Satellites are increasingly used in telecommunications, scientific research, surveillance, and meteorology. These satellites rely heavily on the effectiveness of complex onboard control systems.

The aim of this book is to explain the basic theory of spacecraft dynamics and control and the practical aspects of controlling a satellite. The emphasis throughout is on analyzing and solving real-world engineering problems. For example, the author discusses orbital and rotational dynamics of spacecraft under a variety of environmental conditions, along with the realistic constraints imposed by available hardware. Among the topics covered are orbital dynamics, attitude dynamics, gravity gradient stabilization, single- and dual-spin stabilization, attitude maneuvers, attitude stabilization, and structural dynamics and liquid sloshing.

Spacecraft Dynamics and Control reflects Dr. Sidi's experience as a university instructor and as an engineer working on spacecraft control systems. This book will be useful as a reference for engineers and as a text for students.

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Spacecraft Dynamics and Control

A Practical Engineering Approach

MARCEL J. SIDI
Israel Aircraft Industries Ltd.
and
Tel Aviv University

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To the memory of my parents, Jacob and Sophie,
who dedicated their lives to my education

and

to my wife Raya and children Gil, Talia, Michal and Alon,
who were very patient with me during the preparation of this book

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Marcel J. Sidi
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Preface

The goal of this book is to provide the reader with the basic engineering notions of controlling a satellite. In the author's experience, one of the most important facts to be taught from the beginning is practical engineering reality. Theoretical, "nice" control solutions are seriously hampered when practical problems (e.g., sensor noise amplification, unexpected time delays, control saturation effects, structural modes, etc.) emerge at a later stage of the design process. The control algorithms must then be redesigned, with the inevitable loss of time and delay of the entire program. Early anticipation of these effects shortens the design process considerably. Hence it is of utmost importance to analyze different concepts for engineering solutions of spacecraft control tasks in the preliminary design stages, so that the correct one will be selected at the outset. This is why several approaches may be suggested for a given control task.

Part of the material in this textbook has been used as background for a single-semester course on "Spacecraft Dynamics and Control" – offered since 1986 at the Tel Aviv University and also more recently at the Israel Institute of Technology, the Technion, Haifa. All the material in this book is appropriate for a course of up to two semesters in length. The book is intended for introductory graduate-level or advanced undergraduate courses, and also for the practicing engineer. A prerequisite is a first course in automatic control, continuous and sampled, and a first course in mechanics. This, in turn, assumes knowledge of linear algebra, linear systems, Laplace transforms, and dynamics.

A sequential reading of the book is advised, although the chapters are for the most part self-contained. A preliminary overview is recommended in order to acquire a feeling for the book's contents; this will help enormously in the second, and deeper, reading.

Modern spacecraft control concepts are based on a vast choice of physical phenomena: single- and dual-spin stabilization; gravity gradient attitude control; three-axis stabilization; momentum-bias stabilization; and solar, magnetic, or reaction torque stabilization. It is important to master the essential qualities of each before choosing one as an engineering solution. Therefore, the various concepts are treated, analyzed, and compared in sufficient depth to enable the reader to make the correct choices.

Appendix B and Appendix C detail the space onboard hardware that is essential to any practical engineering solution. Technical specifications of various control items are listed for easy reference.

Acknowledgments

I wish to express my sincere gratitude to the System & Space Technology – MBT, a subsidiary of Israel Aircraft Industries Ltd., on whose premises this textbook was partially prepared. I give special thanks to its manager, Dr. M. Bar-Lev, who encouraged my writing.

Part of the material included here is the result of mutual efforts of the Control and Simulation Department engineers and scientists to develop, design, evaluate, and build the attitude and orbit control systems of the *Offeq* series of low-orbit satellites and of the Israeli geostationary communication satellite *Amos 1*.

It took me more than ten years of effort to study and master, at least partially, the nascent field of space technology. In this context I would like to thank my colleagues, especially P. Rosenbaum, A. Albersberg, E. Zemer, D. Verbin, R. Azor, A. Ben-Zvi, Y. Efrati, Y. Komen, Y. Yaniv, F. Dellus, and others with whom I had long and fruitful discussions and who carefully read parts of the manuscript.

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During my own education in the field of space dynamics and control, I took advantage of many works written by such excellent scientists as Agrawal, Alby, Balmino, Battin, Bernard, Bittner, Borderies, Bryson, Campan, Deutsch, Donat, Duret, Escobal, Foliard, Frouard, Gantous, Kaplan, Legendre, Pocha, Pritchard, Robert, Sciulli, Soop, Thomson, Wertz, and others. To these scientists I owe my deep gratitude.

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