How Spacecraft Fly

Graham Swinerd

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Spaceflight Without Formulae

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This book is dedicated to the memory of
John Robert Preston
(1952–2007)

Foreword

The late science fiction author Sir Arthur C. Clarke, in an article published in 1945 in *Wireless World*, suggested that it would be possible to build a global communications system by placing artificial satellites in a strategically located orbit—the so-called geostationary Earth orbit. From their vantage point high above the Earth, the satellites would be able to relay information from any place to any other place around the world. Just twenty years later, Clarke's tentative proposal became a reality with the launch of the world's first commercial communications satellite—Intelsat 1. Now, a further four decades on from Intelsat 1, many of us would find it difficult to adjust to a world without satellites. Our cars and mobile phones routinely come equipped with satnav, the weather forecasts that we watch on our satellite TVs display images taken from space, Earth observation satellites monitor the threat of global warming and science spacecraft, such as the Hubble Space Telescope, have transformed our view of the universe. There can be no doubt that communications satellites, and the plethora of other satellites in diverse orbits, have profoundly affected the way we live.

But how are these satellites—these marvels of technology—designed? In what orbits can they operate? Once they are in orbit, how can we control them? What hazards do they face? How do we get them into orbit in the first place? Moving beyond Earth orbiting satellites, how can we design and propel spacecraft to rendezvous with comets or land on other planets? And, perhaps most importantly of all, what is the future of manned space exploration?

In this highly readable and entertaining book, Graham Swinerd shares with us his immense and personal experience of the first half-century of the Space Age, to answer these and many other questions—and all without recourse to mathematics!

Stephen Webb
Portsmouth, England
April 2008

Preface

As I write this introduction, it just happens to be 50 years since the launch of the first spacecraft. This dawning of the Space Age occurred in October 1957, when the Soviet Union lofted a small satellite called *Sputnik 1* into orbit. Since then, space activity has become an integral part of our culture, and from the perspective of the 21st century it is hard to appreciate what a major technical achievement and political coup *Sputnik* was. Although it did very little in orbit, other than to announce its presence through the transmission of a simple radio message, it nevertheless galvanized the other superpower, the United States, into a vigorous space program that ultimately led to men walking on the moon in 1969—just 12 years later!

When I was a boy, growing up in the early 1950s, my interest in space was sparked by an elementary school teacher, Mrs. Christian, and her inspirational gift of teaching science to her young class. When I look back over a long career in space, both in industry and academia, I have come to realize that this ball began to roll in that early classroom. I have a lot to thank that teacher for, who planted a lifelong interest and enthusiasm in me. At that time, the Space Age was yet to begin. Nothing was in orbit around Earth—apart from the moon, of course—and the exploration of the solar system was yet to begin. The only source of information about the planets had been gathered by astronomers through telescopes, and the only images of planetary landscapes were those produced by the space artist's brush.

How different it is today. Since the heady days of *Sputnik*, all of the planets of the solar system have been visited by robotic interplanetary spacecraft, with the exception of far-distant Pluto. Even as I write, this omission is being rectified by the launch of the *New Horizons* spacecraft in January 2006, which is due to fly by Pluto and its companion moon Charon in 2015. Ironically, in August 2006, just a few months after the launch, a gathering of astronomers in Prague stripped Pluto of its status as a planet, although the scientific objectives of the mission will of course not be compromised by this intriguing decision. Longer-term studies of the planets have also been undertaken by sending spacecraft to orbit the planets Venus, Mars, Jupiter, and Saturn. These missions have been extraordinary and surprising, having discovered a rich variety of features beyond our scientific expectations and imagination. Small bodies in the solar system, such as asteroids and comets, have also been the focus of recent space missions. One such example is a spacecraft called *Rosetta,* which was launched by the European Space Agency in March 2004 to rendezvous with, and orbit, a comet in 2014. As a consequence of all this activity, it is possible for the imagination and enthusiasm of today's schoolchildren to be stimulated by real photographic imagery from far-flung regions of the solar system.

Another space enterprise that has revolutionized our understanding of the universe is the launch of large space observatories into Earth orbit, where a clearer view of the cosmos is possible above the obscuring window of Earth's atmosphere. The most well known example of such a spacecraft is the *Hubble Space Telescope* (HST), which has revolutionized observational cosmology, to say nothing of the aesthetic quality of many of the images returned by the spacecraft. At the time of this writing, the lifetime of the HST is almost up, and the development of a second generation of large space telescope is currently underway. The new observatory, named the *James Webb Space Telescope*, will be launched around 2013 and have optics nearly three times larger than Hubble. It is hoped that the new telescope will be able to see the first stars and galaxies that formed after the Big Bang!

