EXPLORING THE MARTIAN MOONS

A Human Mission to Deimos and Phobos

Manfred "Dutch" von Ehrenfried

Springer

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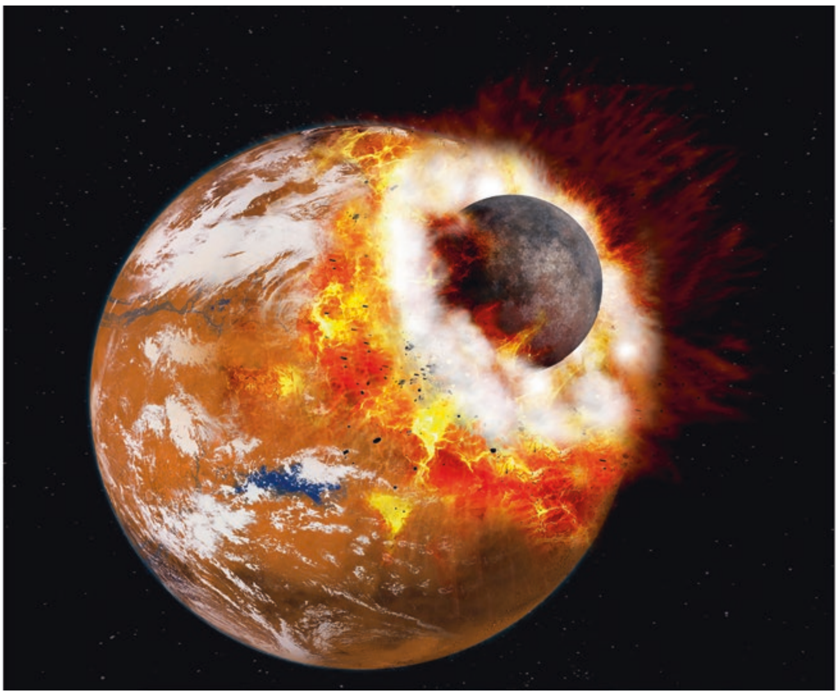

An artist's impression of a giant impact that may have created the Martian moons Phobos and Deimos. At that time, the planet may have had a thicker atmosphere than it does now and water on its surface (Illustration courtesy of Université Paris Diderot/ Labex UnivEarthS. Go to: https://astronomynow.com/2016/07/05/mystery-solved-martian-moons-formed-by-a-giant-impact for a six image sequence of events)

Dedication

This book is dedicated to the thousands of scientists, engineers, technicians, and administrative personnel worldwide that have spent many years studying and writing about Mars, particularly that special group who devoted their attention to the moons Deimos and Phobos. Then there are another thousand or so people actually working on the hardware and software that is, this very day, going into Orion, Space Launch System rockets, engines and boosters and control centers. And there are another thousand or so tearing down old test stands and launch pads and building new ones in readiness to light the fires of one of the biggest candles ever built to launch humans into deep space.

This book is dedicated to those that "took the road less traveled" and paved the way beyond our neighbor the Moon and sent truly amazing robotic payloads that sit this very day on Mars, sniffing around for life and knowledge. While this book is dedicated to those now working on deep space missions, it is also dedicated to younger minds, fresh with new ideas. For alas, some who have taken the road are now weary and eager for fresh blood to pick up the load and fulfill the challenge. The exploration road is long, rough, and not even straight. It will take generations to achieve the ultimate goal of understanding our neighbors and what light they might shed upon our place in the universe.

Acknowledgments

One cannot write a book about the future of the space program without stepping on the toes of those who have a vested interest in a different vision, especially regarding the very first human mission to Mars. While I am urging NASA and the establishment to formally design a precursor mission to the moons of Mars, I find encouraging support from the scientific community to do just that. Because such a mission is many years out, the timing is right to formalize the detailed mission planning and modify the flight schedule. Moreover, the economic timing is also good in that money which has already been spent for the major space exploration elements and systems is directly applicable to a precursor mission. The size of the national debt may also be a driver that may curtail NASA's budget and deep space mission concepts and designs. In fact, not only are many scientists and engineers in favor of the first human mission to Mars being targeted to its moons, the economic and political "stars" may also be aligned in support of this idea.

I am certainly not the first to propose such a mission. There are many who have toiled away on studies and reports, some for many years. However, perhaps this is the first book to present their labors in one volume in a more widely publicized and distributed reference to the public than the original sources. I hope it will be a useful reference for all the students at colleges and universities around the world who are interested in space science and especially about Mars.

Many thanks to the people who encouraged me to even start the book, notably my Springer-Praxis colleagues Maury Solomon and Nora Rawn in New York; Clive Horwood in Chichester, England; and David M. Harland in Glasgow, Scotland. David also edited my text and prepared the images. Liz Cabrera was involved with defining the title and Jim Wilkie designed the covers. The referees who reviewed my initial concept and rough outline a year ago weren't all revealed to me, but I thank them for their constructive comments and favorable recommendations. David Harland was an early enthusiast and helped me to structure my thoughts prior to submitting the book proposal to the publisher. Former astronaut Walter Cunningham was one of the reviewers, and I appreciate his views and support. We worked together on the flight test objectives for his Apollo 7 mission.

In addition, many thanks to planetary scientist Dr. Pascal Lee of the Mars Institute, the SETI Institute, and the NASA Ames Research Center for spending some time with me at Spacefest in June 2016 and encouraging me to write the book. I greatly appreciate his writing the Foreword. He was also on the NASA Human Spaceflight Architecture Mars Moons Team and has spent years in both the Arctic and Antarctic conducting Mars-related research and analog experiments.

