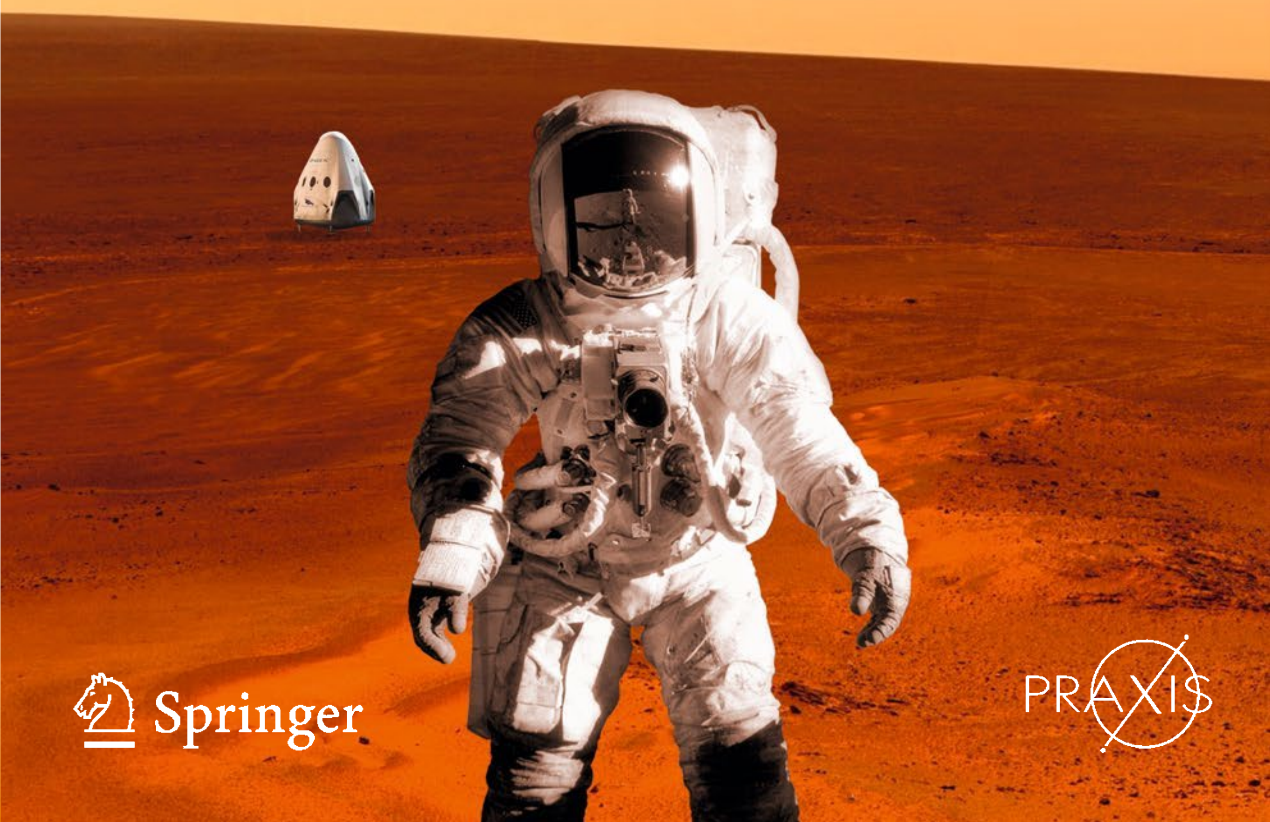
Giancarlo Genta

NEXT STOP MARS

The Why, How, and When of Human Missions



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To Franca and Alessandro

Contents

Foreword

Every space enthusiast knows of the challenge made by President John F. Kennedy during an address to Congress on 25 May 1961, "I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the Moon and returning him safely to the Earth. " This took the world by surprise, coming as it did at a time when the United States had yet to place a man into Earth orbit and NASA, less than 3 years old, manifestly did not have the faintest idea of how to reach the Moon.

Only a few cognoscenti know the genesis of Kennedy's speech. Deeply struck by the double blow to the US space program (and to national pride) delivered first in 1957 by Sputnik and then again by the pioneering orbital mission of Yuri Gagarin on 12 April 1961, the young President wanted to answer the Soviet achievements with a crushing blow that would clearly establish his nation's leadership in space.

According to the story told by Buzz Aldrin in his last book, Kennedy started by asking NASA to place an American crew on Mars. Seriously! The President tried to order NASA to make a Mars mission right away. Panicking NASA officials had the guts to say that Mars was out of the question. They then added hesitatingly, "However, Mr. President, we could maybe do the Moon, if you give us at least 15 years… "

In making his historic speech the next day, the daring President (who could hardly have imagined he would be assassinated a couple of years later) reduced the time estimate for a mission to the Moon to just under 9 years. And to their eternal credit, the space agency was able to fly its proud MISSION ACCOMPLISHED banner in July 1969, after a little over 8 years.

It is fascinating to speculate what might have happened had Kennedy accepted the requested 15 years. In all probability, we would have never been to the Moon. The financial, political and, above all, human and psychological burden of the Vietnam war, whose folly was finally acknowledged in 1975, would have stopped the Apollo program well before it could achieve its goal. As a matter of fact, 1969 was itself a marginal schedule and, as is well known, the program was cut short in 1972.

An indirect proof of this scenario comes from another little known event that concerns Wernher von Braun, who was not only the heart and soul of the Apollo program but also a visionary in the case for Mars. In August 1969, right after the successful Moon landing, von Braun, the hero of the day, told the Congressional Committee for Space, “The Moon is done. Now, on to Mars.”

Von Braun proceeded to give a short presentation (available in the NASA archive) which outlined a detailed and very concrete plan to get to Mars by 1981. He compared the funding requirement to “the cost of a limited operation in a minor theater of war.” His estimate wasn’t a joke, it was true. Impressed by his presentation, the Committee voted on the project, possibly without realizing the historical importance of such a vote for future generations. In view of the pressure of the war, which was then at its peak in terms of US engagement and losses, the proposal was rejected by just a handful of votes. The Mars project was abandoned, Apollo was prematurely terminated in 1972, and in that year Von Braun left NASA. Since then, no human being has gone beyond a low Earth orbit.