As well as all these scientific projects going on, there are a multitude of satellites in Earth orbit providing services to underpin the technological society we have here on the ground. These application satellites have become fully integrated into our lives, but without us really noticing that they are there. Perhaps the best example of this is global communications. If you talk with someone on another continent, your voice is most likely carried by a spacecraft in high orbit. Another example is satellite navigation ("satnav"), the use of which is rapidly spreading into business and leisure activities. At least in this case, we know that satnav has something to do with satellites. The other major application is Earth observation; there is an armada of spacecraft in low Earth orbit with imaging cameras, and other instruments, directed down to Earth's surface. Data from such spacecraft are used for everything from town planning to agriculture, and it is these satellites that give us a grandstand global view of things like climate change.

The final strand in all this is the presence of humans in space, which, apart from the Apollo astronauts reaching the moon in the late 1960s, has been confined to Earth orbit. Indeed, current activity is focused on the development of the *International Space Station* (ISS) in Earth orbit. When completed around 2010, the ISS will be the largest space structure ever built, weighing about 450 metric tonnes. However, many people look back at the

Apollo era and regard that as the golden age of spaceflight. As a consequence, the young people of today who are embarking on their careers not only have missed the main event, but also have not had the benefit of the inspiration that the Apollo era provided people of my generation. The moon landings were going on when I was in high school, and I have to say that Apollo was another reason (along with Mrs. Christian) why I chose to pursue a career in the space sector. Having said all that, it does seem that we are on the threshold of a new beginning for human space exploration. The planned retirement of the U.S. space shuttle fleet around 2010 is forcing a rethinking of American priorities in space, leading to the development of a program to return to the moon, and go on to land people on Mars within the next 30 years. This activity is also spurred on by the declared intention of other nations to return to the moon before 2020.

This book is a distillation of the knowledge and experience that I have acquired over my 30-year career in space. My main motivation is to share my enthusiasm with general readers, not just readers with a technical education. I have attempted to discuss all aspects of how spacecraft work, but in a way that is accessible to people who have an active interest in space but who do not have the scientific and mathematical background to understand the plethora of technical books that are available on this topic. I hope this book satisfies that interest and helps readers learn more about this truly fascinating subject.

The book discusses orbits, orbital motion, and weightlessness; how spacecraft are designed and how they work; and the likely developments in spaceflight in the 21st century, as well as a more speculative glimpse into the longer-term future of interstellar travel.

The book requires no prior knowledge on the part of the reader. There are no mathematical equations, and I have tried to explain everything in an understandable and physically intuitive way, although in a few cases I have had to simplify and generalize for the sake of clarity. The average reader with a nontechnical background will find the text comprehensible, challenging, and, I hope, enjoyable.

The idea of writing a book on spaceflight without resorting to mathematical equations arose from my involvement in short course teaching at the University of Southampton in England. Alongside all the teaching, research, and administration that are a normal part of a university academic's job, I have also been very much involved in professional development courses. Essentially, these are short training courses on space systems engineering, typically lasting 5 days or so, which we offer to professional engineers and scientists. Over the last 20 years, the European Space Agency (ESA) has been a principal customer in this business, and it has been a privilege over this period to visit ESTEC (ESA's technical headquarters at Noordwijk, The Netherlands) on many occasions as a course organizer and a lecturer. Usually these courses are attended by ESA staff members with a strong technical background, but in about 1995 the training department at ESTEC requested a new type of training program: a space engineering course for nontechnical staff! This was a radical departure from our usual training activity. But the ESA wanted to train its nontechnical employees, such as lawyers, accountants, contracts staff, and secretaries, in the technical aspects of the business in which they are involved to increase their motivation and productivity—a very enlightened training strategy. Over the years, this course has become very popular with ESA staff, being offered at a number of ESA venues across Europe. For us, the trainers, it posed significant challenges, in that we needed to put across to the delegates how spacecraft work without relying on prior technical knowledge or resorting to the use of mathematics. Meeting these challenges has been very rewarding, in terms of the appreciation of the course delegates, who have found a new fascination in learning how spacecraft fly. My wish is that readers of this book will find similar rewards.

This book is dedicated to John Preston, a dear friend who died in March 2007. Despite being very ill, John spent much time helping me by reviewing a partial manuscript of this book, which says so much about him as a person. Even John would have agreed that he was not a scientist. Having his view on the text, as someone steeped in the humanities, was particularly useful in helping me craft the text for people without a technical education.

One technical note: metric units of measure are followed by imperial units in parentheses, for the convenience of the reader. There is one exception: although a metric tonne differs from an imperial ton, which is the measure used in the United States (a metric tonne equals 1.102 imperial tons), the difference is slight, so the corresponding ton equivalent is not given.

Graham Swinerd
Southampton, England
October 2007

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Frank Danesy, who was Head of Recruitment and Training at ESTEC during the mid-1990s; the space engineering course for nontechnical staff at ESTEC, which gave rise to the idea for this book, was his brain-child.

Mrs. Christian, the elementary school teacher who set me off on the path of my lifelong love of "everything space."

My mother and my father (who died in 1995), who have supported me wholeheartedly at every twist and turn in my life's journey.

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Last, but not least, my wife, Marion, who has been by my side at every twist and turn, and who has always been my rock.

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