Many thanks to astrobiologist Dr. Christopher McKay of the NASA Ames Research Center, whose many reports and lectures on the search for life in our solar system are truly fascinating. I know he would love to have samples from Deimos and Phobos to analyze in his laboratory.

Thanks to Buzz Aldrin for his ideas on using Lagrangian points about the moons and Mars for station keeping and the deployment of communications and scientific satellites at those locations. The eventual Design Reference Mission should examine this concept from both an operational perspective and a scientific perspective.

Thanks to Daniel D. Mazanek and Raymond "Gabe" Merrill of the NASA Langley Research Center for their work on designing human missions in deep space and for reviewing some of my drafts. They were especially helpful in explaining the trade-offs of Mars orbit trajectories. Much of their work would be applicable to a Design Reference Mission to the moons of Mars. Other people at the Langley Library were also helpful. I am immensely grateful to the NASA Langley Research Center and AMA Studios for letting me use their stunning artwork.

My thanks also to former astronaut Dr. Michael Gernhardt and the NASA Human Spaceflight Architecture Mars Moons Team for their work and report on a mission to Phobos as a precursor to a human Mars landing. It could be a primary reference for a future Design Reference Mission Team to further define the first mission to enter orbit around Mars and visit its moons.

Thanks to Norman D. Knight of the NASA JSC Office of the Flight Directors who arranged for a review of the Mission Operations section and also to Brandi K. Dean of the Public Affairs Office. Several Public Affairs Offices and Education Offices at other NASA Centers also gave useful input. I made great use of the thousands of pages of information on various NASA sites, and although I found it difficult to get exactly the current information I wanted, eventually much information did find its way into this book. Also, many thanks to NASA JPL for all the information on the many successful robotic missions to Mars.

I also acknowledge the NASA Aerospace Advisory Council, the Human Exploration and Operations Committee of the NASA Advisory Council, the NASA Aerospace Safety Advisory Panel, and other such committees. Their publications were very helpful in describing the issues relevant to the subject of deep space exploration.

Many thanks to Wikipedia and Google, which enabled me to fill in the pieces of the puzzle for just about any subject. Their input is woven into many sections. I then found useful articles from the aerospace industry and from science organizations such as the American Institute of Aeronautics and Astronautics, the American Astronomical Society, the National Academy of Sciences, the Institute of Electrical and Electronics Engineers, and others. Some of their reports are listed in the References section. Special thanks to the

Mars Institute, the SETI Institute, and The Planetary Society for their work promoting missions such as the one proposed by this book.

Many thanks to those NASA contractors who responded to a call for information and in some cases provided very important input, for example, Nicole Stewart of Honeywell Aerospace, and Kay Anderson and Vicki Cox of Orbital ATK who reviewed my drafts concerning the SLS solid rocket boosters and habitats. Also thanks to Dr. Shane Jacobs of the David Clark Company for information about the new pressure suits for the Orion and CST-100 Starliner.

In summary, many thanks to all the scientists and engineers whose efforts and many reports about Mars over the years have influenced my thinking sufficiently to prompt me to write this book advocating a human mission to enter orbit around Mars to investigate its moons Deimos and Phobos in order to pave the way for a later mission to the surface of the planet itself.

Foreword

In 2005, while NASA was focused on returning to the Moon, I led a small team of scientists and engineers to study, and eventually advocate, a human mission to Phobos, the inner moon of Mars. The mission was not about going to Phobos for Phobos' sake, but to target a Martian moon as a first step in eventually getting humans to the Red Planet. We called our plan *Mars Indirect*.

The idea wasn't new; as early as 1981, Fred Singer published the *Ph-D Proposal*, a pioneering technical paper in which he proposed a manned mission to Phobos (Ph) and Deimos (D). A few years later, Brian O'Leary, a former astronaut NASA had selected for a potential manned mission to Mars, proposed using Phobos and Deimos as "resource and exploration centers" in the context of manned missions to Mars. Several more studies followed.

The classical arguments in favor of a human mission to Phobos or Deimos included (a) the minimal delta-V (impulse) needed to reach Phobos and Deimos from the Earth, (b) the ability to monitor the planet from a stable platform in low Mars orbit (LMO), (c) the ability to teleoperate robots on Mars from LMO without significant time delay, (d) the opportunity to advance the scientific investigation of small bodies, and (e) the potential of finding water and other resources on Phobos and Deimos. While all important, these arguments had generally not been sufficiently compelling to create a broad consensus that would place Phobos or Deimos on the critical path to human Mars exploration.

Our 2005 study, however, added three new arguments: (1) Phobos and to a lesser extent Deimos might each be a "Library of Alexandria of Mars." That is, their regolith (surface rubble) might contain a unique record of ancient Mars in the form of bits and pieces of rocks which had been ejected from the planet over eons of meteoritic bombardment. Going to Phobos or Deimos might therefore be an opportunity to collect a wide variety of Martian samples, with the bonus that these materials would've been pre-quarantined in Mars orbit. (2) Phobos and Deimos would be ideal "glove boxes" for Mars, that is, places to receive, quarantine, and preprocess fresh new samples collected on Mars by humans or robots prior to the samples being shipped back to Earth. And (3) Phobos and Deimos could serve as catalysts for the human exploration of Mars.

This third argument was, in our thinking, the strongest. In a paper presented in Washington, DC, in May 2005 at the International Space Development Conference and bearing in mind that NASA was, at the time, mandated to return to the Moon, we wrote:

The bulk of the challenge, specific hardware development, and cost of a human mission to Mars lies in that part of the mission that brings astronauts all the way down to the Martian surface, enables their surface ops, and returns them to LMO. If no human journey to Mars were undertaken before humans are ready for an actual landing, decades could elapse after the return to the Moon before humans venture to Mars.

