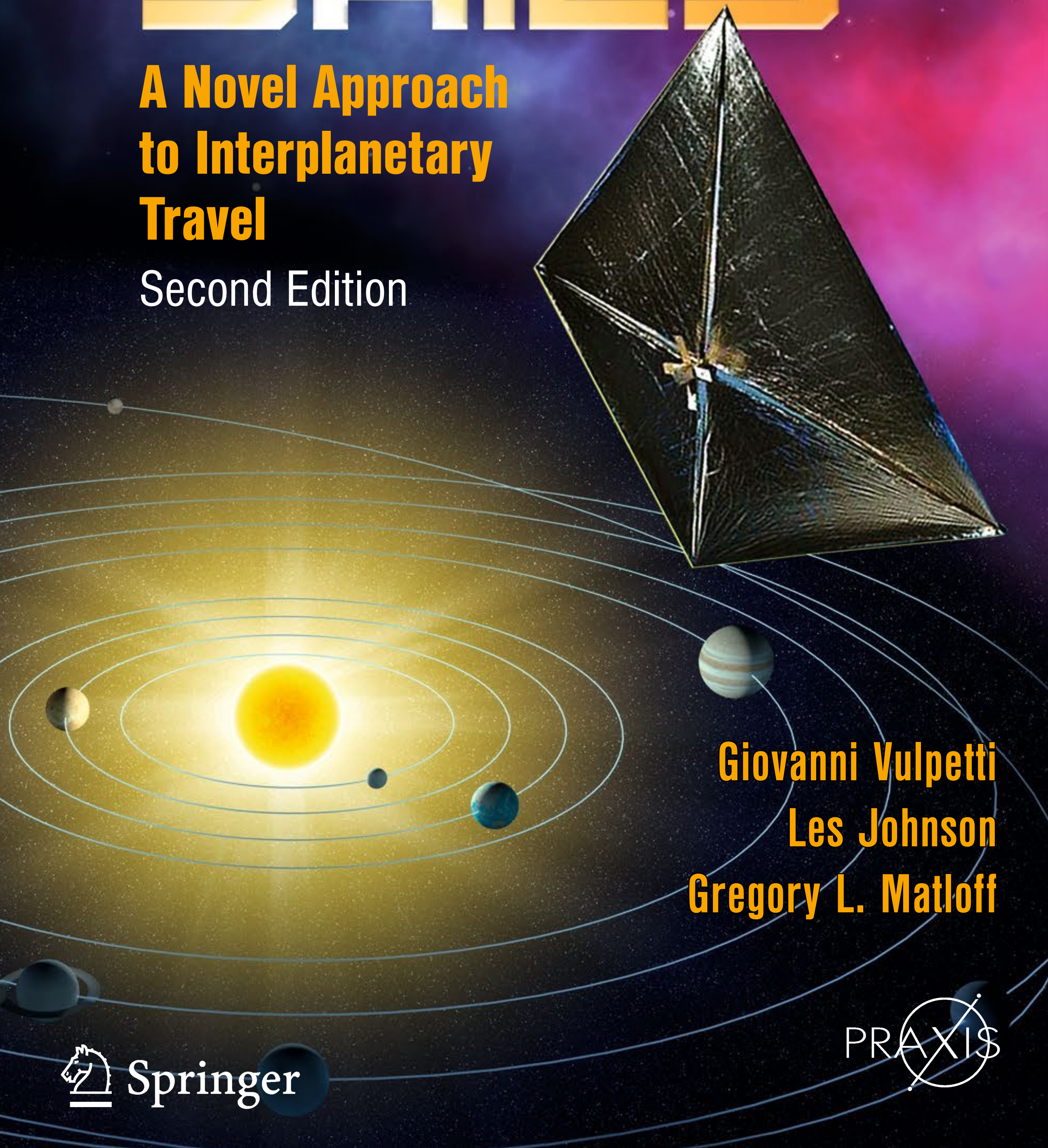
SOLAR SAILS

A Novel Approach to Interplanetary Travel

Second Edition



Giovanni Vulpetti
Les Johnson
Gregory L. Matloff

Springer
PRAXIS

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Published in association with
Praxis Publishing
Chichester, UK

PRAXIS

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SPRINGER-PRAXIS BOOKS IN SPACE EXPLORATION

ISBN 978-1-4939-0940-7 ISBN 978-1-4939-0941-4 (eBook)
DOI 10.1007/978-1-4939-0941-4
Springer New York Heidelberg Dordrecht London

