SPACE MISSION ANALYSIS AND DESIGN

Third Edition

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Space Mission Analysis and Design

Third Edition

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The third edition is the end result of a substantial effort by the authors of all the SMAD editions. Consequently, we would like to acknowledge and express our thanks to all of the authors who have contributed to this series:

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Preface

Space Mission Analysis and Design, known as SMAD to its many friends, has gained widespread use as a text and reference throughout the astronautics community. The purpose of the third edition of SMAD is to both update the book and make it more useful and more practical wherever possible. Some topics, such as astrodynamics and mission geometry, have changed relatively little since publication of the second edition in 1992. Here we have made minor modifications to make the material clearer and more precise. On the other hand, topics such as space computers and the design of observation payloads have been nearly completely rewritten. Because of the growing interest in "LightSats" and low-Earth orbit constellations we have added a SmallSat cost model, expanded the discussion of constellation design, and included a new section on multi-satellite manufacturing. The entire volume reflects a greater emphasis on reducing mission cost and doing more with less people and fewer resources.* Finally, the FireSat sample mission has been extended further and the appendices and end matter updated and expanded to provide greater utility as a quick reference. We hope the new edition is better and more useful to you.

As with the first two editions, the goal of the book to is allow you to begin with a "blank sheet of paper" and design a space mission to meet a set of broad, often poorly defined, objectives at minimum cost and risk. You should be able to define the mission in sufficient detail to identify principal drivers and make a preliminary assessment of overall performance, size, cost, and risk. The emphasis is on low-Earth orbit, unmanned spacecraft. However, we hope the principles are broad enough to be applicable to other missions as well. We intend the book to be a practical guide, rather than a theoretical treatise. As much as possible, we have provided physical and engineering data, rules of thumb, empirical formulas, and design algorithms based on past experience. We assume that the reader has a general knowledge of physics, math, and basic engineering, but is not necessarily familiar with any aspect of space technology.

The third edition represents an amalgam of contributions over the last decade by many engineers and managers from throughout the community. It reflects the insight gained from their practical experience, and suggests how things might be done better in the future. From time to time the views of authors and editors conflict, as must necessarily occur given the broad diversity of experience. We believe it is important to reflect this diversity rather than suppress the opinions of individual experts. Similarly, the level of treatment varies among topics, depending both on the issues each author feels is critical and our overall assessment of the level of detail in each topic that is important to the preliminary mission analysis and design process.

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* The continuing, unrelenting demand to drive down mission cost has led to the creation a companion volume to SMAD, *Reducing Space Mission Cost* [Wertz and Larson, 1996], which addresses cost reduction in all aspects of mission design and includes 10 case studies of how the process works in practice.

The book is intended as a textbook for either introductory graduate or advanced undergraduate courses, or as a reference for those already working in space technology. It can also provide valuable supplementary material for related courses such as spacecraft design or space mission operations. We believe the book can be a key tool for payload designers who need to find out more about space mission design and for those charged with the responsibility of developing space mission requirements and specifications. Finally, we hope that it will be of use to many system engineers in this field who have a detailed knowledge of one area, but need to broaden their background or verify their understanding in related topics.

The book is meant to be read sequentially, although most of the chapters are self-contained, with references to other parts of the book as needed. For readers with specific interests, we recommend the following:

- Those concerned primarily with mission analysis and design should read Chaps. 1–9 and 19–23.
- Those concerned with spacecraft and subsystem design should read Chaps. 1, 2, 4, 8–13, and 16–23.
- Those concerned primarily with mission operations and the ground interaction should read Chaps. 1, 2, 4, and 13–16.
- Those concerned with requirements definition, logistics, and putting a space system in place should read Chaps. 1–4, 7, 9, 10, and 18–23.
- Those interested in constellation design and multi-satellite systems should read Chaps. 1–9, 13–16, and 19–23.
- Those interested in reducing mission cost and the design of low-cost missions should read Chaps. 1–3, 7–10, 12, 20–23, and the companion volume, *Reducing Space Mission Cost*.

