Spacecraft interact with the space environment in ways that may affect the operation of the spacecraft as well as any scientific experiments that are carried out from the spacecraft platform. In turn, the study of these interactions provides information on the space environment. Adverse environmental effects, such as the effect of the radiation belts on electronics and spacecraft charging from the magnetospheric plasma, mean that designers need to understand interactive phenomena to be able to effectively design spacecraft. This has led to the new discipline of spacecraft–environment interactions. The emphasis in this book is on the fundamental physics of the interactions.

Spacecraft–Environment Interactions is a valuable introduction to the subject for all students and researchers interested in the application of fluid, gas, plasma, and particle dynamics to spacecraft and for spacecraft system engineers.

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SPACECRAFT–ENVIRONMENT INTERACTIONS

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CAMBRIDGE
UNIVERSITY PRESS

PUBLISHED BY THE PRESS SYNDICATE OF THE UNIVERSITY OF CAMBRIDGE
The Pitt Building, Trumpington Street, Cambridge, United Kingdom

CAMBRIDGE UNIVERSITY PRESS
The Edinburgh Building, Cambridge CB2 2RU, UK
40 West 20th Street, New York NY 10011–4211, USA
477 Williamstown Road, Port Melbourne, VIC 3207, Australia
Ruiz de Alarcón 13, 28014 Madrid, Spain
Dock House, The Waterfront, Cape Town 8001, South Africa

http://www.cambridge.org

First published 1996
First paperback edition 2004

A catalogue record for this book is available from the British Library

Library of Congress Cataloguing-in-Publication Data

Hastings, Daniel.
Spacecraft-environment interactions/Daniel Hastings, Henry Garrett.
p. cm. – (Cambridge atmospheric and space science series)
Includes bibliographical references and index.
ISBN 0 521 47128 1 (hardback)
1. Space environment. 2. Space vehicles – Design and construction.
I. Garrett, Henry B. II. Title. III. Series. 95-47376
TL1489. H37 1996 CIP
629.4′16 – dc20

ISBN 0 521 47128 1 Hardback
ISBN 0 521 60756 6 Paperback

Cambridge University Press
0521607566 - Spacecraft-Environment Interactions
Daniel Hastings and Henry Garrett
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Preface

At the very beginning of the space age, spacecraft designers learned that the effects of the space environment on a spacecraft's systems would be vital factors in spacecraft design and operation. Since those early years, the topic of spacecraft–environment interactions has developed into a multidisciplinary field involving engineers and scientists from all over the world. Traditionally, engineers have been interested in spacecraft design and operational issues, and scientists have concentrated on the fundamental physics and chemistry associated with the interactions. These diverse interests have led to numerous books and conferences. The field has grown substantially in the past decade with the advent of the Shuttle and the ability to perform repeatable, in-situ experiments. The authors therefore concluded that, with the growth of the field and the expanding interest in it, it was timely to prepare a comprehensive book summarizing the many recent discoveries. In particular, since the field has evolved in a way that has been driven by mission and spacecraft requirements rather than as a specific discipline, a book would be a valuable step in integrating the field intellectually. Such a book would also serve as an introduction to the discipline for graduate students and professionals. For specific applications, these individuals could then turn to one of the handbooks or collections of conference papers referenced throughout the book.

This book is the direct outgrowth of courses that the authors have taught. One of us (DEH) has for several years taught a class at the Massachusetts Institute of Technology (MIT) on the subject of spacecraft–environment interactions. This course, aimed at MIT seniors or first-year graduate students, is intended to serve as an entry point for students wishing to go on to research in the field of spacecraft–environment interactions or to learn about the discipline so that they can then go on to spacecraft system engineering. It is also intended as the final course for undergraduate or Master's engineering students interested in the applications of fluid, gas, and plasma dynamics to spacecraft. The other author (HBG), an internationally recognized consultant in the field, has developed a short course based on his actual experiences in spacecraft interactions which has been taught throughout the U.S. Air Force, industry, and internationally. He has participated in almost all of the recent interplanetary missions and many of the Earth-orbiting spacecraft (*SCATHA*, TDRSS, INTELSAT, Galileo, Cassini, HST, *Space Station*, and *Clementine*). These missions have provided numerous practical examples for the book and illustrate many of the issues that arise in designing spacecraft or diagnosing failures.

The central idea developed in this book is that every spacecraft has a set of characteristic interactions (to be defined) with the ambient environment and its self-induced environment. These interactions affect the basic operation of the spacecraft as well as any scientific experiments undertaken from the spacecraft platform. The interactions in turn shed light on the ambient environment. The emphasis in this book is on the physics of the interactions in order to introduce, the basic concepts. However, at the end of most of the sections of the book, the reader will be able to make a simple estimate of the effect of the interaction on the spacecraft. For specific applications, the reader is referred to other books in the field aimed at professional engineers and scientists (also see the extensive References provided):

(1) Al'pert, Ya. L., Gurevich, A. V., and Pitaevskii, L. P., *Space Physics with Artificial Satellites*, Consultants Bureau, New York, 1965
(2) Garrett, H. B., and Pike, C., *Space Systems and Their Interactions with Earth's Space Environment*, Progress in Aeronautics and Astronautics, Vol. 71, AIAA, Washington, DC, 1980