Library of Congress Control Number: 2014950112

Cover design: Jim Wilkie

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Contents

Part III Construction of Sailcraft

Part IV Breakthroughs in Space

Part V Space Sailing: Some Technical Aspects

Dedicated to

My daughter Désirée and my son David

Giovanni Vulpetti

Carol, my wife and companion on this life's journey

Les Johnson

My wife, partner, and colleague, C Bangs

Gregory L. Matloff

Foreword

The title of this book indirectly reflects the rich history of solar sailing's dual existence in fiction and reality. Solar sailing was first invented in a technical analysis by Russian scientists Fredrikh Tsander and Konstantin Tsilokovsky in the 1920s applying laws of physics discovered only a few decades earlier. The first Western technical consideration of it was an engineering analysis published in a science-fiction magazine. Then it received attention in science-fiction literature and early NASA technical publications, about equally, until the advent of the space shuttle, which made it possible to consider deployment of large structures in space. That allowed NASA to at least consider its practical application for a rendezvous with Halley's Comet.

This second edition of Vulpetti's, Johnson's, and Matloff's compendium all about solar sails is well timed to chronicle the transition taking solar sail firmly from fiction to reality. This edition tells the story of the first successful solar-sail flight, IKAROS, by the Japanese space agency and that of other efforts now under way for solar-sail missions in Earth orbit, cis-lunar space, and the first interplanetary missions.

Sailing appeals both because it is beautiful—gossamer structures reflecting light in space, sailing without motors, and because it is the only technology that we know which might enable interstellar flight. It is the vision of flying to other worlds beyond our solar system that makes solar sailing of special interest. Realizing that vision may take centuries, but the technology, flying by light, has practical applications right now—monitoring solar weather helping to protect the Earth's power and communications grids, observing Earth's climate over the poles, carrying large payloads on round-trip missions to the planets, and providing a light-weight source of propulsion for a new class of nano-spacecraft are examples.

The authors' text, updated to include the new missions and new concepts, gives us a complete view of the technology. It also helps bring the vision of the distant missions into focus with description of current activities, research and development.

Louis Friedman

Foreword to the First Edition

At the time of writing, a true solar sail has yet to be flown in space. Yet despite this, there is tremendous international interest in this exciting and visionary concept. The excitement is captured in this excellent book which contains something for everyone, from a non-mathematical discussion of the principles of solar sailing to a detailed mathematical analysis of solar-sail trajectories. More than that, the book places solar sailing in its proper context by providing a discussion of other propulsion technologies and highlights the benefits (and limitations) of solar sailing.

For the lay reader the book provides a complete introduction to, and discussion of, space propulsion. For the professional scientist and engineer it provides a starting point to further explore the uses of solar sailing. For all readers, it should inspire. Solar sailing is perhaps the most captivating form of spacecraft propulsion currently under development. While other advanced concepts will not make the jump from imagination to reality for many years to come, solar sailing promises to become a reality in the near term. Read this book, and then tell your friends and colleagues that someday very soon we may be literally sailing through space on a sun beam.

Glasgow — Colin McInnes
31 May 2007

Preface to the First Edition

This is one of the first books devoted to space solar sailing written in the twenty-first century. It is intended for both space enthusiasts (nonexperts) and those who are more technically trained. Never before has solar-sail propulsion been so close to being demonstrated via real missions around the Earth. After a number of preliminary tasks in space, the National Aeronautics and Space Administration (NASA), the European Space Agency (ESA), and the Japan Aerospace Exploration Agency (JAXA) are now designing real experimental missions to be accomplished by the first generation of solar-sail technology. Historically, we mention three serious attempts that began the solar-sail era in space. First, the solar-sail mission to the comet Halley, fostered by JPL in the 1970s, was ultimately not approved by NASA. In 1997, the precursor sailcraft Daedalus, fostered by ESA/ESTEC, received no approval from the ESA Council. In 2005, the small experimental sailcraft Cosmos-1, sponsored by the Planetary Society (USA), was not successful due to the failure of the Russian submarine-based launch vehicle. However, despite these aborted attempts, the problems these mission planners dealt with provided a serious base for many further studies and serious technology development activities. Strangely enough, following these "failed" attempts, theoretical research and ground demonstrations of small-sail deployment increased in number. The benefits of solar sailing are so clear and compelling that national space agencies and private organizations could not miss the chance to make a quality jump forward in space propulsion, potentially enabling exciting new science and exploration missions throughout the solar system.