Phobos presents the key programmatic advantage of (a) being a Martian target that is technically achievable in the immediate wake of humans returning to the Moon, requiring only a low-cost near-term spiral development since lunar systems can readily be qualified for Phobos; (b) reducing risk through a stepwise buildup to full-up Mars landing missions; and (c) enabling a steady cadence of exciting, meaningful, and tangible near-term missions at Mars, thus ensuring programmatic focus and continued public support.

By the time of the second presentation of our arguments at the Lunar Exploration Analysis Group (LEAG) Conference in Houston, Texas, in September 2005, we felt that interest in Phobos and Deimos had been rekindled. Shortly thereafter, I got the greenlight from NASA Headquarters to convene the *First International Conference on the Exploration of Phobos and Deimos*, with a subtitle that generated much excitement and raised some (lunar) eyebrows: *The Science, Robotic Reconnaissance, and Human Exploration of the Two Moons of Mars*. The conference was held at the NASA Ames Research Center in November 2007 and was a success. Since then, two additional conferences have been held, one in March 2011 and the latest one in July 2016. They are now a series.

In this landmark book, "Dutch" von Ehrenfried makes his own case for a manned mission to Phobos and Deimos. He explains how this Mars Orbital Mission would be to a human landing on Mars what Apollo 8 and 10 were to Apollo 11: namely, a critical and enabling precursor mission. His case is compelling. Firstly because Dutch had front-row involvement in the Mercury, Gemini, Apollo, Skylab, and International Space Station programs and therefore has firsthand knowledge and understanding of human space mission design, development, operations, management, and science. Secondly, to help the reader fully appreciate the benefits of targeting the moons of Mars as an initial step, Dutch presents up front the monumental magnitude and cost of landing humans on Mars itself. He then shows us how, in contrast, a mission to Phobos and Deimos would be so much more feasible and affordable and could be undertaken much sooner. As NASA is presently in the process of readjusting its focus for the years to come, Dutch is to be praised for producing such an insightful, timely, and visionary book.

Pascal Lee, Ph.D.
Director, Mars Institute
Planetary Scientist, SETI Institute
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February 2017

Preface

This book is an appeal to NASA, the Mars science and mission support community, and the powers that be to recognize that before we attempt to land on Mars, there ought to be a precursor, crewed orbital mission to the planet's moons, Deimos and Phobos.

The desire to land on Mars is driving the mission planning and clouding the real risks and extreme difficulties of taking the ultimate step from orbit to the surface. The magnitude of the difference between an orbital mission and a landing/stay mission could be a decade and many billions of dollars. From an operational point of view, there is great value in learning "how" to "fly" to Mars's moons first. This would include all of the tasks that a crew and their supporting team in Mission Control must conduct in order to just get there and come home. While it is very clear to the JPL operations people how to send a robotic spacecraft to Mars, it is quite another thing for the NASA Johnson Space Center (JSC) flight operations people to send a crew to Mars and return them safely back to Earth. Would the Apollo 11 mission have been successful if we had not carried out the Apollo 8 and Apollo 10 missions first? Would we have ever attempted a mission as demanding as Apollo 11 without those precursor missions?

One argument for doing the landing first is: "Would you ever go all the way to Mars and not land?" Some do not realize the amount of equipment and systems required to land, stay, and get back off the surface of Mars, let alone "how." The increase in risks to achieve these goals and activities is orders of magnitude more than those required for a Mars Orbital Mission. But as of 2017, many of those landing/stay vehicles and systems are not yet designed or developed, and they are certainly not yet budgeted. Mission planners and engineers can conceive of systems far ahead of actually getting funds to design, develop, and test their creations. They can actually be decades, even hundreds of years, ahead of reality – as is evidenced by those who have visions of colonies of people living on Mars and terraforming it. Operations people live more in the "here and now." They must "do" what the "dreamers" conceive. But then, what would we do without the dreamers? Isn't everyone working on the Mars program a dreamer? Flight operations people dream of completing the mission. Interwoven throughout this book are operational perspectives from the crew and flight operations point of view.

I have attempted to describe what can be done to explore the Mars orbital environment sooner than a landing mission and hope to encourage the NASA administrators and planners to begin a detailed "Design Reference Orbital Mission" to Deimos and Phobos. The scientific community definitely has goals and objectives for undertaking science there, and many scientists agree that an orbital mission should be a precursor to a landing. These objectives have been defined for years. The more the scientists learn from the robotic missions, the more they can "fine-tune" their detailed science objectives for human missions. The potential astronaut crews need to be educated and trained to conduct those experiments. There are some very interesting operational EVA aspects related to how to collect samples from the Martian moons and deploy sensors that can assist in gathering more scientific data, as well as leaving equipment behind that might facilitate future flights.

After putting the planning of a Mars mission into a historical context, the book will describe what is currently planned which relates to an orbital mission. It will describe what is *not* required to go to the Martian moons, to ensure that the reader understands the vast difference in missions and therefore how much sooner an orbital mission can be achieved and at significantly less risk. The risks to the astronauts will be covered, as will the habitability considerations for such a long and perilous flight. Some of the unique technology advances that enable such a mission are also described.

Also included are references to what many of the organizations and contractors are doing to support a flight to Mars. An important aspect of the planning is the experience gained over the decades from the robotic missions to Mars. This is included in one of the several Appendices. It is apparent that future human missions to Mars will involve the commercial space industry and our international space partners. The cooperative nature of the International Space Station (ISS) is an illustration of how a Mars mission should be organized.