Giancarlo Genta has now given us a book that represents a small step in the right direction for a giant leap to the Red Planet. This truly remarkable book has been badly needed. It contains not only Giancarlo’s wisdom, experience and endurance, but also the work of the global IAA working group that he coordinated. As such, the book is even more precious. It addresses all aspects of the exploration of the Red Planet, from its early history to the upcoming plans for human missions of a variety of types. More than a textbook, it is a veritable pocket guide, and a must-read reference for the beginner and for the expert alike.

In addition, its publication comes at a time where new bold plans for landing people on Mars are under serious consideration all across the world. The clock is ticking.

Imagine you find yourself, all of a sudden, thanks to some magic space-time machine, in the US, in rural Ohio, in the dusty summer of 1930, only one year after the start of the Great Depression. You are actually near the small town of Wakaponeta. It is the end of August and, in the heat of the day, you encounter a young woman nursing a small baby in the shade of a tree. You approach her and discover that her name is Viola Armstrong. You smile and tell her, “In 39 years, your baby boy will be the first man to walk on the Moon.” She would certainly look at you in wide-eyed disbelief…

Yes, the clock is indeed ticking, and the baby who will walk on Mars (boy or girl) has already been born. Giancarlo’s book will help it all happen.

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May 2016

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I have made every effort to obtain permission from the copyright holders of the figures, but I apologize for cases, in particular for figures taken from the internet, where I have not been able to achieve my objective. If any reader has appropriate information, please contact the publisher and I shall happily include a credit in a future edition of this book.

And I must express my sincere thanks to Clive Horwood of Praxis Publishing in the United Kingdom, Maury Solomon of Springer in New York, and David M. Harland, their appointed editor, for constructive criticism and suggestions which greatly improved the project.

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Author’s preface

On 20 July 1969 two humans landed for the first time in history upon a celestial body: the Moon. This was the fulfillment of the dreams of many pioneers of astronautics and appeared to open a new era. As Konstantin Tsiolkovsky wrote, “Earth is the cradle of humanity, but one cannot live in a cradle forever.” In the new era we would start our true life as citizens of the Universe. In a less poetic manner, nowadays we would say we would start a spacefaring civilization.

That sooner or later we would land on the Moon was not taken for granted by everybody. Forty-three years earlier, in 1926, a British scientist A.W. Bickerton wrote, “This foolish idea of shooting at the Moon is an example of the absurd lengths to which vicious specialization will carry scientists. To escape Earth’s gravitation, a projectile needs a velocity of 7 miles per second. The thermal energy at this speed is 15,180 calories [per gram]. Hence the proposition appears to be basically impossible.”[1]

What Bickerton considered impossible was leaving the Earth’s gravitational well.In his view, reaching the Moon was as impossible as going to Mars or any other body in our solar system. Now that we have proven him wrong in the case of the former, we can make plans to go farther.

Space travel seemed to belong more to fiction, particularly to science fiction, than to science or technology. Perhaps more so in the opinion of scientists aware of the difficulties involved in such an enterprise, as opposed to the men-of-letters who were much interested in it. As an example of the latter, in 1952 the Italian writer Carlo Emilio Gadda wrote about the exploration of the Moon, Venus and Mars, and defined these celestial bodies as the New Indies, a definition which implies not only exploration but also colonization.

Unfortunately once the technical problems seemed to have been solved, other problems, mostly to do with politics and economics, forced a stop to the creation of a spacefaring civilization.

[1] This much quoted sentence, however, likely was meant to deny the possibility of literally shooting to the Moon using a gun, as in Jules Verne’s famous novel. Bickerton probably did not mean that traveling to the Moon using a rocket would be impossible.

This false start has still to be fully understood. Perhaps our technology was still inadequate, or the projected costs were too high, or the motivations for the lunar adventure were too bound up with the Cold War and had to fade away once one of the two parties had demonstrated it could beat the opponent in this area. It is clear that the technological advances made since the time of Apollo, and those that are predicted for the near future, will make human space exploration much easier, safer, and less costly, thereby enabling us finally to realize the dreams of recent decades.

There is no agreement on the target for this renewal of exploration beyond low Earth orbit. Some hold that we should return to the Moon, saying this is the natural candidate for our first experience of colonization, the first place beyond the Earth where humankind can live, work, create communities, and prosper both culturally and economically. They insist that the exploitation of lunar resources is sufficient reason in itself, because these will be necessary to venture farther and settle Mars and other more distant destinations.

Others argue that humans should focus directly on the exploration of Mars because the Moon, with its lack of an atmosphere, low gravity, and a day that is almost one month long, is too inhospitable for human colonization. Mars, on the contrary, is a true planet that could be made suitable for human life.

A third group argues for creating space stations either in Earth or lunar orbit, or in the gravitationally neutral Lagrange points of the Earth-Moon system. Their short-term goal is to colonize cislunar space. They say the first missions into deep space should be to asteroids, which offer immense resources.

Actually these three ways of seeing the future of humankind in space are not as different as it might appear, at least as far as long-term goals are concerned. The difference is more about the early priorities than the ultimate goals, as it is likely that humankind will ultimately settle both the Moon and Mars, plus many other celestial bodies, and that many people will live permanently in space habitats at various locations. The short-term difficulty is in choosing the best programs on which to concentrate our scarce resources.

Although there is little real doubt that we must return to the Moon as soon as possible and that asteroid missions might be pursued in a more or less far future, the next important destination for human exploration will be Mars. In this sense therefore, Mars is the next stop in our travel toward the stars.

In the opinion of the author, it is not a matter of whether human explorers will reach the Red Planet, but when this will occur, who will do it, and how they will do it. Advances in technology will make this increasingly possible and the growth of the world economy will make it increasingly affordable.