This book has four parts. The first three parts are intended for the nontechnical reader who wishes to learn more about one of the most intriguing aspects of near- and medium-term spaceflight: solar-sail propulsion and the missions that solar sailing will enable. These parts are completely self-consistent and self-sufficient. Various "technical boxes" have been inserted to provide the interested reader with a more technical or historical explanation. The fourth part contains the supporting mathematics, intended for more technical readers, and in particular for undergraduate students. A glossary is provided at the end of the book containing definitions of many key terms. Many topics discussed in this book are technical in nature, yet the fundamental principles may be readily understood by even the most casual reader. Regardless of the reader's general interest level, the authors have made significant efforts to achieve the following goals:

- Technical correctness in all aspects of the book
- Completeness of the main topics and subtopics within the limits of a reasonably sized book
- Timeliness, as the designs, realizations, and information related to space sailing were updated up to the moment the manuscript was sent to the publisher.

Part I, Space Engines: Past and Present, contains five chapters. Chapter 1 introduces the fundamentals of spacecraft propulsion. Chapter 2 describes how rocket engines work. Chapter 3 addresses the problems and limitations of chemical, nuclear, and ion rocket propulsion. Chapter 4 considers various non-rocket technologies that may be used for space propulsion. Chapter 5 introduces the sailing concept by starting from afar—about 45 centuries ago in the Mediterranean Sea, where the Phoenicians invented a very efficient way for navigating the seas. Some of their intuitions still hold for both sailing earthly seas and in space. The authors then summarize how conventional wind sailboats work. From related physical phenomena, consider space sails—their operational analogies and their first important differences with respect to wind-powered sails. The authors subsequently introduce the amazing nature of light and its progressive scientific comprehension that began just a few centuries ago.

Part II, Space Missions by Sail, contains five chapters. Chapter 6 states that space sailing is "free," deriving propulsion from either sunlight or the solar wind. Differences between the concepts of sunlight-driven solar sails, magnetic sails, plasma sails, and electric sails are discussed. Chapter 7 is devoted to the concept of sail spacecraft, or sailcraft, and how they drive the design of a completely new class of spacecraft. Also, the concept of micro-sailcraft is introduced. Chapter 8 compares rocket propulsion and (photon) solar-sail propulsion from many practical viewpoints: design, complexity, risks, mission requirements, and range of application. Chapter 9 is devoted to exploring and developing space by sailcraft. Near-term, medium-term, long-term, and interstellar missions are discussed; sailships to other stars are given a special emphasis. Chapter 10 describes different ways of "riding" a beam of light. Sailing via laser or microwaves is discussed and compared with the so-called particle-beam sail propulsion.

Part III, Construction of Sailcraft, contains four chapters. Chapter 11 tackles the problem of designing a solar sail. There exist different sail types according to their mission aims and stabilization modes. Maneuvering a solar sail is a fundamental operation in space. This chapter explains what spacecraft attitude is and the various sail attitude control methods that may be used. Chapter 12 deals with the problem of building a sailcraft by using today's technologies or emerging technologies for tomorrow's high-performance space sailing missions. After exploring the current policies for the first solar-sail missions, the chapter introduces nanotechnology fundamentals and some of its expected features. The chapter ends by stressing what one may conceive beyond nanotechnology—a science-fiction realm indeed. Chapter 13 discusses the advancements made to date, starting from the pioneering sail/sailcraft designs and the role of the various national space agencies, and concludes with past and current private initiatives and collaborations. Chapter 14 discusses the future plans for solar sailing in the USA, Europe, and Japan.

Part IV, Space Sailing: Some Technical Aspects, is intended for more technical readers, in particular for undergraduate students in physics, engineering, and mathematics. Although the math has been kept simple, a modest background in physics and elementary calculus is advisable. The chapters in this section contain concepts, explanations, and many figures to more technically describe sailcraft missions and their feasibility. Chapter 15 is devoted to the space sources of light, and the Sun in particular. After basic optical definitions and concepts, emphasis is put on the solar electromagnetic radiation spectrum, its variability, and the measurements made in the space era by instruments on some solar-physics satellites. Total solar irradiance, a fundamental element in solar sailing, is discussed widely. Chapter 16 starts from the heliocentric and sailcraft frames of reference and shows how to get the inertial-frame thrust acceleration from the lightness vector, defined in the sailcraft frame, through momentum-transfer phenomena. The main features of the sailcraft acceleration are highlighted via reference accelerations of particular physical meaning. Chapter 17 is the central piece of Part IV. The authors show the class of sailcraft trajectories via several technical plots. Some trajectories have been designed in the past decades, some others were investigated in the first years of this century, and others have been calculated specifically for this book by means of modern (and very complex) computer codes. After a discussion of the formal sailcraft motion vector equation, the reader is introduced to general Keplerian orbits. Then, interplanetary transfer trajectories to planets are discussed. Non-Keplerian orbits are explained, as are many-body orbits and their main characteristics, and fast and very fast solar sailing. Chapter 18 deals with the important and delicate matter of the impact of the space environment on the whole sail system design. The reader is introduced to the main environmental problems that affect a solar-sail mission, especially if it is close to the Sun.