More recent works are:

(3) DeWitt, R. N., Duston, D. P., and Hyder, A. K., *The Behavior of Systems in the Space Environment*, Kluwer Academic Publishers, 1994
(4) Tribble, A., *The Space Environment: Implications for Spacecraft Design*, Princeton University Press, 1995

A book that contains aspects of the interaction issues, but from a systems engineering viewpoint, is:

(5) Wertz, J. R., and Larsen, W. J., *Space Mission Analysis and Design*, Kluwer Academic Publishers, 1991

The chapters in the book are roughly divided between those describing the environment and those describing the interactions. The chapters on the space environment treat both the ambient and the induced environments. The chapters describing the interactions introduce the interaction, describe the relevant physics and chemistry, and then describe qualitatively the practical issues for a spacecraft. Each chapter has extensive references and a bibliography. However, because this book is aimed at individuals entering the field, we have generally included only references that can be found easily in a research library. Occasionally, it is necessary to refer to conference proceedings when no other source of information is available. However, given the difficulties in obtaining copies of the older proceedings, this is kept to a minimum.

The book is arranged as follows.

In Chapter 1, the environments that a spacecraft experiences are described qualitatively. The practice of describing the environment in terms of common orbits is introduced. Next, the notion that the spacecraft is an active player in its environment is discussed. Finally, the history of spacecraft–environment interactions that have been identified and their impact on spacecraft operations are briefly reviewed.

In Chapter 2, the concepts of the characteristic lengths, time scales, and critical velocities for plasma physics, gas dynamics, and radiation physics are introduced. The relevant equations that describe the interactions are introduced along with the terminology and approximations necessary to reduce the equations that describe the physics down to manageable solutions. For example, in the area of plasma physics, the concept of a Debye length and the comparison of this characteristic length to the spacecraft body scale are introduced. The physical approximations that are allowed in the Poisson equation when the Debye length is large or small compared to the body scale will then be presented. In the area of gas dynamics, the Knudsen number is introduced and the physical approximations that result when the Knudsen number is small or large are addressed. For radiation interactions with matter, the idea of linear energy transfer is introduced, which permits straightforward estimates of single-event effects on microelectronic devices.

In Chapter 3, the ambient space environment is described. The ambient environment is analyzed in terms of the regions encountered along common spacecraft orbits or of the type of environment (plasma, radiation, neutral particle, or macroscopic particulates). The intent is to allow the reader to estimate the ambient environment around a spacecraft along a typical orbit.

In Chapter 4, the physics of the interactions of a neutral gas with a spacecraft are addressed. Interactions such as drag, sputtering, glow, and contamination are introduced. The modification of the environment by spacecraft operations is discussed. The physics of each type of neutral interaction are explored using the concepts developed in Chapter 2.

In Chapter 5, the interactions of the space plasma with a spacecraft are addressed. Interactions associated with charging, arcing, electromagnetic interference, and power generation are introduced. The physics of each type of plasma interaction are developed. The operational spacecraft database built upon these interactions is explored along with the implications of each interaction for the design and operation of a typical spacecraft.

In Chapter 6, the interactions of the space radiation environment with spacecraft materials are addressed. Of the interactions, physical damage due to radiation and single-event effects are the most important. Recent information from the *CRRES* satellite are incorporated.

In Chapter 7, the interactions of macroscopic particulates with a spacecraft are discussed. Impact of a spacecraft with orbital debris and scattering of electromagnetic radiation from particulates are introduced. Tactics for designing effective debris and meteoroid shields are outlined and compared with case studies.

In the concluding chapter, Chapter 8, the state of the field as it existed in 1995 is discussed. In addition, future trends in environmental interactions are addressed. A critical issue that emerges in this chapter is the inherent cost of carrying out detailed analyses of the interactions – the means for assessing what interactions are important for a specific mission is an important consideration for the future.

Finally, a word about units. As far as possible we have used MKS units with the choice that energies are frequently in electron volts (eV). However, in the field of environmental interactions, there is still widespread use of CGS units and their use is unavoidable, especially when using figures from older works. The convention that we adopt is to give all formulae in MKS units unless we explicitly state that they are in other units.

Daniel Hastings
Henry Garrett

Acknowledgment

This book is the product of years of research and support from countless individuals. We would like to acknowledge MIT for allowing one of us (DEH) to take time off to write this book. At this time the Air Force Phillips Lab at Hanscom AFB must be acknowledged for their hospitality and for providing an intellectual environment where high-quality work is possible. The support and encouragement of Dr. David Hardy was critical. The stellar work of Robie SamantaRoy, Gabriel Font-Rodriguez, Jim Soldi, David Oh, Carmen Perez de la Cruz, Graeme Shaw, and Derek Plansky in providing pictures as well as insightful comments is also greatly appreciated. Henry Garrett would also like to acknowledge his two mentors in this field: A. J. Dessler (space environments) and N. J. Stevens (space interactions). Many colleagues also provided insightful comments and read the draft. Without them, this work could not have been completed. Particular credit goes to Carolyn Purvis of NASA Lewis and Albert Whittlesey of JPL who read the entire manuscript and have always been great supporters of the field. Finally, we would like to acknowledge our wives, Donna Hastings and Katherine Garrett, and our families whose encouragement and support made this work possible.