As Donald Rapp points out in the preface of his book *Human Missions to Mars* [22], in science there are roles for both advocates and skeptics. The former play an important role in imagining what might be, and stubbornly pursue a dream which might be difficult to realize but in the end be achievable. The latter identify the difficulties, the barriers, the pitfalls, and the unknowns that impede the path and point out the technical developments needed to enable such dreams to be fulfilled. Skeptics therefore play an essential role in the study of an enterprise as complex as a human mission to Mars. Their viewpoint must be accurately weighted so that we can proceed safely.

The aim of my book is to discuss in detail the problems, the opportunities, and the alternatives for performing the first human Mars exploration mission, possibly in a not-too-distant timeframe.

To explore a whole planet like Mars is an enormous, costly, dangerous task, the more so because it will be the first planet the human species attempts to explore. Of course I am not dismissing the Moon, but the distance to Mars, its size, and its complexity make it a much tougher objective. To speak of organizing a mission to Mars is necessarily reductive, because to explore Mars we must initially mount a campaign that consists of at least three coordinated missions, the organization of which will be as complex as the technological, scientific, and human aspects.

To proceed with this military jargon, we will speak of a 'campaign' made of a number of missions. The first one might be just a 'sortie' (as often a flyby or a short-stay mission is defined) but subsequent ones must be full-blown missions in which humans will spend more than one year on Mars. Since the cost, complexity, and risks of a 'sortie' are only marginally less than those for a longer mission, it has been suggested that even the first mission should have humans on the planet for more than a full year. Right at the beginning therefore, we must establish an 'outpost' on the planet which later can be permanently inhabited and become the nucleus from which the colonization of the Red Planet will start.

This book has 14 chapters and four appendices. The first chapter summarizes briefly the history of the various early projects that were devised with the aim of starting the human exploration of Mars. The motivations that justify resuming our operations beyond low Earth orbit, and in particular mounting a campaign which aims at human exploration of Mars, are described in Chapter 2. The environments humans will face when on Mars and on its satellites are described in Chapter 3. The issues related to both backward and forward contamination are briefly discussed.

In order to reach Mars (and later to come back) it is necessary to cross a large span of interplanetary space, with all the related problems due to radiation which constitute the biggest of the difficulties humans will encounter in this enterprise. Chapter 4 discusses interplanetary space and the dangers presented by this very harsh environment. Crew issues are very important in all human space missions, and will be particular so for a long and difficult voyage to Mars. These are dealt with in some detail in Chapter 5.

Chapter 6 focuses upon the journey to Mars. This is one of the most critical aspects and is right at the frontier of modern technology. Chapter 7 reviews the design of human Mars missions and the choices we must make in preparing to mount such an enterprise. How many astronauts must travel to Mars? How long must they remain on the planet? And which kind of propulsion ought we to use? These, and several other design choices are dealt with.

The explorers will need a place to live on Mars, in particular in case of long-stay missions. They will need a power plant and a number of other infrastructure items and devices. These are dealt with in Chapter 8. Then Chapter 9 considers devices which will allow astronauts to move around on Mars, crawling on the ground, flying in the atmosphere, and hopping from one place to the other.

Although apparently a less important issue, a number of infrastructures on Earth will be instrumental in undertaking a human mission to Mars. These include the communication network, the ground control centers, the astronaut training facilities, and laboratories needed to perform simulations of the various devices. This theme is the focus of Chapter 10.

An enterprise like a human mission to Mars cannot be improvised. It requires a long preparation and a roadmap must be studied in detail and implemented in the due timeframe, as described in Chapter 11. In this chapter the need to return to the Moon on our way to Mars, and the construction of an outpost (perhaps even a Moon Village) are discussed.

Chapter 12 deals with some more futuristic possibilities that may make it easier to reach Mars, to build an outpost there, and ultimately to colonize the Red Planet.

Chapter 13 contains examples of Mars missions designed using different criteria that address various different requirements. Missions of different types that use different types of propulsion are considered and compared.

Some conclusions are drawn in Chapter 14, and a reference section lists some of the books that have been published on this and related subjects. For the technically minded, there are appendices explaining astrodynamics and the issues of mobility on Mars.

Giancarlo Genta
Torino, Italy
May 2016

Acronyms

ABS	Antilock system (in German)
AC	Alternating Current
ACR	Anomalous Cosmic Rays
ALARA	As Low As Reasonably Achievable
AM	Additive Manufacturing
aRED	advanced Resistive Exercise Device
ARM	Asteroid Redirect Mission
ATV	All-Terrain Vehicle
ATV	Automated Transfer Vehicle
AU	Astronomical Unit
BLEO	Beyond Low Earth Orbit
CAPS	Crew Altitude Protection Suit
CEV	Crew Exploration Vehicle
CEV	Constant Ejection Velocity
COSPAR	COmmittee on SPAce Research
COTS	Commercial Orbital Transportation Services
COUPUOS	Committee on the Peaceful Use of Outer Space
CSTS	Crew Space Transportation System
CVT	Continuously Variable Transmission
DC	Direct Current
DOD	Department of Defense
DOE	Department Of Energy
DRA	Design Reference Architecture
DRM	Design Reference Mission
DSN	Deep Space Network
ECLSS	Environment Control and Life Support System
EEG	ElectroEncephaloGram
EDL	Entry Descent and Landing
EGR	Exhaust Gas Recirculation

