field of structural dynamics and control is covered in Part 4. Chapter 8 provides a review of the concepts and tools used for structural dynamic modeling, including analysis of bars, beams, rigid bodies with flexible appendages, frames with pretensioned membranes, and flexible toroidal structures. Since the majority of these subjects are covered in great detail in many texts, I believe this chapter could have been reduced to a couple of pertinent subsections within Chapter 9 by limiting the discussion to flexible appendages and frames. Chapter 9 provides a discussion of combined attitude and structural control concepts for many interesting and pertinent problems, including thrust vector control with propellant slosh, attitude control of a bias-momentum spacecraft with flexible solar arrays, attitude and stationkeeping control of a three-axis stabilized spacecraft with flexible solar arrays, nonlinear pulse-modulated control of a flexible spacecraft, and control redesign of the Hubble Space Telescope to reduce pointing jitter induced by the flexible solar arrays. Additionally, a discussion and summary of recent research activities in active structural vibration control is provided in the final section. Although not typically considered under the auspices of spacecraft control, these concepts are applicable to large spacecraft with tight payload pointing requirements. The final chapter provides a detailed discussion of robust optimal maneuvers of flexible spacecraft. Included are time- and fuel-optimal maneuver strategies, control with one-sided inputs, and preshaped feedforward command generation. Though primarily intended for jet thruster control systems, some of these concepts can be applied to reaction wheel control as well. As in Part 3, the wide range of topics covered within the chapters of Part 4 demonstrate the diverse knowledge and experience Professor Wie brings to the field of spacecraft control.

In summary, I highly recommend this text for advanced undergraduate- and graduate-level studies as well as for practicing spacecraft control engineers, especially in the area of spacecraft attitude control. The book includes a compendium of both recent research and established practice, and the wide selection of references provided at the end of each chapter and in the Bibliography present the interested reader with multiple sources for further research and understanding of the subject.

Glenn Creamer
Spectrum Astro, Inc.

Errata

Autonomous Maneuver Tracking for Self-Piloted Vehicles

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[J. Guidance 22 (1), pp. 58–67 (1999)]

EQUATION (10) should be corrected as follows:
Equation (10) should read

$$\begin{bmatrix} \frac{1}{QSb}(-I_{xz}(pq) - (I_{yy} - I_{zz})qr) \\ \frac{1}{QS\bar{c}}\Big(- I_{xz}(r^2 - p^2) - (I_{zz} - I_{xx})rp\Big) \\ \frac{1}{QSb}(-I_{xz}(-qr) - (I_{xx} - I_{yy})pq) \end{bmatrix} - \begin{bmatrix} C_{l_0} \\ C_{M_0} \\ C_{N_0} \end{bmatrix} - \begin{bmatrix} C_{l_\alpha} & C_{l_\beta} & C_{l_{\delta_t}} & C_{l_p} & C_{l_q} & C_{l_r} \\ C_{M_\alpha} & C_{M_\beta} & C_{M_{\delta_t}} & C_{M_p} & C_{M_q} & C_{M_r} \\ C_{N_\alpha} & C_{N_\beta} & C_{N_{\delta_t}} & C_{N_p} & C_{N_q} & C_{N_r} \end{bmatrix} \cdot \begin{bmatrix} \alpha \\ \beta \\ \delta_t \\ \hat{p} \\ \hat{q} \\ \hat{r} \end{bmatrix}$$

$$= \begin{bmatrix} C_{l_{\delta_e}} & C_{l_{\delta_a}} & C_{l_{\delta_r}} \\ C_{M_{\delta_e}} & C_{M_{\delta_a}} & C_{M_{\delta_r}} \\ C_{N_{\delta_e}} & C_{N_{\delta_a}} & C_{N_{\delta_r}} \end{bmatrix} \cdot \begin{bmatrix} \delta_e \\ \delta_a \\ \delta_r \end{bmatrix}$$