SI (metric) units are used throughout the book. Conversions for essentially all common units are contained in Appendix F. Conversion factors and physical constants are generally given to their full available accuracy so that they can be inserted into computer programs and not considered further. As discussed in the introduction to the appendices, the values given are those adopted by the National Bureau of Standards based on a least-squares fit to the fundamental physical constants or international agreement on the definitions of various units. In the case of astronomical constants, values adopted by the International Astronomical Union are given. The most commonly used astronautical formulas and constants are in the appendices. An expanded table of space mission parameters for Earth orbits is on the inside back endleaf. For those wishing to expand that table or use it for other central bodies, the formulas used for creating it are on the preceding pages.

Leadership, funding, and support essential to updating the book were provided by numerous programs at the Air Force Space and Missile Center, Air Force Space Command, NASA Headquarters, NASA/Goddard Space Flight Center, and the Advanced Projects Research Agency. Obtaining funding to create and maintain much-needed reference material is exceptionally difficult. We are deeply indebted to the sponsoring organizations, particularly Air Force Phillips Laboratory, for their support and their recognition of the importance of projects such as this one.

The third edition of this book is the result of nearly two years of effort by a dedicated team of government, industry, and academic professionals. The Department of Astronautics, United States Air Force Academy, provided unwavering support for

the project. Michael DeLorenzo, Chairman of the Department of Astronautics, provided the leadership and continuing support critical to projects of this type. Both Doug Kirkpatrick and Perry Luckett performed a detailed grammatical review in a valiant effort to prevent the rest of us from demonstrating why we became engineers rather than writers. Several graphics artists at the Academy, particularly Mary Tostanoski and Debra Porter, spent many hours developing and updating artwork. Joan Aug and Bert Reinertson cheerfully handled the huge administrative burden at the Academy. Numerous faculty members, staff, and students graciously sacrificed their time to provide assistance, review, and comments. Daryl Boden assisted with the editing and reviewing even after changing assignments to the Naval Academy. Doug Kirkpatrick managed the task for the Air Force with great skill and patience and reviewed nearly all of the material for both technical and linguistic correctness!

OAO Corporation, Colorado Springs, Colorado, provided the contract support for the project. Anita Shute at the Air Force Academy spent many hours revising drafts, creating artwork, and working all aspects of the project. Eugene deGeus of Kluwer Academic Publishers supplied substantial assistance with all aspects of the publishing activity. This was his final project at Kluwer before taking a science administration position with the Dutch government. We will miss his wisdom and guidance and wish him the best of future success.

At Microcosm, the entire analysis and publications staff worked virtually all aspects of the book (art, grammar, equation checking, technical reviews, and camera-ready copy) and suffered patiently through “the book project” as it continually absorbed great amounts of limited resources. Much of the new graphics was done by undergraduate students Karen Burnham, Paul Murata, Alan Chen, and Julie Wertz under the very capable guidance of Kevin Polk and Simon Dawson. Jennifer Burnham and Judith Neiger did much of the proofing. Robert Bell did most of the demanding task of updating units and conversion factors. John Collins created the new FireSat cost model. Wendi Huntzicker and Joy Sakaguchi created the new camera-ready copy for most of the book. Joy and Chris deFelippo did much of the new art. Finally, Donna Klungle did a truly remarkable job managing, administering, editing, reviewing, and preparing revisions, drafts, and the final camera-ready copy. Donna accomplished this with skill and good humor, while dealing with the conflicting demands of multiple authors and editors.

Arthur Cox of Lawrence Livermore National Labs and the editors of *Astrophysical Quantities* [1999] graciously permitted the use of drafts of their forthcoming volume so that we could obtain the most current values for physical quantities. We highly recommend that readers consult *Astrophysical Quantities* for solar system and astronomical parameters which are not contained here.

Every effort has been made to eliminate mathematical and factual errors. Many errors from prior editions have been found largely through readers’ comments and constructive criticism. Please continue to send any errors, omissions, corrections, or comments to either editor at the addresses below. We sincerely hope that the book will be of use to you in our common goal of reducing the cost and complexity of space utilization.

Finally, one of the most exciting aspects of space mission analysis and design is that after 40 years of space exploration we have only begun to scratch the surface of the variety of important missions that can and should be done. In spite of problems, setbacks, and higher costs than any of us would like, people young and old remain excited about space. The exploration of space will take dramatic new turns in the future, from

communications constellations and microgravity work now beginning to become a reality to solar power satellites, space tourism, space industrialization, and settlements on the Moon and planets which are still to be designed. We hope that this volume provides a portion of the roadmap and incentive to those who will undertake these tasks. We wish you the best of success in this endeavor.

June, 1999

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