EMPIRE	Early Manned Planetary-Interplanetary Roundtrip Expeditions
EMU	Extravehicular Mobility Unit
ERTA	Electro-Raketniy Transportniy Apparat (Russian)
ERV	Earth Return Vehicle
ESA	European Space Agency
ESOC	European Space Operations Centre
ESTRACK	European Space TRACKing network
EVA	Extra Vehicular Activity
FAR	Federal Acquisition Regulations
FLEN	Flyby Landing Excursion Module
FY	Fiscal Year
GCR	Galactic Cosmic Rays
GDP	Gross Domestic Product
GES	Global Exploration Strategy
GER	Global Exploration Roadmap
GN&C	Guidance, Navigation & Control
HEAB	High Energy AeroBraking
HIAD	Hypersonic Inflatable Atmospheric Decelerator
HMI	Human-Machine Interface
HMMFI	Human Mars Mission Feasibility Index
HMMWV	High Mobility Multipurpose Wheeled Vehicle
HRP	Human Research Program
HSTI	Human Space Technology Initiative
HT	High Thrust
IAA	International Academy of Astronautics
IAC	International Astronautic Congress
IAF	International Astronautic Federation
ICAMSR	International Committee Against Mars Sample Return
ICE	Internal Combustion Engine
ICME	Interplanetary Coronal Mass Ejections
IMF	Interplanetary Magnetic Field
IMEF	International Mars Exploration Forum
IMLEO	Initial Mass in LEO
ISAS	Institute of Space and Astronautical Science
ISECG	International Space Exploration Coordination Group
ISRU	In Situ Resource Utilization
ISPP	In Situ Propellant Production
ISP	Specific Impulse
ISRO	Indian Space Research Organization
ISS	International Space Station
JPL	Jet Propulsion Laboratory
LED	Light Emitting Diode
LEO	Low Earth Orbit
LEVA	Lunar Extra-vehicular Visor Assembly
LMO	Low Mars Orbit

LH2	Liquid Hydrogen
LN2	Liquid Nitrogen
LOC	Loss Of Crew
LOX	Liquid OXygen
LRV	Lunar Roving Vehicle
LOM	Loss Of Mission
LOP	Loss Of Program
LT	Low Thrust
MARIE	Mars Radiation Environment Experiment
MARPOST	MARs Piloted Orbital STation
MAV	Mars Ascent Vehicle
MAVR	MArs-VeneRa
MEK	Mars Expeditionary Complex
MEM	Mars Excursion Module
MEPAG	Mars Exploration Program Analysis Group
MIT	Massachusetts Institute of Technology
MMH	MonoMethylHydrazine
MO	Mars Orbit
MOI	Mars Orbit Insertion
MORL	Manned Orbiting Research Laboratory
MPK	Mars Piloted Complex
MSR	Mars Sample Return
MSSR	Mars Surface Sample Return
MTV	Mars Transfer Vehicle
NASA	National Aeronautics and Space Administration
NCRP	National Council on Radiation Protection
NEA	Near Earth Asteroids
NEP	Nuclear Electric Propulsion
NERVA	Nuclear Engine for Rocket Vehicle Application
NIMF	Nuclear rocket using Indigenous Martian Fuel
NTO	Nitrogen TetrOxide
NTP	Nuclear Thermal Propulsion
NTR	Nuclear Thermal Rocket
OPS	Oxygen Purge System
PEL	Permissible Exposure Limit
POF	Probability Of Failure
PLSS	Portable Life Support System
PVA	PhotoVoltaic Arrays
PVT	Psychomotor Vigilance Test
PWM	Pulse Width Modulation
RCS	Reaction Control System
RCU	Remote Control Unit
REID	Risk of Exposure Induced Death
RWGS	Reverse Water Gas Shift
RTG	Radioisotope Thermoelectric Generator

SAA	South Atlantic Anomaly
SAIC	Science Applications International Corporation
SAS	Space Adaptation Syndrome
SCB	Sample Collection Bag
SEI	Space Exploration Initiative
SEP	Solar Electric Propulsion
SETV	Solar Electric Transfer Vehicle
SHAB	Surface HABitat
SI	International System of units
SLS	Space Launch System (NASA heavy launcher)
SM	Service Module
SNAP	System Nuclear Auxiliary Power
SPE	Solar Particle Event
SRC	Sample Return Capsule
STCAEM	Space Transfer Concepts and Analyses for Exploration Missions
STEM	Science, Technology, Engineering and Mathematics
STP	Standard Temperature and Pressure
TEI	Trans-Earth Injection
TMI	Trans-Mars Injection
TMK	Heavy Interplanetary Spacecraft (in Russian)
TPS	Thermal Protection System
TRL	Technology Readiness Level
UNOOSA	United Nations Office for Outer Space Affairs
UDMH	Unsymmetric DiMethylHydrazine
UMPIRE	Unfavorable Manned Planetary-Interplanetary Roundtrip Expeditions
VASIMR	Variable Specific Impulse Magnetoplasma Rocket
VDC	Vehicle Dynamics Control
VEV	Variable Ejection Velocity
ZBO	Zero-Boil-Off

1

Half a century of projects

Mars has always been a source of fascination for humankind, and dreams of traveling to the Red Planet are common in literature. In the last 65 years however, increasingly realistic plans have been proposed. The history of projects for human Mars missions is a long one. The most important cases are summarized in this chapter.

1.1 THE NINETEENTH CENTURY MARS

The Red Planet has for centuries fostered dreams and legends. Galileo, who in 1609 was the first man to clearly observe geographical features on an extraterrestrial body, the Moon, aimed his telescope also to Mars without succeeding in detecting anything except the fact that its disc was slightly flattened at the poles. The first person to claim to have seen something on Mars was Francesco Fontana who, in 1636, drew a rough map of the planet. Unfortunately it was later realized that the features he saw were optical illusions.

In the following centuries, generations of astronomers tried to map the surface of the Red Planet. Christian Huygens and Giandomenico Cassini succeeded in measuring the length of its day, which is now known as a *sol*. Cassini's value of 24 hours 40 minutes is remarkably close to the correct 24 hours 39.6 minutes. He also discovered the southern polar cap.

