DREAM MISSIONS

Space Colonies, Nuclear Spacecraft and Other Possibilities

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Published in association with
Praxis Publishing
Chichester, UK

PRAXIS

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SPRINGER PRAXIS BOOKS IN SPACE EXPLORATION

Springer Praxis Books
ISBN 978-3-319-53939-3 ISBN 978-3-319-53941-6 (eBook)
DOI 10.1007/978-3-319-53941-6

Library of Congress Control Number: 2017936899

Cover design: Jim Wilkie
Project Editor: Michael D. Shayler

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer International Publishing AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

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Acknowledgements

I would like to thank Clive Horwood of Praxis Publishing and Maury Solomon of Springer for their support and ideas, especially for suggesting a more positive spin on the subject. Looking for information on missions that never happened, I kept coming back to David Portree's Spaceflight History blog, as well as the articles he wrote for *Wired*. I would like to thank him for his permission to draw on his research and to quote him in this book. Another great source of information was the series of insightful articles on past and present space developments on thespacereview.com ("*essays and commentary about the final frontier*"); especially those written by Dwayne Day and Jeff Foust, which provide a welcome antidote to some of the more inflated expectations. Thanks to Dr. Rick Fleeter for the interesting conversations and the permission to quote him regarding the myth that good ideas inevitably happen. Arno Wielders (of Mars One fame), Stella Alexandrova, Rogier Schonenborg and Alessandro Atzei were, as always, great sources of ideas and references; I expect you may not agree with all my evaluations, but that should result in some more interesting conversations in the pub. Finally, many thanks to Michael Shayler for the expert editing and to Jim Wilkie for making this book look good.

For Elisa

About the Author

Michel van Pelt (b. 1972) lives in Leiden, The Netherlands, in an old house filled with Dutch-Italian children, books and spacecraft models. He works as an engineer at the European Space Agency (ESA), where he is involved in the conceptual design of a variety of launchers, satellites and space probes. He is an editor and writer for the Dutch space magazine *Ruimtevaart*, while he has also published in *Mars Exploration Magazine*, *Spaceflight* and *Aeroplane* on topics ranging from 1930s Dutch rocket pioneers to future interstellar missions.

Michel regularly presents on space-related topics such as Mars missions, spaceplanes and the future of spaceflight at events organized by the Nationaal Ruimtevaart Museum / Aviodrome, Science Cafe Nijmegen, the Club of Amsterdam, the Netherlands Space Society and at the ESA ESTEC Open Day.

In addition, he is an active BSAC scuba diving instructor.

Dream Missions is his fifth book; following his previous works *Space Tourism*, *Space Invaders*, *Space Tethers and Elevators* and *Rocketing into the Future*.

Preface

In hindsight, the year I was born – 1972 – can be considered to have been a pivotal year for spaceflight. It was the year of the last manned lunar landing, Apollo 17, ending the hectic and exciting era of the Space Race. It was also the year that Wernher von Braun, the main architect of U.S. human spaceflight development, retired from NASA, frustrated that the space agency was no longer progressing in accordance with the vision he had laid out way back in the 1950s. This was exemplified by the discontinuation that same year of the development of NERVA, the nuclear rocket engine meant to enable human spaceflight forays further into the solar system. In January 1972, President Nixon instead announced the Space Shuttle as the next major goal of the agency, effectively limiting NASA's astronauts to low Earth orbit to this day. And 1972 also saw the fourth and final attempt – and failure – of the Soviet Union to launch its N1 moon rocket, thus ending their Space Race manned lunar landing ambitions.

Influential in another respect was the publication in 1972 of the *Limits to Growth* report, the first widely publicized warning of the consequences of unbridled economic growth. Disregard for the environment, climate change and abuse of our planet's limited resources were getting out of hand, the report stressed, and without drastic measures our life on Earth would quickly become unsustainable. General concerns about pollution, overpopulation, urbanization, nuclear energy, the arms race and other problems on our home planet increased, ironically symbolized by the pictures sent back by the Apollo lunar astronauts that showed our planet as a little, vulnerable island in the hostile blackness of space.

