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.

Springer

http://www.springer.com/978-1-4939-0940-7

Solar Sails
A Novel Approach to Interplanetary Travel
Vulpetti, G.; Johnson, L.; Matloff, G.L.
2015, XXIV, 277 p. 89 illus., 39 illus. in color., Softcover
ISBN: 978-1-4939-0940-7