In summary, the intent of this book is foremost a plea to NASA to begin detailed planning for a human orbital mission to the Martian moons as a precursor to a landing on the planet itself. In addition, it is hoped the book will become a reference for such a mission for university students and space aficionados. As of the spring of 2017, the book will cover what vehicles and systems are required and what needs further definition. Appendices provide not only a historical context for the current state of Mars exploration but also a review of the human analog research undertaken over the years. Links to NASA and contractor sources are included for the reader desiring even more information.

Manfred "Dutch" von Ehrenfried
Lago Vista, Texas, USA
Approaching the Vernal Equinox of 2017

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Part I
The Current Plan

1

Introduction

This book is about a human mission to Mars, but not the way you might think. Nor is it about what NASA is currently planning, although their current plans are described here in order to put them into context for what I feel is a better first step to the planet. This book is about a mission mentioned only briefly in studies over the years and, in a way, is arguably a better path. Years ago, such a mission was listed, almost as an afterthought, in what was then called "The Flexible Path." It was simply called a "Mars Orbital Mission." This book proposes that such a mission to the moons of Mars, Deimos and Phobos, be undertaken prior to any attempt to land on Mars. But first, a little background.

It is 2017 and we humans still haven't been beyond Earth orbit for two generations. It's been nearly a half century since we first landed on the Moon. The farthest that we've been in space is 248,655 miles; I have more miles on my Buick! What happened to the nation's will to explore? What happened to all the dreams of exploring Mars? Yes, we have robots on Mars and orbiting around the planet that are simply fantastic. The rovers on Mars have been magnificent and have defined the conditions in the atmosphere and on the surface to a sufficient degree to enable us to zero-in on the minimum architecture and overall system design for the first crewed mission. The rover and orbital missions need to continue to more thoroughly define the planet to the scientists' satisfaction. There is still much to learn. The scientists, engineers and technicians that designed, built, and operate these spacecraft are true space pioneers and should be recognized and honored for their extraordinary accomplishments. These missions have redefined what we know about the planet and its atmosphere. They have enabled us to develop the orbital mechanics and navigation techniques to reach Mars; manned or unmanned. We know how to plan the trajectories to Mars; robots have now taken "the road less traveled" but none have returned with samples. The history of this exploration is reviewed in Appendix 2.

In 1976 two Viking robots landed on Mars seeking life. They found no signs of it. Almost all subsequent missions and instruments have looked for water as the way to find life. "Follow the water" is the mantra of the scientists. The life forms need not be sophisticated; a living cell will do. What will that tell us? As Dr. Philip Morrison of the Massachusetts Institute of Technology once pointed out, the discovery of extraterrestrial

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organisms would "transform the origin on life from a miracle to a statistic." Perhaps human beings are not so special after all! Did God create other life forms like us? Did he create more intelligent beings than us? Considering the number of stars and the seemingly unlimited vastness of the universe, certainly the odds are in favor of there being extraterrestrial life. But is there life elsewhere in our solar system? Back in 1961 Dr. Frank D. Drake used what became known as the "Drake Equation" to estimate the number of civilizations whose electromagnetic emissions ought to be detectable by us. His work was aimed at radio research, rather than to seek primordial or primitive life forms. The number of habitable planets was just part of the equation. At the time, he lacked data on the nature of other planetary systems. Data from the recent Kepler mission to observe such systems is indicating that Drake's estimate may be more accurate than was once thought.

Thousands of people are working to answer this simple question. They range from those of pure scientific curiosity to those who seek aliens that might conquer the Earth. There are whole communities of people in the "astrobiology" world studying the question of life. Many research projects are well funded and include distinguished scholars, some of whom are quoted herein.

The Kepler mission has been searching for planets that might harbor life since it was launched on March 6, 2009. Astronomer Dr. Natalie Batalha from the NASA Ames Research Center has worked to identify potential candidates. Indeed, she led the analysis that yielded the discovery in 2011 of Kepler 10b as the first confirmed "extrasolar" rocky planet. The Planetary Habitability Laboratory at the University of Puerto Rico at Arecibo has catalogued 2,331 confirmed planets that seem to fall in what is termed the "Goldilocks zone" for life around their host stars; being neither too hot nor too cold, but just right! Of these, about 44 seem to be in the potentially small habitable zone for life, of which 15 are Earth-sized. While this effort should continue, there is a more familiar planet called Mars that fits that description, so why not look there too? Let us start with the planet's moons which are much, much easier to reach (and depart from) than going to the surface of Mars (and then lifting off again). Exploring Deimos and Phobos might not be the ultimate goal of landing on Mars, but it will be a lot safer, quicker, and cheaper as a first step for humans venturing into deep space.

Some of the missions to Mars have onboard instruments to look for evidence of life and the conditions for life. The scientists tell us that three things are needed: energy, organic materials, and water. Planetary scientist Dr. Christopher McKay, who is also from NASA Ames, has shown us that there are "extremophiles" living in the most inhospitable conditions and places here on Earth. Perhaps they are living on Mars and its moons as well, albeit having to migrate a distance under the surface in order to get away from the inhospitable temperatures and radiation. Plans are underway to develop a special drill to sample to a depth of 3 ft into the polar ice-cemented soil near the Mars polar site explored by the Phoenix spacecraft in 2008. This small special purpose lander is called the Mars Icebreaker Life Mission. It has been proposed as a Discovery Program mission for the 2021 time frame. Small scientific experiments such as this and others planned for future robotic missions may also be the type of equipment that the Mars Orbital Mission could emplace on Deimos and Phobos, deployed by astronauts in much the same manner as the Apollo astronauts deployed the Apollo Lunar Surface Experiment Packages (ALSEP).