Whereas confidence in the improvement of life through technical and scientific progress, including spaceflight, had been high in the 1950s and 1960s, people now started to be uncertain about their future and ever more skeptical towards technology. In the U.S., the 'Watergate' scandal further eroded confidence in the government. To make matters worse, economic growth started to slow down worldwide, especially when the 1973 oil crisis triggered a recession.

However, 1972 also saw the launch of Pioneer 10, the first spacecraft to leave the solar system, and the first successful landing on the surface of Venus of a robotic space probe, by the Soviet Union's Venera 8. The launch of the Copernicus Orbiting Astronomical

Observatory, a collaborative effort between NASA and the UK's Science Research Council, paved the way for later astronomical observatories in space, such as the Hubble Space Telescope. Not all was doom and gloom.

As I grew up in the 1980s, the era of the Space Shuttle, I admired the variety of missions the Shuttle accomplished, but also became increasingly frustrated about the seeming lack of progress, especially in comparison to what I found depicted in books written before and during the Space Race. Mars missions now always seemed to be 20 years in the future; true spaceplanes remained forever on the drawing board. And while the 1970s sales pitches for the Shuttle had promised routine access to space for an increasing number of people with a variety of backgrounds, the optimism that I might grow up to visit a space station myself gradually decreased, especially after the *Challenger* disaster of 1986.

In my mind, something had clearly gone wrong around the time I was born. Up till 1972, humanity had been gloriously expanding its presence in the solar system; first reaching Earth orbit and then landing on the Moon. But after that point, we had become stuck in low Earth orbit. I started to read books about space colonization, and soon understood that was another dream that was going nowhere fast.

Around the time that I went to study aerospace engineering, I started to realize that while progress in human spaceflight might have stagnated, in robotic exploration things were not all that bad. Voyager 2 flew past Uranus and Neptune; ESA's Giotto flew past Halley's Comet; Galileo went into orbit around Jupiter; the first rover landed on Mars; and the Hubble Space Telescope returned spectacular views of the universe. In the meantime, while not flying very far, astronauts still fixed satellites and cosmonauts lived in space stations for extended durations. The Soviets launched a new super heavy-lift launcher and their own version of the Space Shuttle.

I nevertheless retained my interest in many of the original, far more ambitious, "dream missions," such as human landings on Mars, routine spaceplane flights, nuclear spaceships, lunar bases and vast orbital habitats. Why was it that at one time these projects seemed inevitable, while a few decades later they appeared hopelessly naïve and optimistic? What had changed? What could we learn from this? Could any of them still become reality, one way or another? I was not alone in such musings; towards the end of the 20th century, at the approach of the new millennium, there was much reflection on the overall accomplishments of spaceflight in comparison with the expectations of the 1950s and 1960s. The supposedly realistic depictions of the 1968 movie, *2001, A Space Odyssey*, contrasted sharply with the real year 2001, which saw only a tiny stub of a space station, and lacked both lunar bases and giant nuclear spaceships carrying their crews to Jupiter.

After touching on the topic of unrealized projects in my previous book on rocketplanes and spaceplanes, I wanted to expand my view to the wider scope of spaceflight in general. Initially, my idea was a book about 'the greatest missions that never happened', but the publisher rightly felt this too negative an angle that would likely result in a melancholic book about might-have-beens. Writing such a book could have easily turned into a depressing experience; maybe not to a historian, but certainly to a space enthusiast engineer like me. We thus decided on a more positive approach, focusing not on what didn't happen, but rather on why things did not follow 'the plan', and what may eventually still make new and old "dream missions" a reality.

Nevertheless, writing this book proved to be a somewhat thought-provoking experience, with me having to face the fact that several favorite grand projects are unlikely ever to come to fruition because of serious technical and financial issues, or merely because the whole idea is now hopelessly outdated.