But distinguishing details on Mars was very difficult, and beyond the performance of the telescopes of those times. When telescopes powerful enough to see details on the planet's disc became available, new surprises were at hand. The features were changing over time. In particular, the ice caps at the poles extended in winter and contracted in summer. Variations in the colors of the surface suggested the presence of vegetation. Darker areas were interpreted as seas. As a whole, Mars seemed to be a smaller sister of Earth: a living planet inhabited by an unknown flora and, perhaps, fauna. Now we know that most of the changes we see on the surface of Mars are due to sand and fine particles being blown around by the wind, but at that time there was no way to ascertain this.

In 1867, Richard Anthony Proctor drew a detailed map on which he assigned names to the various features. In 1869, Jules Janssen, using a spectroscope, concluded that although the atmosphere was thin there was water on the surface of the planet.

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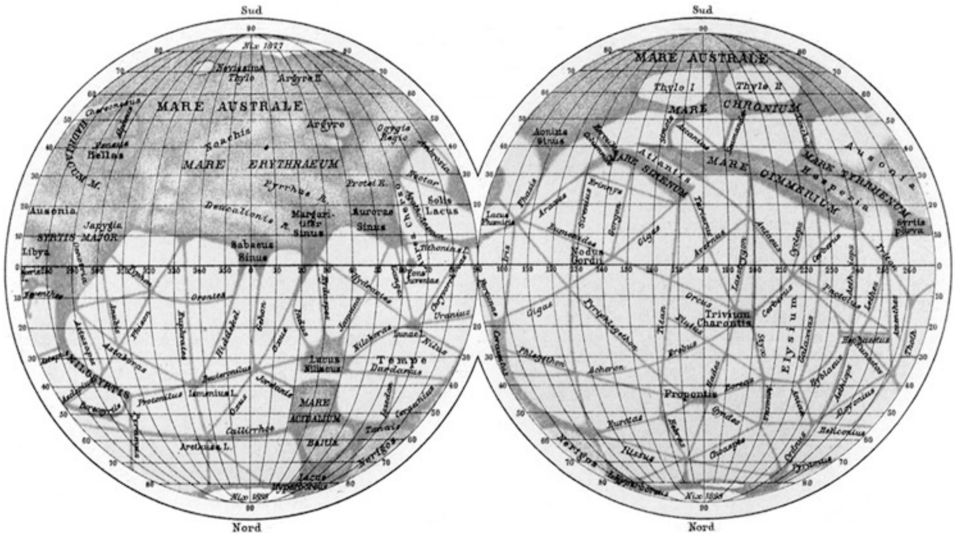

Figure 1.1 A map of the two hemispheres of the planet Mars drawn by Schiaparelli following his observations during six oppositions between 1877 and 1888.

It was presumed that not only living creatures but also intelligent beings – more or less similar to ourselves – roamed on the surface of Mars.

In the latter half of the nineteenth century, three great astronomers, the Italian Giovanni Schiaparelli, the Frenchman Camille Flammarion, and the American Percival Lowell made a series of contributions both to the scientific knowledge and mythology concerning Mars. The former plotted a number of maps (e.g. Figure 1.1) that remained an important reference until the first images to be received from a space probe completely changed our understanding of the planet.

As shown in the figure, the maps drawn by astronomers were oriented in the same manner that they saw the planet in their telescopes, namely with south toward the top and the western limb on the right. Hence to compare the map of Figure 1.1 with the modern one in Figure 3.4, the former must be rotated 180°.

Schiaparelli was the first to detect some thin dark features on the surface of the planet. He described these lines using the Italian word canali, which can be used both for artificial and natural water courses. However, the translation into English as "canals" was limited to artificial waterways and this led to many speculations about the civilization that might have undertaken such gigantic works of engineering, supposedly to survive the rapid process of desertification on their planet.

The idea that there were intelligent beings on Mars prompted many novels, ranging from *The War of the Worlds* by H.G. Wells to *Under the Moons of Mars* by E.R. Burroughs, and from *Out of the Silent Planet* by C.S. Lewis to *The Martian Chronicles* by Ray Bradbury… to name just a few.

Although some of the classical misconceptions were corrected in the first half of the twentieth century – notably, because there was neither oxygen nor water vapor in substantial quantity in the atmosphere, there could be very little water on the surface and the

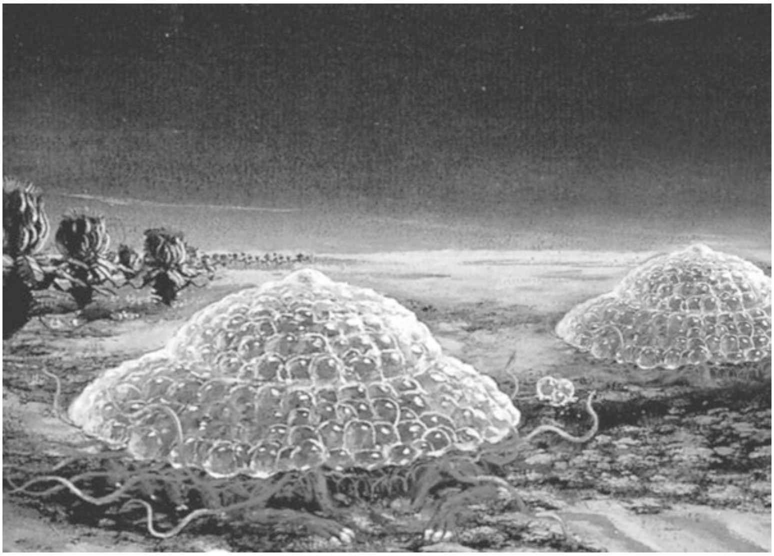

Figure 1.2 Hypothetical forms of Martian life. Drawing by Douglas Chaffee for an article by Carl Sagan in *National Geographic* in 1965.

canals were an optical illusion – our impression of the Red Planet continued to bear a striking resemblance to that of Schiaparelli and Lowell, except with it being a dry world possessing a thin atmosphere which was probably inhabited at least by some primitive forms of life. Intelligent beings, if still present, must have sought refuge underground. A common feature of many descriptions were the "atmosphere machines," huge artifacts built by the intelligent Martians to maintain for as long as possible the conditions necessary for their survival. In many descriptions even some canals survived the likelihood that they were merely optical illusions.