To date, we still haven't answered the questions about whether there is now, or ever has been, life on Mars; nor has any mission returned a sample to Earth for more detailed analysis than can be undertaken by a robot "in situ." They have established that Mars did have water and probably has water below the surface. We also have what are thought to be rocks thrown out by asteroids colliding with Mars, which reached Earth and landed in Antarctica. But many mysteries remain. What happened to Mars over the billions of years since it formed? What happened to the water? What happened to the atmosphere? What happened to the magnetic field? What are the lessons for us on Earth?

It seems apparent from all the robotic missions to Mars that ultraviolet radiation and lack of liquid water are at least two of the main reasons that life, if it did exist, was killed off or migrated underground. Another reason that no life has been found on Mars to date could be the existence of perchlorates in the soil, because these also tend to kill off life. On the other hand, the presence of perchlorates suggests a possible reaction with iron that could support metabolism. We need to know more.

The scientific knowledge gained from all the robotic planetary missions over the decades has helped us to plan for crewed Mars missions and to select the best sites for landing on that planet. Moreover, experience of planetary missions and operating the International Space Station (ISS) has taught us (and other nations) how to cooperate in such endeavors, and to bring each nation's many talents and skills together for a common good. The ISS has shown us how to, at least to a degree, mitigate long duration weightlessness; once thought to be major problems facing a trip to Mars. We now know how to work and live in the space environment for extended periods of time and also how to perform complex extravehicular activities. A mission to the moons of Mars will necessarily require crew habitation and logistics modules whose designs will be based upon ISS experience. This same experience might also lead to an international crew for the first precursor mission to the Mars environment; hopefully to the planet's moons.

Over the decades, reality has awakened us from our dreams of exploration beyond Earth orbit. Not only is Mars more than a hundred times farther away than our Moon, but there are hazards in deep space such as radiation, which, although known and generally understood, are not yet fully mitigated. While long duration flights in space are very costly, they don't compare to the wasted spending on political follies in just the past decade. To compare the benefits of space missions to domestic programs and military missions, consider the following: it cost us approximately $2.5 billion to send the robotic rover Curiosity to Mars. That is just about the same as the increase in our national debt in *one day!* That program includes eight years of development and two years of exploration. It has employed thousands of people in 20 states and four countries. Average the cost over the decade and it is about $1 per citizen per year. That is the magnitude of the cost of a major scientific planetary science mission. That is cost effectiveness at its best! The money spent on space flight programs goes back into the economy by a factor of 8 to 10. This has been shown in many studies over several decades. Contrary to the arguments of pessimists, we did not spend any money on the Moon; it was spent here on Earth and yielded thousands of spinoffs that have improved the lives of billions of people around the world. Therefore space science is one of the best examples of mankind's contribution to the understanding of the world in which we live; an understanding that is still unfolding.

So what would it cost to send humans to Mars? The NASA FY 2017 budget is $19B. Of this, $8.4B is for Human Exploration Operations ($3.3B is for Exploration and $5.1B for Operations) which includes the Orion spacecraft, the Space Launch System (SLS), and the associated ground systems for checkout and launch. But that is just for one year.

Thousands of people are spending that money in ways that advance science and technology that will already have benefited society before a single launch to Mars takes place. In addition, the work provides jobs for thousands of truly gifted people. In an era when our National Debt is $20 *trillion*; how long can we continue to fund NASA at these rates? Will there be sufficient money over the next 20 years to undertake a mission to Mars? Perhaps this is another reason to plan for a cheaper, easier and quicker Mars Orbital Mission rather than the much more expensive Mars landing/stay mission.

This book focuses on a cost effective effort to send humans into orbit around Mars, not to the surface, as quickly as possible, and reviews what this will involve. There are those who wish to colonize and terraform Mars, but these goals lie far, far in the future; if indeed they are possible at all. What is the earliest we can reach Mars and get some answers? Why do some people want to revisit the Moon or investigate an asteroid first? Are these merely political distractions due to money? Or are they sound judgements? While some people may find those types of missions of scientific interest, certainly we don't *need* to go there before we go to Mars orbit. As the saying goes, "We have the technology!" We do not need to test systems on the Moon in order to go to Mars orbit; we can do that in vacuum chambers and other traditional ways to "shake, rattle and roll" vehicle components to qualify them for flight. We have been doing that for many decades. Appendix 3 describes the many experimental analogs on Earth that have been investigated over the years. These have also contributed to the technologies and methodologies required for deep space travel. We do not need to go to an asteroid for the same reasons. If you want to go to the Moon or to an asteroid then do so, just don't take money and resources away from a mission to Mars.

There are people who dream about and work on future systems like nuclear and solar electric propulsion to shorten the trip to the planet, but this book focuses on the next couple of decades; specifically from now to approximately 2035. Others are already working on systems to process the local soil in order to obtain oxygen and methane for fuel, and ways the crews could utilize in situ resources for extended stays on the surface. That may be good research for future flights, but it isn't needed for an orbital mission. It could even be taking money away from a much earlier opportunity to visit Deimos and Phobos and establish a base of operations in orbit around the planet.

An orbital mission doesn't require the launch vehicles, spacecraft, landers, surface vehicles, and resources that would be required to undertake a landing and long stay on the planet. These must still be developed for later missions, but they aren't needed for the mission to Mars orbit and its moons. This book makes the case that such a precursor mission should be attempted in advance of attempting a landing mission. NASA and the scientific community need to shift the priorities and flight schedule of the current human Space Exploration Program.