Somewhat naively delving into the subject, I quickly found out how much material there really was. The number of abandoned spaceflight ideas, concepts and projects far outweighs the number that have actually flown. Researching one concept inevitably led to another idea; the rabbit warren seemed to go on forever. Where to stop? When does science forecasting become science fiction? When does technological possibility become technology fantasy and thus beyond the scope of this book? How many abandoned manned Mars mission concepts would I need to describe to make a point? I decided not to strive to be all-inclusive, focusing on a more general narrative with examples of concepts that have been seriously considered and that appeared reasonably credible at one time, if not today.

Unlike many books on the subjects I touch on, I do not offer any clear solutions or strategies that will lead to a glorious continuation of humanity's expansion into the cosmos. I wish I had any, really. The observations, predictions and opinions I describe in this book are my own, and you are welcome to disagree. In fact, I would be very grateful if anybody could manage to convincingly revive the idea of the giant space colony, a childhood favorite. I would love to visit one, just like it was depicted in those stunning NASA artists' impressions of the 1970s.

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Introduction

When I was a kid in the late 1970s, *Lego Space* was my favorite toy. The theme included various types of space bases, mobile laboratories and spacecraft operating in a Moon-like setting. It depicted a future in which mankind had expanded throughout the solar system, and maybe even beyond. One particular brick, part of a space command post, featured a large television screen which said '*L.L. 2079*', apparently for '*Lego Land 2079*', which was about a century in the future at that time.

Back then, that didn't look too unrealistic. Developments in space exploration in general had been spectacular since the start of the 'Space Age', with only eleven years between the launch of Sputnik and the first manned flight around the Moon. Apollo 11 landed on the lunar surface just over six months later. Then, after Apollo 17, there was a kind of quiet period, at least for manned spaceflight. The 1970s, however, was the decade in which the Voyager probes were launched, the Viking probes landed on Mars, and commercial telecom satellites became operational. At the end of that decade, the Space Shuttle was about to make its first flight, and was soon expected to make low Earth orbit (LEO) a relatively easy to access hub of activity for just about anybody. As a child, I tried to imagine what another hundred years would bring. Surely it was going to be awesome, and probably similar to what my *Lego Space* play sets were depicting: boundless exploration; endless possibilities; and easy-to-reuse space transportation. And everything modular, *Lego*-style. Above all, it was going to be spectacular, extensive and focused on astronauts rather than automated spacecraft.

As such, *Lego Space* was following the vision of spaceflight evolution as set out by famous and highly influential space pioneer Wernher von Braun and others in *Collier's* magazine during the early 1950s: steady progress from unmanned satellites to large space bases routinely serviced by reusable launchers and shuttles, Moon landings and the manned exploration of Mars. Using spectacular artistic impressions and convincing descriptions, these articles basically defined how the general public in the U.S. expected

M. van Pelt, *Dream Missions*, Springer Praxis Books,
DOI 10.1007/978-3-319-53941-6_1

spaceflight to develop. And such ideas were not limited to the United States; a similar vision was laid out in 1951 by the famous British writer Arthur C. Clarke, in his farsighted book *The Exploration of Space.* Some six years before the launch of Sputnik, this book basically predicted all the spaceflight possibilities and uses that did actually materialize by 1969, including practical satellite applications and manned lunar landings.

One space spectacular followed another during the 1960s, mostly driven by the U.S.-Soviet Space Race. Many of the expectations popularized by von Braun, Clarke and other space advocates for developments up to the first human landings on the Moon did materialize, quite often sooner than they had foreseen in the early 1950s. This led NASA, other space experts, the general public and the makers of the famous 1968 movie, *2001, A Space Odyssey*, to extrapolate wildly into the future. They envisaged large space stations, lunar mining, semi-permanent bases on Mars and maybe even manned exploration of the outer solar system before the end of the 20th century.

Take for instance the grandiose vision of Krafft Ehricke, a German rocket propulsion engineer who worked on the infamous V2 missile under Wernher von Braun during World War II and afterwards, like von Braun, became a fervent spaceflight advocate in the U.S. Ehricke believed in what he called the 'Extraterrestrial Imperative', a philosophy which postulated that it was mankind's responsibility to explore space and exploit the resources of the solar system, to ensure the survival and development of the species.