This was the planet described by Wernher von Braun [1] when popularizing his 1950s project for a human expedition to Mars.

By the 1960s, further astronomical work showed that if the planet hosted any form of life, that could only be the most primitive of species. Nevertheless, when Carl Sagan published an article in the *National Geographic* in 1965 and suggested that Mars lacked an ozone layer, he illustrated his article with hypothetical forms of life that had developed a protective layer against radiation from the Sun (Figure 1.2).

1.2 THE DISAPPOINTMENT OF THE PROBES

In 1960, just three years after launching Sputnik 1 as the first Earth satellite, the Soviet Union attempted to send two probes to fly past Mars. Mars 1960A and Mars 1960B each weighed 650 kg and carried a variety of scientific instruments. Both were lost when their rockets failed. At the next launch opportunity in 1962, the Russians launched three more probes. Two failed to start their interplanetary voyage and the third, designated Mars 1, was lost en route to the Red Planet. A further attempt in 1964 with the Zond 2 probe also failed.

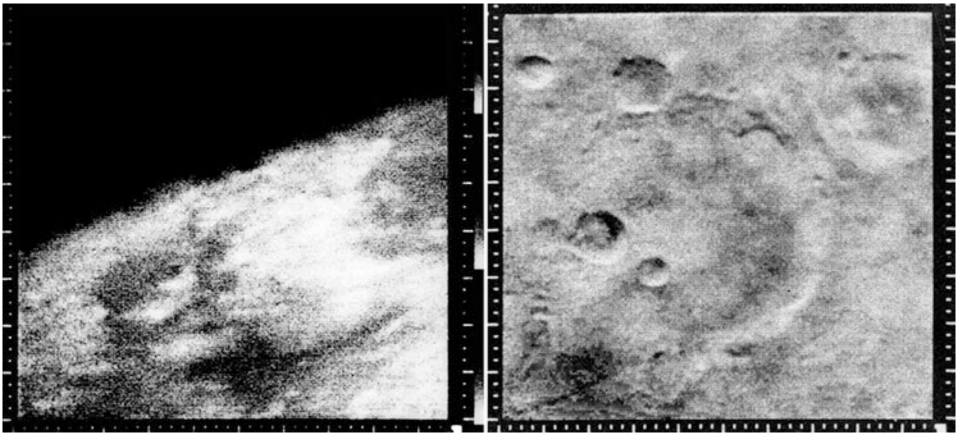

Figure 1.3 The Mariner 4 probe in 1965 gave us our first close view of the surface of Mars. (NASA images)

In 1964, America tried its hand at Mars exploration by launching Mariner 3 and Mariner 4. Built by the Jet Propulsion Laboratory (JPL), these probes were to fly close to the planet. The first mission failed, but the second, launched on November 28, reached its target on July 14, 1965. Twenty two pictures were recorded on tape on board and later transmitted to Earth over a period of 4 days. Altogether the images recorded about 1 percent of the surface of the planet.

Two of the pictures are shown in Figure 1.3. The one on the left is the first image ever received from Mars. It is an oblique view of the limb and covers an area of about 330 km by 1,200 km.

The images were shocking and really disappointing because they showed many impact craters, some of which appeared to indicate traces of ice. The overall impression was of a planet unsuitable for life. Mars was apparently a desolate place, rather similar to the Moon. Other data showed that the planet has only a very weak magnetic field (evaluated at about 0.1 percent of the strength of Earth's). The manner in which the radio signal was attenuated as the probe crossed the limb of the planet revealed the atmosphere to be made almost entirely of carbon dioxide rather than, as had been believed, mostly nitrogen.

In 1969 Mariner 6 and Mariner 7 made similar flybys of the planet and transmitted a larger number of pictures which were better than those of Mariner 4. Although these results essentially confirmed what had been learned in 1965, it was also realized that Mars is not so similar to the Moon as was initially suspected. In particular, the south polar cap appeared to be primarily solid carbon dioxide, and the mean atmospheric pressure at the surface of 6 to 7 millibars was lower than expected.

The next mission was Mariner 9. This entered orbit around the Red Planet in order to map it. Launched in 1971, the probe arrived when most of the planet was covered by a global dust storm. When the dust settled, the many images transmitted over a period of almost a year revealed that Mars is much more complex than the impression gained from the limited coverage of the flyby missions. It has huge volcanoes and canyons and, above

Figure 1.4 Chryse Planitia viewed from ground level by the Viking 1 lander. (NASA image)

all, dry river beds. For sure, if Mars today is a dry and dead world, then earlier in its history it must have been both warmer and wetter. There was the tantalizing prospect that life originated in that earlier era, then perhaps it may still survive today.

The next step was to attempt a landing on the planet. In the late summer of 1975 a pair of Viking missions were launched, carrying for the first time scientific instruments to analyze the surface of Mars in order to search for life. Both landers, each with a mass of 576 kg, touched down safely: the first on the western slope of Chryse Planitia (Figure 1.4) and the second on Utopia Planitia, located on the opposite side of the planet.

Besides taking pictures and collecting other science data, the two landers conducted three biology experiments designed to identify the presence of living organisms. These experiments revealed unexpected and enigmatic chemical activity in the Martian soil, but provided no clear evidence for the presence of life at the landing sites. Apparently, Mars' surface is sterile owing to a combination of solar ultraviolet radiation, the extremely arid conditions, and the oxidizing nature of the soil.

The results from the probes of the 1960s and 1970s led many scientists to pessimistic conclusions not only about finding life in the solar system but also of humans being able to explore Mars with a view to ultimately colonizing it.

The Viking results completed the shift of the paradigm about Mars. The Red Planet of the astronomers had yielded to the Mars of the space probes. In later years other missions were sent by NASA, Roscosmos, ESA, ISAS and ISRO, and a succession of orbiters, landers and rovers gradually refined our impression of the planet (Figure 1.5). Although the results have unveiled many of the mysteries, thousands of important details remain to be clarified before humans will be able to land there.