Preface to the Second Edition

This is the first mostly popular, and partially technical, book devoted to solar-photon sailing after the first sailcraft mission of the history of Astronautics, namely, the Japanese sailcraft IKAROS, launched by JAXA from the Tanegashima Space Center on May 21, 2010. IKAROS, or the Interplanetary Kite-craft Accelerated by Radiation Of the Sun, was the second passenger of the JAXA launcher H-IIA No. 17. The GUINNESS World Record certified IKAROS mission is a breakthrough for space solar sailing. It has been proved that the in-space propulsion known as *the solar-sail thrusting* exists with, no doubt, closing silly controversies (especially via Internet) on the physics of space solar sailing, whereupon there were produced wrong statements by whom who do not know Physics very well (and often claim to be expert at it).

NASA NanoSail-D2, the first sailcraft mission with purposes different from IKAROS—but demonstrating that not only solar sailing is real but also that it could be used for mitigating humans-caused problems in Space—was launched on November 19, 2010 as a payload on NASA's Fast, Affordable, Science and Technology SATellite (FASTSAT) from Kodiak, Alaska. (This satellite was fully designed and developed in 14 months at NASA's Marshall Space Flight Center (MSFC) in partnership with the Von Braun Center for Science & Innovation and Dynetics, both in Huntsville, Alabama, and with the Department of Defense's Space Test Program.) Ground operations support for IKAROS was provided by Santa Clara University, while the NanoSail-D experiment was managed by MSFC.

This book tells the reader about the past efforts, the current plans, and the future programs of the very promising in-space propulsion, which scientists and engineers call the Solar-Photon Sailing (SPS), by putting an emphasis on *solar* and *photon*. As a point of fact, such propulsion mode resorts to the solar irradiance (not to maser or laser-originated light), which—being electromagnetic waves—carries a pressure (called the radiation pressure) coming to act on a surface, the sail's one. The incident solar waves are essentially reflected or absorbed by the (first) layer of the sail. The process of reflection comes from the diffraction of the solar light, which can be described classically. Space sailing works by using an object with sufficiently high area-to-mass ratio in order to take advantage of the *momenta* of the *scattered* and *absorbed* (solar) *photons*. Thus, the space sailing concept—now a reality—described in this book is propulsion sustained by the photons continuously released by the Sun into space. There are other space sailing concepts, namely, the magnetic-sail, the plasma-sail, or the electric-sail concepts, that are based on the dynamical pressure of the solar wind. This one is over three orders of magnitude lower than the solar radiation pressure, and fluctuates considerably. In contrast, the solar radiation pressure is sufficiently stable for designing a quasi-deterministic trajectory for a space vehicle endowed with a sail or a sailcraft. A sailcraft consists of the sail system and its payload, i.e., the spacecraft. In other words, sailcraft = sail system + spacecraft.

Just for the mentioned properties, SPS sailcraft could be very small, or also very large, as the materials and the spacecraft concepts evolve. Enormous advance in this sense, literally, is expected from the Nanotechnology. Mature SPS sailcraft will have none of the limitations exhibited by rocket-based space vehicle.

With respect to the first edition, this book has been changed by (1) adding new chapters, (2) enlarging many of the previous ones, (3) updating many pieces of information, and (4) amending a number of items with clearer explanations. The authors hope that even undergraduate students may benefit from an entire part devoted to them.

This edition has been arranged as follows: there are *five* parts instead of four. The first four have been intended for the nontechnical reader who wishes to "visit" the intriguing world of SPS without the expertise of a scientist. Such parts are completely self-sufficient. The last part—the fifth one—is devoted to the more technically inclined reader who could, in addition, benefit of the popular parts, and enlarge her/his view by learning the history, the current scenarios, and the plans of SPS. This book consists of 21 chapters so arranged:

Part-I, entitled **Space Engines: Past and Present**, consists of five chapters. Chapter 1 introduces the reader to space propulsion from a historical viewpoint; propulsion history is an integral part of the history of Astronautics. Chapter 2 describes how rocket engines work in general. Chapter 3 addresses the intrinsic limitation of rocket propulsion, beginning from the chemical one, and analyzing nuclear and electric propulsion. Chapter 4 considers different-from-rocket concepts and the related technologies. Chapter 5 uses an approach unusual with respect to the normal talking on advanced space propulsion. It introduces the sailing concept by starting from afar, namely, about 45 centuries ago in the Mediterranean Sea, where the Phoenicians invented a very efficient way for navigating the seas. Some of their intuitions still hold for both sailing earthly seas and in space. The authors then summarize how conventional wind sailboats work. From the related physical phenomena, they consider space sails, their operational analogies, and their first important differences with respect to wind-driven sails. The authors subsequently introduce the amazing nature of light and its progressive scientific comprehension that began just a few centuries ago.

Part-II, **Space Missions by Sail**, has five chapters. In Chap. 6, it is stated that space sailing is "free," as propulsion deriving from either sunlight or the solar wind. Differences between the concepts of sunlight-driven solar sails, magnetic sails, plasma sails, and electric sails are discussed. Chapter 7 deals with the concepts of sail-based space vehicles (sailcraft) and how they lead up to a class of spacecraft completely new. In addition, the concept of micro-sailcraft is introduced. Chapter 8 compares rocket propulsion and (photon) solar-sail propulsion from many practical viewpoints: design, complexity, risks, mission requirements, and range of application. Chapter 9 is devoted to exploring and developing space by sailcraft. Near-term, medium-term, long-term, and interstellar missions are discussed. Sailships to other stars are given a special emphasis. Chapter 10 describes different ways of "riding" a beam of light. Sailing via laser or microwaves is discussed and compared with the so-called particle-beam sail propulsion.

Four chapters can be found in Part-III, called **Construction of Sailcraft**. Chapter 11 tackles the problem of designing a solar sail. There is no single "best" solution, which will fit all potential needs and mission scenarios. This chapter is divided into two major sections. First, we will discuss the most viable solar-sail design options, and the pros and cons of each, including the problem of controlling the orientation of a sail in space. Then, we will face with technological aspects in building a sailcraft. Chapter 12 deals with the problem of building a sailcraft by using today's technologies or emerging technologies for tomorrow's high-performance space sailing missions. After exploring the current policies for the current generation of sail-based missions, the chapter introduces nanotechnology fundamentals and some of its expected features. The chapter ends by stressing what one may conceive beyond nanotechnology—a science-fiction realm indeed. Chapter 13 discusses the advancements made to date, starting from the pioneering sail/sailcraft designs and the role of the various national space agencies, and concludes with past and current private initiatives and collaborations. Chapter 14 discusses the plans for solar sailing advancements in (substantially) the USA, Europe, and Japan, as (at the time of this writing) no other country appears to have space sailcraft plans.

Part-IV, **Breakthroughs in Space**, contains three completely new chapters, which describe what happened in the SPS area from the first edition (of the book) to the new sailcraft designs in progress. Chapter 15 is devoted to the breakthrough in SPS, i.e., the IKAROS mission. Chapter 16 regards the smaller, but remarkable, sailcraft NanoSail-D2 by NASA. Chapter 17 informs the reader how many SPS projects are in progress in Europe, Japan, and USA.

Finally, undergraduate students and technical people, wanting to enter the SPS via some mathematics, may find some of the basics of SPS in the four chapters of Part-V, namely, **Space Sailing: Some Technical Aspects**. Mathematics has been kept simple; however, a modest background in physics and elementary calculus is advisable. The chapters in this section contain concepts, explanations, and many figures in order to describe sailcraft missions (and their feasibility) more quantitatively. Chapter 18 is devoted mostly to the features of the solar light. After basic macroscopic optical concepts, emphasis is put on the solar electromagnetic radiation spectrum, its variability, and the measurements made by instruments onboard solar-physics spacecraft. Total solar irradiance, a fundamental element in solar sailing, is discussed widely. Chapter 19 starts from the heliocentric and sailcraft frames of reference, and shows how to get the thrust acceleration by using the formalism of the lightness vector, defined in the sailcraft frame, through momentum-transfer phenomena. The main features of the sailcraft acceleration are discussed by highlighting particular physical meanings. Chapter 20 is the central piece of Part V. The authors show the class of sailcraft trajectories via several technical plots. Some trajectories have been designed in the past decades, some others were investigated in the first years of this century, and others have been calculated specifically for this book by means of modern (and very complex) computer codes. After a discussion of the formal sailcraft motion vector equation, the reader is introduced to general Keplerian orbits. Then, interplanetary transfer trajectories to planets are discussed shortly. Non-Keplerian orbits are explained, as are many-body orbits and their main characteristics, and fast solar sailing. Chapter 21 deals with the important and delicate matter of determining the behavior of an unusual large object in the space environment. The reader is introduced to the main environmental problems that affect a solar-sail mission, especially if it is close to the Sun.