During the 1966 American Astronautical Society symposium, '*Space Age in Fiscal Year 2001'*, he expressed the following expectations for manned solar system transportation at the turn of the millennium: "Today, in the fall of 2000, the interplanetary flight corridors from Mercury to Saturn are alive with manned vehicles of relatively luxurious and sophisticated design, driven by quite advanced propulsion systems … Our helionauts, as these men who fly our large interplanetary vehicles call themselves in this era of continuing specialization, have covered the solar system from the sun-scorched shores of Mercury to the icy cliffs of the Saturn moon Titan. They have crossed, and some have died doing so, the vast asteroid belt between Mars and Jupiter and have passed through the heads of comets. Owing to the pioneer spirit, the courage and the knowledge of our helionauts and of those engineers, scientists and technicians behind them, astrophysicists today work in a solar physics station on Mercury; biologists experiment on Mars, backed by a well-supplied research and supply station on the Mars moon Phobos; planetologists have landed on Venus; and teams of scientists right now study what has turned out to be the two most fascinating planets of our solar system, Jupiter and Saturn, from research stations on Callisto and Titan." Today, this reads as wild science fiction, but in 1966 such visions were frequently outlined by various recognized spaceflight experts, and were commonly accepted as credible.

Looking back at the short history of the space age up to that point, you can understand the optimistic extrapolation through which Ehricke and others arrived at a glorious interplanetary infrastructure 34 years into their future. In 1932, German pioneers were launching liquid-propellant rockets of a few tens of kilograms that reached altitudes no higher than a kilometer, unless they blew up, as they frequently did. Just 34 years later, in 1966,

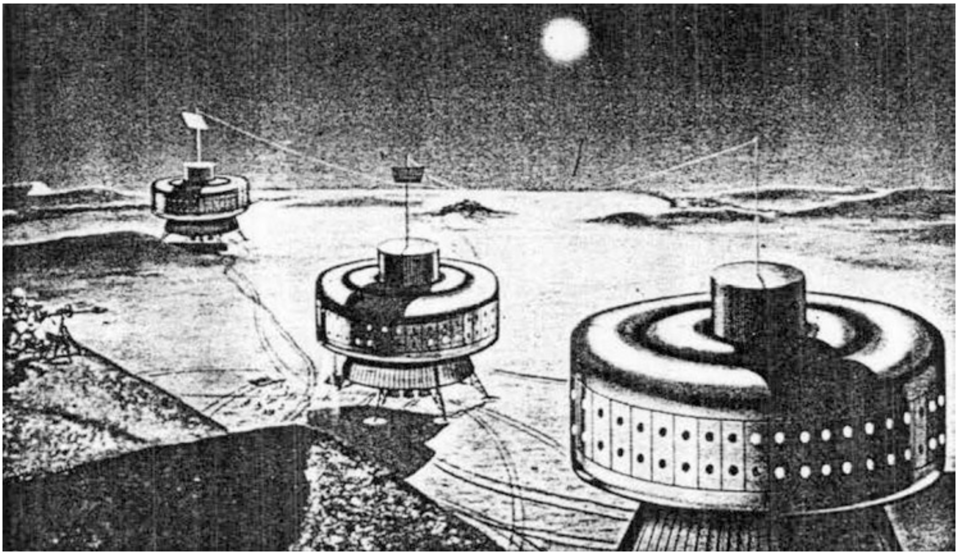
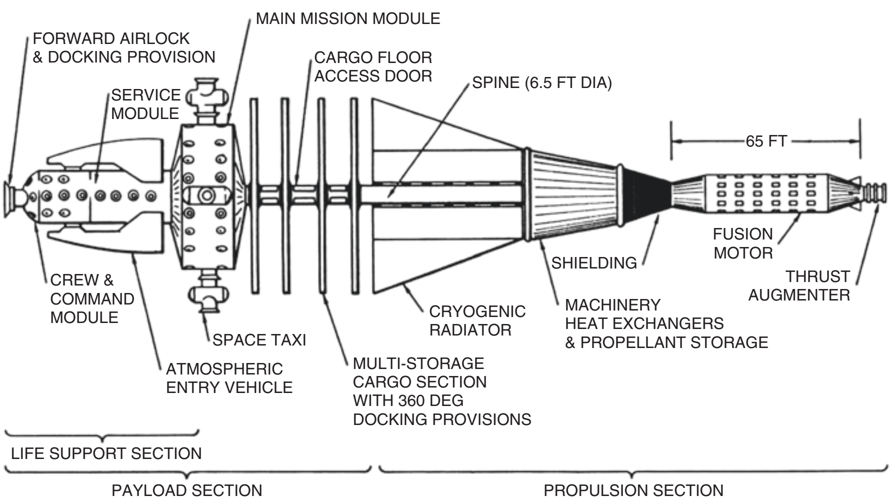