We are now sure that liquid water flowed on the surface of Mars in the distant past, at a time when it was much less desolate than today. The low pressure and temperature, and the composition of the atmosphere together with the results of the experiments aimed at searching for life, eliminated all hopes of finding higher forms of life and, for the majority of scientists, even the prospect of finding bacteria seems bleak.

Figure 1.5 A view of Mount Sharp at the center of Gale Crater, taken by the Curiosity rover on September 9, 2015. (NASA image)

Phobos and Deimos, the small satellites of Mars, have also attracted attention. Prior to probes providing images, some scientists, for instance, explained the low density of the former by assuming it to be an artificial satellite or, better still, a large space station built by the dying Martian civilization as a sort of library or museum to preserve its legacy. Several probes have imaged the two satellites, showing them to be irregular shapes with cratered surfaces. There have been several unsuccessful attempts to land instruments on Phobos, the larger of the pair. These bodies play an important role in some plans for human Mars exploration.

Since the first attempts in the early 1960s, not all of the probes launched to Mars were successful. Some failed to leave Earth. Some fell silent during the interplanetary voyage. A few remained operational but flew by the planet at too great a distance to make any proper observations. Some made perfect flybys. Some failed to achieve Mars orbit. Some achieved the wrong orbit. Some worked perfectly. Some intended landers missed the planet entirely. Others crashed. A few reached the surface and functioned perfectly. Landing on Mars was a formidable challenge, but the success rate has increased over the years and nowadays we are able to make precision landings with reasonable safety.

Many unknowns remain. We know that Mars hosts a large amount of water – although likely not in liquid form. It is present in the form of subsurface ice, but we are still unsure of where it is located and at which depth. We have clues to the existence of large caves. These might be useful as bases when settling the planet, but we aren't sure about how many there are. We still need to ascertain the radiation dose to which humans will be subjected while on the surface. There are many such questions. Many automatic missions are still required and, above all, there will need to be sample return missions before anyone is able to set foot on the Red Planet. The dream of sending a human mission to Mars is becoming ever more feasible, and at some time in the not too distant future the first ambassador from Earth will send back a message from its surface.

1.3 THE EARLY PROJECTS (1947–1972)

1.3.1 General considerations

This early period starts with the first detailed studies carried out in the immediate aftermath of World War II, and lasts until the setback of human space exploration which terminated the Apollo lunar program. As stated above, fictional accounts of voyages to Mars can be found in the literature much earlier, namely since the last decade of the nineteenth century.[1]

Often the voyage to Mars – in many case the very first expedition – is described in detail, but sometimes the problem of how this is achieved is completely bypassed. For instance, John Carter, the main character of Burroughs' novels, simply falls asleep (or dies) on Earth and awakens (or is re-embodied) on Mars. Even where an actual journey is described, that is a fantasy and therefore has little to do with the subject of this book.

Essays written by true space travel pioneers like Konstantin Tsiolkovsky, R.H. Goddard, Hermann Oberth and several others accurately represent the basic concepts that will make a flight to Mars possible, but they do not elaborate the details of the design of such a mission.

To qualify as a project for a mission, a study must contain at least the main details required to actually implement the mission, and must at least touch on basic issues regarding the feasibility, safety, and possibly the cost of sending the crew to Mars and home again. If possible, it should also account for the emergencies which may take place, and how these might be dealt with.

The earliest detailed studies began in 1947, and were based on the assumption that Mars was like the nineteenth century astronomers described, namely a dry but not completely dead world, with an atmosphere which humans could not breathe but neither would they require a full space suit (as would be needed on the Moon), and an air density which, although low, was sufficient for aerodynamic flight.

But this optimistic picture was ruled out by the first close pictures taken of the planet by Mariner 4 in 1965. Slowly it was realized that the atmosphere was only marginally better than the vacuum of the Moon, that astronauts would require full space suits, and that using a glider in order to land would be impracticable. Thus 1965 marks a turning point.

In most early designs, the idea was that the crew would reach Mars without much previous knowledge of the planet, and that they would spend their first days in orbit mapping in order to select their landing site. Perhaps they might send automatic probes down to the surface to get some idea of what they would find when they themselves landed. Otherwise they would make the first sortie without any knowledge of what they would find, including whether there might be hostile or possibly even friendly Martians. As an alternative, they might send down teleoperated probes that would be driven from orbit, a possibility which was rightly deemed to be within the scope of predictable technology.

The need for humans to control and maintain spacecraft meant that some people would have to remain in orbit while others explored the surface. This was the way that the Apollo lunar missions were conducted.

[1] Several are described in https://en.wikipedia.org/wiki/Mars_in_fiction

After 1965, the Martian surface was considered a dangerous place, perhaps more so than space. In case of an accident, the astronauts would require to take off, enter orbit around the planet and then wait for the correct time to start the return journey: space was a safe haven. Following this idea, short stay missions or even flybys without landing were considered more expedient than long stay missions (see Section 7.2). Indeed, there was also the possibility of staying on Phobos or Deimos and teleoperating robots on the planet. Phobos orbits closer in and the time delay for teleoperating robots on Mars is just 40 ms; much less than the delay from Deimos (134 ms).

Even if knowledge of conditions on Mars was clearly insufficient to correctly design a mission, astrodynamics was very well known and (even without the powerful computers we have now) it was feasible to compute trajectories in enough detail to deal with that aspect of the mission design in a satisfactory manner.

1.3.2 Von Braun's project

A list of the studies for human Mars missions carried out between 1947 and 1972 is given in Table 1.1.[2] This lists complete projects along with partial studies, but is far from complete. It also specifies the name of the author (or the company or agency), the type of propulsion used for the interplanetary transfer, the crew size, and the Initial Mass in Earth Orbit (IMLEO) in tons (t).[3]

The first detailed study of a human mission to Mars was undertaken by Wernher von Braun between 1945 and 1948, and he published the results in 1949 as *Das Marsprojekt*. This technically-sound analysis established the feasibility of reaching Mars using a technology that was likely to become available in the not too distant future. An English translation of the study was published in 1952 [1].