Many scientists have proposed acquiring samples of the Martian moons in order to enhance our understanding of the planet. They have even said that such a sample return mission ought to occur ahead of a mission to the surface. With an added capability, the Mars Orbital Mission with visits to Deimos and Phobos could offer a way to obtain samples of the regolith and leave some scientific experiment packages behind. Some believe this material also includes ejecta from the surface of Mars, ejected by impacts that made huge craters on the planet. Is this as dangerous as lunar dust? Wouldn't it be good to find out before making a landing and long stay on the planet? Acquiring and returning samples could be accomplished by an astronaut or by a robot. The term used in the scientific community for this debate is "boots or bots." An orbital mission carrying a human crew could use both techniques. It is important to realize that such a mission might be no more complicated than the proposed rendezvous with a captured asteroid to obtain samples. Why go to the effort of capturing an asteroid and maneuvering it close to Earth in order to undertake a rendezvous to sample its materials? Surely it is better to go where you really want to go anyway, namely Mars.

A Mars Orbital Mission is not currently in NASA's near term plans, but is mentioned in many formal papers. The planners have simply jumped over that option and placed their emphasis and priority on the ultimate goal; a landing mission. One could argue that learning to operate in Mars orbit and rendezvousing with its moons would be a necessary learning and training experience as well as a means of acquiring samples prior to attempting the most difficult, costly, and dangerous feat of attempting to land on the surface and operate there for an extended period while awaiting suitable conditions for a return to Earth. One might consider this logic as similar to the rationale for the Apollo 8 and Apollo 10 lunar orbit missions which paved the way for the lunar landing by Apollo 11.

The landing/stay crews would still have to acquire and return samples to Earth for exhaustive analysis. Furthermore, a Mars Orbital Mission could occur many years, if not decades, before a landing mission. It would raise the probability of success of a landing/stay mission, and by the lessons learned from the orbital experience it would reduce the risk to the crew. Such a mission might excite the world and provide NASA and our international partners the additional funding for future exploration flights.

Although NASA would prefer to test systems in a lunar environment and rendezvous with an asteroid, neither of these missions are required to go to Mars orbit because those systems can be qualified by other means. These missions are added more for test and checkout and cost reasons than to qualify systems for use in deep space. Of course, our Moon is only three days away and there are return-to-Earth trajectories in case of emergency. Such is not the case for a mission to the neighborhood of Mars – it is a long way home in even the best of conditions. But surely by now space flight has evolved to the point where, after extensive ground testing and qualification, a couple of unmanned flights and a long duration crewed checkout in a high Earth orbit (rather than an asteroid), NASA could commit the next flight to orbiting around Mars.

Test and checkout of an ISS-derived deep space habitation module and logistics module (both necessary for a mission lasting at least two years) could be thoroughly checked out on the ground and on a separate flight. If successful, these could be parked in Earth orbit to await the arrival of a crewed Orion spacecraft for subsequent rendezvous, docking and checkout prior to committing to a Mars trajectory. Needless to say, the Mars Orbital Mission, including visits to its two moons, requires a thorough mission planning activity because without that it is purely conceptual, albeit based upon some reasonable logic. What is lacking is a focused analysis and a consensus on the preferred options and necessary equipment. What is needed is for the NASA mission planners to recognize the value of an orbital mission ahead of a landing mission. What is needed is a Design Reference Mars Orbital Mission to Deimos and Phobos. This was briefly mentioned in a NASA 2013 report and termed "Design Reference Mission 8" but not subsequently pursued. Studies by academia and industry have also mentioned this type of precursor mission. In the spring of 2015 the Planetary Society, with input from a study group at the Jet Propulsion Laboratory, also made a case for a Mars Orbital Mission.

As recently as July 2016, the 3rd International Conference on the Exploration of Phobos and Deimos was convened at the NASA Ames Research Center. The subtitle of the conference was "The Science, Robotic Reconnaissance, and Human Exploration of the Two Moons of Mars."

So how did we get to where we are now? This book discusses why we should go to Mars and gives a brief history of the decision processes over the past quarter of a century. The two moons of Mars, Deimos and Phobos, are described as targets for the proposed Mars Orbital Mission, as well as the probable trajectory paths and mission duration. An operational concept for acquiring samples of both moons and returning them to Earth is presented along with a review of required technologies and resources.

The major elements of the currently planned Space Exploration Program are discussed, since most of the elements which are now in development by the United States and Europe would be used by a Mars Orbital Mission. In addition, the latest technologies being used to manufacture the vehicles and systems will be reviewed, since many are truly amazing advances. The approach taken is to discuss each major element and then the enabling and/or emerging technologies. For example, the Orion spacecraft exploits advances in welding techniques; development and testing of state-of-the-art heat shielding; the latest in parachutes; the use of 3D modeling; advances in life support systems and in cryogenic storage, and more. Likewise the Space Launch System uses advances in rocketry to modify the existing RS-25 engines and components, and to manufacture new RS-25 engines for later missions. The major technology advances and/or new technologies will be discussed for all key elements supporting the Mars missions.

In addition to the hardware, human and software systems will be covered. This will include the latest in spacesuits, many flight operational concerns such as aborts, radiation monitoring and warning, as well as advanced communications concepts for deep space. There are also new test and checkout methods being developed, and advanced ground systems to support the SLS at the launch complex at the Kennedy Space Center. The role of each of the NASA Centers and their contractors will be included, since the Space Exploration Program involves them all. There will also be DOD organizations lending support. In addition, commercially supplied launch vehicles and cargo spacecraft will deliver payload to low Earth orbit for subsequent transfer to the Mars vehicles.