Illustration of a Mars base in Krafft Ehricke's description of spaceflight in the year 2000. The original caption reads "Astrobiological Research Base on Mars, 1992." The three base modules shown are supplied with electrical power from a nuclear power generation module seen partly buried in the background. [General Dynamics/Convair]



A thermo-nuclear reactor spaceship as envisioned by Krafft Ehricke. He expected several would be cruising the solar system by the year 2000.

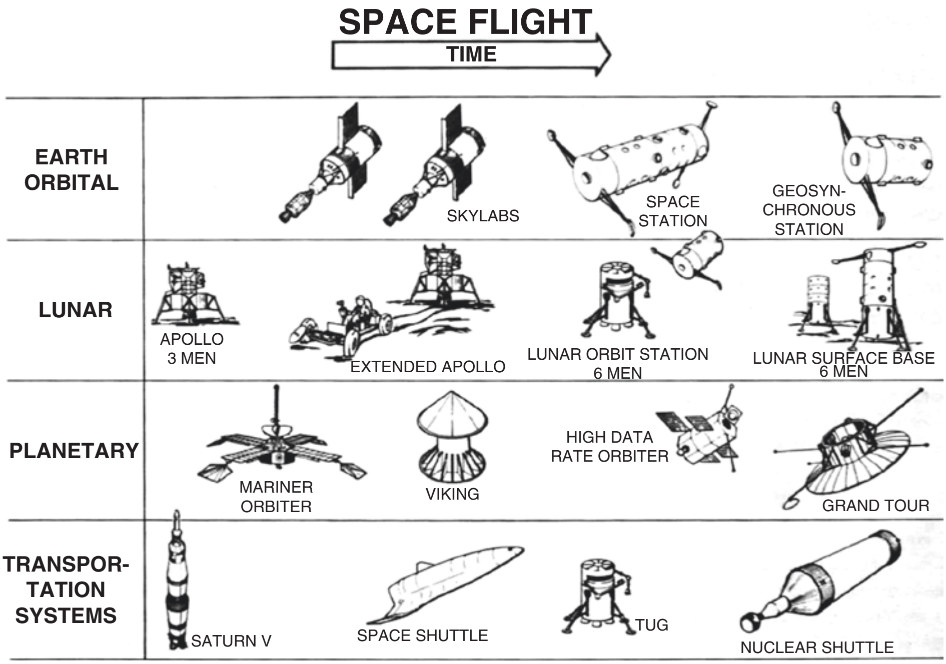
those same engineers were preparing the 111-meter tall, 2,970,000 kg Saturn V Moon rocket (which flew for the first time in September 1967). No wonder they thought the sky was the limit, and that in another three decades or so, giant nuclear-powered spaceships would be crossing the solar system on a regular basis.

Even in 1980, noted U.S. rocket pioneer Robert Truax was still of the opinion that: "By the year 2000, fifty thousand people will be living and working in space." In reality (up to the time of writing in 2017), the population in orbit has never exceeded 13. The furthest anybody has gone away from Earth in the last 45 years, since the last manned lunar landing in 1972, is a mere 620 kilometers. No astronaut has ever escaped Earth's gravity field.