The expedition was to be performed by a fleet of ten 3,720 t spaceships with a total crew of 70 astronauts. All interplanetary spacecraft would be powered by chemical rockets, operating on storable propellant (hydrazine and nitric acid). The ships would be assembled in Earth orbit, and this preliminary phase would require a total of 950 launches of huge multistage rockets of a size that would now be defined as heavy lift launchers.

An interesting solution was devised for landing on Mars. After all ships had entered Mars orbit, a winged craft equipped with skis would glide down to land on the north polar ice cap. This method was selected because the prevailing opinion at that time was that the atmosphere was much denser than it later proved to be. Consequently, von Braun designed entry vehicles as gliders with very large wings (Figure 1.6) which had to land horizontally like airplanes in a similar manner to the large military gliders of World War II.

Then those people who had landed would engage in a 4,000 km trip using a tractor to reach a suitable place near the equator at which to build a runway to permit two other winged ships to land with other landing parties and the materials to build an outpost which would allow the expedition to live on Mars for more than a year. After their wings had been removed, the landers would lift off vertically to reach Mars orbit. The entire crew would then occupy those ships designated for the return journey and head home.

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[2] More detailed information can be found on *Encyclopedia Astronautica* (www.astronautix.com).

[3] The SI symbol for ton (t) is used throughout this book.

Table 1.1 Studies for human Mars missions performed between 1947 and 1972.

Year	Expedition	Country	Author	Prop.	Stay	Crew	IMLEO
1947	von Braun Mars Ex.	USA	W. von Braun	C	L	70	37,200
1956	MPK	USSR	Tikhonravov	C	L	6	1,630
1956	von Braun Mars Ex.	USA	W. von Braun	C	L	12	3,400
1957	Stuhlinger Mars	USA	Stuhlinger	NEP	L	200	6,600
1959	TMK-1	USSR	Maksimov	C	F	3	75
1960	TMK-E	USSR	Feoktistov	NEP	L	6	150
1960	Bono Mars Vehicle	USA	P. Bono	C	L	8	800
1960	Mars Ex. NASA	USA	NASA Lewis	NTP	S	7	614
1962	EMPIRE A	USA	Aeronutronic	NTP	F	6	170
1962	EMPIRE L	USA	Lockheed	NTP	F	3	100
1962	EMPIRE G.D	USA	Gen. Dyn.	NTP	S	8	900
1962	Stuhlinger Mars	USA	Stuhlinger	NEP	S	15	1,800
1963	Mavr Mars flyby	USSR	Maksimov	C	F	3	75
1963	Faget mars Ex.	USA	M. Faget	NTP	S	6	270
1963	Faget mars Ex.	USA	M. Faget	C	S	6	1,140
1963	TRW Mars Ex.	USA	TRW	C	S	6	650
1964	Project Deimos	USA	P. Bono	C	S	6	3,996
1964	UMPIRE C	USA	G. D. & Convair	C	L	—	—
1964	UMPIRE D	USA	G. D. & Douglas	NTP	S	6	450
1965	MORL Mars Flyby	USA	Douglas	C	F	3	360
1966	KK Mars Ex.	USSR	K. Feoktistov	NEP	S	3	150
1966	FLEM Mars Ex.	USA	R.R. Titus	C	S	3	118
1968	IMIS Mars Ex.	USA	Boeing	NTP	L	4	1,226
1969	von Braun Mars Ex.	USA	W. von Braun	NTP	S2	12	1,452
1969	MEK Mars Ex.	USSR	Chelomei	NEP	S	6	150
1971	NASA Mars Ex.	USA	NASA	C	S	5	1,700
1972	MK-700	USSR	Chelomei	NTP	S	2	1,400
1972	MK-700	USSR	Chelomei	C	S	2	2,500

(C: Chemical; F: flyby; S: Short stay; L: Long stay; S2: Short stay, 2 months; IMLEO is in t).

The total travel time of such a mission would be about 3 years, so this mission can be defined as a long stay one.

Although technologically consistent, this project did not take into account the likely costs and, as perhaps was inevitable for a first attempt, it was not economically sustainable. An artist's impression of the orbital assembly of the huge winged vehicles which were to land on Mars is shown in Figure 1.6.

Von Braun also wrote a science fiction novel (probably in the early 1950s) based on the mission to Mars described above, but this was not published until 2006 [20]. Apart from the very large crews involved, what is most striking for the modern reader is the description of the planet. It was very close to the late-nineteenth century impressions of Schiaparelli and Lowell. The intelligent beings living on Mars are somewhat more civilized than those of Burroughs' novels, but not all that different from them. Other points that might surprise modern readers, but were typical of the time in which von Braun was writing, are that the 70 person crew was all male and that psychological problems are not addressed. A mission to Mars was felt to be not much different from any wartime mission of the navy, particularly in submarines.

Figure 1.6 An artist's impression of the assembly in Earth orbit of the winged spacecraft designed by von Braun for landing on Mars. (NASA image)

Von Braun's project was updated and simplified by its author in 1956 and then again in 1962. In 1969 he proposed a smaller project in which the number of spacecraft was reduced to just two, one being a winged landing module, and the crew was cut to twelve people. By then, the Saturn V, a veritable superheavy lift launcher, was operational, sending Apollo crews to the Moon. This could certainly be used to assemble a Mars expedition in Earth orbit, but during the effort to reach the Moon even larger launchers had been studied. One of these, called Nova, was intended to directly launch a large spacecraft to land on the Moon and lift off for the return to Earth without involving a rendezvous in lunar orbit. Far larger than the Saturn V, this rocket would be capable of placing 250 t in LEO. Although abandoned for the Moon, the Nova was a natural choice for going to Mars.