To research this book, basic information and various documents were acquired from NASA websites and then summarized and placed into context. Thousands of pages were reviewed for relevance. Likewise, information was gleaned from contractor websites and organizations such as the National Academies Press, the National Research Council, IEEE, and AIAA. The website of the European Space Agency was also searched for information on the Orion Service Module, as well as other sites supporting the ISS and Mars missions.

An excellent review of mission planning for Mars and the various NASA Design Reference Missions and Architectures is *Human Mission to Mars*, the 500 page volume by Donald Rapp that was published in 2016 by Springer-Praxis. It is more focused on landing missions, surface operations, and use of in situ resources. This coupled with information from NASA will give the serious reader much to digest, because the topic is complex.

So it is hoped that by condensing hundreds of sources and thousands of pages into a single bound volume, the current book will enable students and space enthusiasts to contemplate the first human mission to Mars's moons. It is also hoped it will have some influence upon mission planning to Mars, and that NASA will actually conduct a precursor mission to the Mars orbital environment in advance of attempting the far more complex, costly, and dangerous landing and stay mission.

2

NASA's Plans

2.1 BACKGROUND

Remember that old saying "You can't tell the players without a score card"? Well it is hard to tell how we got to the current plan to go to Mars without a roadmap. There have been so many studies over the decades by so many people that one requires to be guided to the current plan. If that isn't difficult enough, this book proposes to change the plan, or at least to alter the sequence of events. But before that is discussed, it is important to understand how we got to where we are now. I don't think we need to go back more than a generation to understand that, but if you want to go back further, read *Humans to Mars: Fifty Years of Mission Planning, 1950–2000* by David S. F. Portree, published in 2011 by the NASA Headquarters History Office.

The table provides a chronology of key dates.

1991	"America at the Threshold, Report of the Synthesis Group on America's Space Exploration Initiative"
1993	1st Design Reference Mission (DRM), Space Exploration Initiative
1997	DRM 2.0 by a NASA Mars Exploration Study Team
1998	DRM 3.0, an addendum to the 1997 study
1998	DRM 4.0 examined Nuclear Thermal and Solar Electric Propulsion
1998	First module launch of the International Space Station (ISS)
2004	George W. Bush announced a new Vision for Space Exploration
2005	NASA Exploration Systems Architecture Study (ESAS), a report of 758 pages produced by 20 core team members collocated at Headquarters, supported by hundreds of Field Center staff over a period of three months
2006	Boeing selected to build the Orion heat shield, Lockheed Martin selected to build the Orion Crew Vehicle
2007	The Global Exploration Strategy: the Framework for Coordination
2009	The Augustine Panel described the "Flexible Path" option in "Seeking a Human Spaceflight Program Worthy of a Great Nation"

(continued)

Manfred "Dutch" von Ehrenfried, *Exploring the Martian Moons: A Human Mission to Deimos and Phobos*, Springer Praxis Books, DOI 10.1007/978-3-319-52700-0_2

2009	DRM 5.0, with an addendum in July and a second in 2014; the most current version and the one discussed herein
2010	NASA Authorization Act of 2010
2010	U.S. National Space Policy, mentioned Mars in only one sentence
2010	Constellation Program canceled
2010	NASA formally established planning teams at MSFC and JSC
2011	"Vision and Voyages for Planetary Science in the Decade 2013–2022" (National Research Council of the National Academies)
2011	Last flight of the Space Shuttle
2011	NASA adopts the Space Launch System design
2013	NASA Langley published "Considerations for Developing a Human Mission to the Martian Moons"
2014	Latest addendum to DRM 5.0
2015	NASA published "Journey to Mars: Pioneering the Next Steps in Space Exploration"
2015	The Planetary Society published "Humans Orbiting Mars"
2016	Third International Conference on Exploration of Phobos and Deimos

2.2 INTERNATIONAL INPUT TO THE PLANNING PROCESS

In May 2007, fourteen space agencies jointly released "The Global Exploration Strategy (GES): the Framework for Coordination." Many of these international space agencies are participating on the International Space Station and also on robotic missions to the planets. Many have space programs of their own. The agencies share a vision of coordination on human and robotic space exploration. The report identified a common set of very broad exploration themes and benefits, and called for a voluntary, non-binding coordination mechanism among the space agencies. This led to the establishment of the International Space Exploration Coordination Group (ISECG) in November 2007.

The ISECG is a forum to enable space agencies to identify ways to strengthen their individual exploration programs, to facilitate collaborations and to advance the GES by coordinating mutual efforts in space exploration. As a result of their coordination and workshops, they focus on non-binding products such as findings, recommendations, and consensus opinions. Decisions on how to implement specific mission scenarios are not made by the ISECG, however. These will follow national policy decisions and international consultation at multiple levels, informed by products such as architectures and mission designs developed collectively.

This organization produced a 26 page report "Benefits Stemming from Space Exploration" in 2013. It describes the fundamental benefits that are expected to flow from continued investment in the missions and activities described in the "Global Exploration Roadmap (GER)." Both these documents are available on line. While these are high level documents, they serve to strengthen governmental support for international cooperation in human and robotic space exploration and provide the technical basis for the information that will be needed to establish agreements by the space agencies and their governments.