Although this book contains some hundred pages, the covered areas are vast. However, the authors made much effort for achieving the following objectives:

1. Taking care of the technical correctness.
2. Giving the reader as wide a general view of the subject as possible.
3. Being timely, namely, all pieces of information are updated up to the moment the manuscript was sent to the publisher.

Acknowledgments

Six years have elapsed from the issue of the first edition of this book. Even more, the authors continue to express plenty of thanks to their wonderful families for the comprehension, the patience, and even for some very fine suggestions received in additional 18 months of writing effort, a job carried out mostly in the evening and during many, many weekends.

Many and friendly thanks go to Mr. Paul Gilster, writer and editor of Centauri Dreams, and lead journalist at Tau Zero Foundation. He kindly accepted the authors' invitation to preview this book, a fact considerably appreciated by the authors.

Special thanks go to the Springer New York and, in particular, to Ms. Jennifer Satten, the Associate Editor for Physics, Astronomy & Astrophysics. Her support during the copyediting process has been invaluable indeed.

Finally, the authors appreciated the many emails received from students (high schools or university), from many countries of three continents, asking the authors for further explanations. Many of them received a bachelor's, a Master's, or a PhD too in these six years; someone conceived new solar-sail missions and published the results of their calculations on prestigious scientific journals. All this is of great satisfaction for the authors.

June 2014

Giovanni Vulpetti
Les Johnson
Greg Matloff

About the Authors

Giovanni Vulpetti received his Ph.D. in plasma physics in 1973. Subsequently, he specialized in astrodynamics. He wrote many tens of scientific papers about astrodynamics, advanced propulsion concepts, and interstellar flight, with particular regard to matter–antimatter annihilation propulsion. In 1979, he joined Telespazio SpA (Rome, Italy). From 1995 to 2011, he has attended the committee for Lunar Base & Mars exploration of the *International Academy of Astronautics* (IAA). He has been involved in solar-photon sailing since 1992. In the 1990s, he found out new types of sailcraft trajectories and published his theory mainly on Acta Astronautica, JPL workshops, and IAA symposia. In 1994, he was elected a Full Member of IAA. In spring 1997, he was a consultant at ESA/ESTEC about the solar-sail mission concept Daedalus. In 1979–2004, he contributed to 11 Italian and European space programs. In 2001, he was a consultant at NASA/MSFC for the NASA Interstellar Probe. In the course of two decades, he accomplished some large computer codes devoted to mission analysis and trajectory optimization via rockets and/or solar sails. In the 1990s, he was a member of the IAA committee for small satellites and, consequently, he participated in the design of Telespazio TemiSat (launched in August 1993). During 2006–2007, he joined Galilean Plus (Rome, Italy) as chief scientist, and participated in the program of the Italian Space Agency for lunar explorations. To date, he has published about 120 research papers and reports. He was a COSPAR-Associate in 2002–2007. In 2009 and 2014, he served as managing guest editor of Acta Astronautica special issues. He wrote the book *Fast Solar Sailing, Astrodynamics of Special Sailcraft Trajectories*, Space Technology Library 30, Springer 2012. Since spring 2013, he has been a guest lecturer on the physics of in-space propulsion at the Dept. of Astronautical Engineering of University of Rome "La Sapienza."

Les Johnson is a physicist at NASA's Marshall Space Flight Center in Huntsville, Alabama, where he serves as the Senior Technical Advisor for the Advanced Concepts Office. He was a Co-Investigator on the Japanese T-Rex space tether experiment, the Principal Investigator of the NASA ProSEDS mission, and the first manager of NASA's In-Space Propulsion Technology Project. He holds three patents and was thrice awarded

NASA's Exceptional Achievement Medal. He is a TEDx speaker, was the featured "interstellar explorer" in National Geographic's January 2013 issue, and is a member of the Advisory Board for The Journal of the British Interplanetary Society. Les and his wife, Carol, have two children and live in Madison, Alabama (a satellite community of Huntsville—the original "Rocket City, USA!").

Greg Matloff is a leading expert in possibilities for interstellar propulsion, especially near-Sun solar-sail trajectories that might ultimately enable interstellar travel, and is an astronomy professor with the physics department of New York City College of Technology, CUNY, a consultant with NASA Marshall Space Flight Center, a Hayden Associate of the American Museum of Natural History, and a Member of the International Academy of Astronautics. He coauthored with Les Johnson of NASA and C Bangs *Paradise Regained (2009)*, *Living Off the Land in Space* (2007) and has authored *Deep-Space Probes* (edition 1: 2000 and edition 2: 2005). As well as authoring *More Telescope Power* (2002), *Telescope Power* (1993), and *The Urban Astronomer* (1991), he coauthored with Eugene Mallove *The Starflight Handbook* (1989). His papers on interstellar travel, the search for extraterrestrial artifacts, and methods of protecting Earth from asteroid impacts have been published in *JBIS, Acta Astronautica, Spaceflight, Space Technology, Journal of Astronautical Sciences*, and *Mercury*. His popular articles have appeared in many publications, including *Analog* and *IEEE Spectrum*. In 1998, he won a $5000 prize in the international essay contest on ETI sponsored by the National Institute for Discovery Science. He served on a November 2007 panel organized by *Seed* magazine to brief Congressional staff on the possibilities of a sustainable, meaningful space program. Professor Matloff is a Fellow of the British Interplanetary Society. He has chaired many technical sessions and is listed in numerous volumes of *Who's Who*. In 2008, he was honored as Scholar on Campus at New York City College of Technology. In addition to his interstellar-travel research, he has contributed to SETI (the Search for Extraterrestrial Intelligence), modeling studies of human effects on Earth's atmosphere, interplanetary exploration concept analysis, alternative energy, in-space navigation, and the search for extrasolar planets. His Web site is www.gregmatloff.com.

Part I
Space Engines: Past and Present

1

An Historical Introduction to Space Propulsion

We'll never know when the dream of spaceflight first appeared in human consciousness, or to whom it first appeared. Perhaps it was in the sunbaked plains of Africa or on a high mountain pass in alpine Europe. One of our nameless ancestors looked up at the night sky and wondered at the moving lights in the heavens.

Was the Moon another world similar to Earth? And what were those bright lights—the ones we call planets[1]—that constantly change position against the background of distant stellar luminaries? Were they gods and goddesses, as suggested by the astrologers, or were they sisters to our Earth?

And if they were other worlds, could we perhaps emulate the birds, fly up to the deep heavens and visit them? Perhaps it was during a star-strewn, Moon-illuminated night by the banks of the river Nile or on the shores of the Mediterranean, as early sailing craft began to prepare for the morning trip upriver or the more hazardous sea voyage to the Cycladic Isles, that an imaginative soul, watching the pre-dawn preparations of the sailors, illuminated by those strange celestial beacons, might have wondered: If we can conquer the river and sea with our nautical technology, can we reach further? Can we visit the Moon? Can we view a planet close up?

It would be millennia before these dreams would be fulfilled. But they soon permeated the world of myth.

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[1] "Planet" is a very old and popular word, coming from the Greek, which means *wanderer* or "wandering star", namely, something like a star that moves on the *background* of *fixed stars* on the celestial sphere. Only in August 2006, the International Astronomical Union (http://www.iau.org/) adopted a scientific definition of planet. Accordingly, Pluto is now considered as a dwarf planet, and even it is the prototype of a set of bodies (in the solar system) called the *plutoids*, the orbits of which are beyond the planet Neptune (http://www.iau.org/public/themes/pluto/).

G. Vulpetti et al., *Solar Sails,* Springer Praxis Books,
DOI 10.1007/978-1-4939-0941-4_1

A BRONZE AGE ASTRONAUT

These early ponderings entered human mythology and legend. According to one Bronze Age tale, there was a brilliant engineer and architect named Daedalus who lived on the island of Crete about 4,000 years ago. For some offense, he and his son, Icarus, were imprisoned in a tower in Knossos, which was at that time the major city in Crete.

Being fed a diet of geese and illuminating their quarters with candles, Daedalus and Icarus accumulated a large supply of feathers and wax. Being a brilliant inventor, Daedalus fashioned two primitive hang gliders. Wings could be flapped so that the father and son could control their craft in flight.

It's not clear what their destination would be. One version of the story has the team attempting the long haul to Sicily. Another has them crossing the more reasonable 100-km distance to the volcanic island of Santorini. It's interesting to note that a human-powered aircraft successfully completed the hop between Crete and Santorini only a few years ago, thereby emulating a mythological air voyage of the distant past.