2.3 DESIGN REFERENCE ARCHITECTURE AND MISSIONS

The terms “architecture” and “mission” are a bit confusing at first. During the first two decades of conceptual Mars mission planning, the term “Design Reference Mission (DRM)” was used. Around 2009, the term “Design Reference Architecture” was introduced to encompass the entire sequence of missions and related supporting infrastructure. Keep in mind that over the years, the conceptual studies became better defined and served as input to trade-off studies and to identify technology needs. They were used to identify system “drivers” that needed further study. They often included broad, high level strategies but also identified specific types of hardware such as a nuclear thermal and solar electric propulsion system. The time constant between some of these concepts and reality could be decades. In some cases, related DRMs were produced; for example an “Austere” DRM for a Mars mission or a Lunar DRM.

In the DRM 5.0, dated July 2009, the Mars Architecture Working Group (MAWG) says that the report should not be viewed as constituting a formal plan for the human exploration of Mars. Instead, the report provides a vision of a potential approach for human Mars exploration based upon the best available knowledge. From 2009 to 2015 the emphasis switched to the necessary technology for the conceived Mars mission. The near term capabilities for the heavy lift launch vehicle, the ground-based checkout systems, and the spacecraft, became well defined. The result was the Space Launch System, the checkout and launch processing systems to be created at the Kennedy Space Center, and the Orion spacecraft. The longer term systems became the focus of the Human Spaceflight Architectural Team (HAT).

It became clear that the systems which required much more research and definition as well as funding would have to be postponed until later; in some cases much later. But studies continued for many areas that fall within NASA’s space exploration research and the roles and specialties of the NASA Centers. The systems relating to the initial Mars landing/long stay mission require much more research, much more money, and much more time. This is one of the main reasons to pursue a Mars Orbital Mission as a precursor.

2.3.1 From Three Missions to Three Phases

In the 2009 DRA 5.0 three missions were defined by the Mars Exploration Program Analysis Group (MEPAG) for exploration of Mars. It was thought that this effort could be completed in approximately 10 years. Each of the missions used the conjunction class (long stay) trajectory option. This concept used pre-deployment of assets up to two years prior to a crewed mission. This concept also called for a nuclear thermal rocket, a surface nuclear power source, use of in situ Martian resources, descent/ascent vehicles, surface habitats, and more. Six years later, this concept had been superseded by a more strategic three phased approach that included lunar and asteroid missions.

In 2015, NASA published “Journey to Mars: Pioneering Next Steps in Space Exploration.” This 36 page document picks up all of the input from the National Space Policy, the National Space Act of 2010, the Global Exploration Roadmap, and the current work of the Centers and laboratories. It is fundamentally a strategic overview document, but presents the status of space exploration plans in a format which is very readable. It focuses on high level concepts such as the approach, principles, programs, plans and challenges, and presents them using beautiful art work. It is not a design reference mission document.

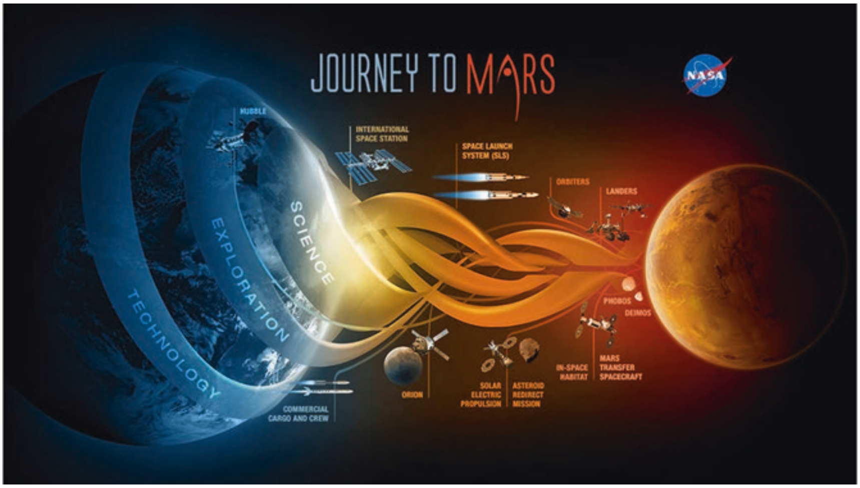

Fig. 2.1 The journey to Mars. (Photo courtesy of NASA)

This document argues that the journey to Mars crosses three thresholds, each of which poses increasing challenges as humans move farther from Earth. NASA manages these challenges by developing and demonstrating capabilities in incremental steps.

Briefly, the three thresholds are:

- *Earth Reliant*. This is basically research onboard the ISS and at the Centers, including commercial participation.
- *The Proving Ground*. This involves missions in cislunar space to validate capabilities required for Mars. It envisages both Exploration Mission-1 scheduled for 2018 and the Asteroid Redirect Mission in 2020.
- *Earth Independent.* Building on what is learned from the above two thresholds, this calls for missions to the vicinity of Mars; perhaps a Mars Orbital Mission and possibly visiting Deimos and/or Phobos. Of course, the ultimate mission is to the surface of the planet and staying there for an extended period until conditions are right to return to Earth. This also describes in situ resource utilization and advanced communications.

According to William H. Gerstenmaier, Associate Administrator for Human Exploration and Operations at NASA Headquarters, this three phase approach "connects near-term activities and capability development to the journey to Mars and a future with a sustainable human presence in deep space" and it "charts a course toward horizon goals while delivering near-term benefits and defining a resilient architecture that can accommodate budgetary changes, political priorities, new scientific discoveries, technological breakthroughs and evolving partnerships."

In view of all the documents developed over the past decades this statement makes a lot of sense, because a Mars Exploration Program will take so long (decades) to achieve the ultimate goal that it will likely be subject to the varied priorities of several Presidents and very different Congresses. Similarly, the participating nations could revise their participation.