Daedalus, being more mature, was cautious and content to be the first aviator. The youthful, headstrong Icarus was somewhat more ambitious. Desiring to become the first astronaut, he ignored his father's pleas and climbed higher and higher in the Mediterranean sky. Unlike modern people, the Bronze Age Minoans had no concept of the limits of the atmosphere and the vastness of space. Icarus therefore flapped his wings, climbed higher, and finally approached the Sun. The Sun's heat melted the wax; the wings came apart. Icarus plunged to his death as his father watched in horror.

A few thousand years passed before the next fictional physical space flight was attempted. But during this time frame, several Hindu Yogi are reputed to have traveled in space by methods of astral projection.

EARLY SCIENCE FICTION; THE FIRST ROCKET SCIENTIST

Starting with Pythagoras in the sixth century B.C., classical scholars began the arduous task of charting the motions of the Moon and planets, and constructing the first crude mathematical models of the cosmos. But they still had no idea that Earth's atmosphere did not pervade the universe. In what might be the first science fiction novel, creatively entitled *True History*, the second-century A.D. author Lucian of Samosata imagined an enormous waterspout carrying himself, inside the belly of a whale, up to the Moon. Other authors assumed that flocks of migratory geese (this time with all their feathers firmly attached) could be induced to carry fictional heroes to the celestial realm.

What is very interesting is that all of these classical authors chose to ignore an experiment taking place during the late pre-Christian era that would pave the way to eventual cosmic travel. Hero of Alexandria, in about 50 B.C., constructed a device he called an aeolipile. Water from a boiler was allowed to vent from pipes in a suspended sphere. The hot vented steam caused the sphere to spin, in a manner not unlike a rotary lawn sprinkler. Hero did not realize what his toy would lead to, nor did the early science fiction authors. Hero's aeolipile is the ancestor of the rocket.

Although Westerners ignored rocket technology for more than 1,000 years, this was not true in the East. As early as 900 A.D., crude sky rockets were in use in China, both as weapons of war and fireworks.

PERHAPS HE WANTED TO MEET THE "MAN IN THE MOON"

Icarus may have been the first mythological astronaut, but the first legendary rocketeer was a Chinese Mandarin named Wan Hu. Around 1000 A.D., this wealthy man began to become world-weary. He asked his loyal retainers to carry him, on his throne, to a hillside where he could watch the rising Moon. After positioning their master facing the direction of moonrise, the loyal servants attached kites and strings of their most powerful gunpowder-filled skyrockets to their master's throne.

As the Moon rose, Wan Hu gave the command. His retainers lit the fuse. They then ran for cover. Wan Hu disappeared in a titanic explosion. More than likely, his spaceflight was an elaborate and dramatic suicide. But who knows? Perhaps Wan Hu (or his fragments) did reach the upper atmosphere.

In the thirteenth century A.D., the Italian merchant-adventurer Marco Polo visited China. In addition to samples of pasta, the concept of the rocket returned west with him.

In post-Renaissance Europe, the imported rocket was applied as a weapon of war. It was not a very accurate weapon because the warriors did not know how to control its direction of flight. But the explosions of even misfiring rockets were terrifying to friend and foe alike.

By the nineteenth century, Britain's Royal Navy had a squadron of warships equipped with rocket artillery. One of these so-called "rocket ships" bombarded America's Fort McHenry during the War of 1812. Although the fort successfully resisted, the bombardment was immortalized as "the rocket's red glare" in the American national anthem, "The Star Spangled Banner."

The nineteenth century saw the first famous science fiction novels. French writer Jules Gabriel Verne wrote *From the Earth to the Moon* (1865), *Twenty Thousand Leagues Under the Sea* (1869), *Around the Moon* (1870), and *Around the World in Eighty Days* (1873). Particularly intriguing concepts can be found especially in the latter two books. In *Around the Moon*, Captain Nemo discovers and manages a mysterious (nonchemical) "energy", which all activities and motion of Nautilus depend on. In *Around the World in Eighty Days*, Phileas Fogg commands the crew to use his boat structure materials (mainly wood and cloth) to fuel the boat steam boiler and continue toward England. A rocket ship that (apart from its propellant) burns its useless materials progressively is an advanced concept indeed! Jules Verne is still reputed to be one of the first great originators of the science fiction genre.

In 1902, French director Georges Méliès realized the cinematographic version of Verne's novel *From the Earth to the Moon* in his film, *A Trip to the Moon*. Many other films describing men in space followed. For his film, Méliès invented the technique called "special effects." Thus, science fiction cinema was born and consolidated in the first years of the twentieth century, just before the terrible destruction caused by World War I.