The belief that exponential spaceflight progress was the inevitable result of the road NASA had taken has come to be known as the 'von Braun paradigm'. It was based on the optimistic idea that anything that could technically be done would be done, and that there would be a logical progress to humanity's expansion into the solar system. In von Braun's vision, routine access to space would be enabled by using a reusable launcher with a winged shuttle vehicle, which would transfer cargo and crews to and from large Earth-orbiting space stations. This infrastructure would then be used to organize expeditions to the Moon and subsequently Mars, with the necessary vehicles assembled at a space station from elements brought up by the shuttle. Instead, Apollo went straight for the Moon, without a reusable launcher or space station. Nevertheless, von Braun expected these to be developed later, when routine access to Earth orbit and the Moon would require them once the post-Apollo 'Space Race' period was over.

But by 1972, the seemingly unrelenting progress already appeared to be running out of steam. During the live CBS broadcast of the launch of the last manned lunar mission, Apollo 17, in December 1972, famous presenter and space enthusiast Walter Cronkite noted that people were gloomy about the future of space exploration, before cutting to a short interview with Wernher von Braun, who had headed the development of the mighty Saturn V Moon rocket. Unhappy with the severe budget cuts and the premature termination of the Apollo program, von Braun had already retired from NASA in May that year. Von Braun appeared weary, but nevertheless enthusiastically declared: "We will go to the Moon again. There may be a ten-year gap or so…" Then he explained how the future Space Shuttle would launch reusable two-stage space tugs that would enable lunar landings at a tenth of the cost of Apollo. He thus effectively foresaw a return to his original vision, the proper evolution of spaceflight development he had advocated in *Collier's*. Cronkite then questioned von Braun on whether he really meant ten years, not "a much longer period," but von Braun maintained that manned Moon missions would become routine by the early 1980s. Cronkite appeared unconvinced, noting how quickly the public had grown blasé with the space program only two years after Apollo 11. Clearly Cronkite, whose job as a newsman demanded that he kept up with the latest politics and public opinion, has been proven the more prescient in this respect.

At this point, for the first time since its founding, NASA was facing significant restrictions to its human spaceflight ambitions, and the agency was struggling to come to grips with the new political, economic and social realities. The blossoming optimism of the 1950s and 1960s was over; the austerity of the 1970s had arrived.



NASA's plans for the period 1970 – 1980, as seen by the agency at the end of the 1960s. Only the (robotic) Planetary timeline progressed accordingly. The large post-Skylab space station didn't happen until the ISS was put into orbit in the late 1990s, while the geosynchronous station never materialized. The Space Shuttle eventually took flight in 1981, but the lunar orbit station, lunar surface base, space tug and nuclear shuttle were all cancelled in the early 1970s and will not materialize at least till the 2030s. [NASA]

In March 1970, President Richard M. Nixon declared that "space expenditures must take their proper place within a rigorous system of national priorities." In other words, there would be no more seemingly unlimited budgets and therefore no lunar colonies and Mars expeditions in the 1980s. The new idea was that spaceflight had to be developed economically to sustain further developments, and would no longer be the exclusive domain of professional astronauts with a military pilot background. In his 1972 announcement of the new NASA program, Nixon declared that the Space Shuttle would "make the ride safer, and less demanding for the passengers, so that men and women with work to do in space can 'commute' aloft, without having to spend years in training for the skills and rigors of old-style spaceflight." Using the Space Shuttle, orbital laboratories and zero-gravity factories would be built that would turn manned spaceflight into a profitable business, paving the way for further exploitation of the Moon, Mars and the asteroids.

Nixon tasked NASA with the development of the Space Transportation System (STS), a.k.a. Space Shuttle, for civil as well as military (spy satellite launch) applications, but his authorization did not include the development of a space station, which von Braun and NASA had always envisioned would go together with a shuttle system.

In spite of this, and to some degree as a reaction to the lack of progress and vision of this new direction, Gerard K. O'Neill's humongous space colony concepts were added to the dream list in the 1970s, as an attempt to still implement Krafft Ehricke's 'Extraterrestrial Imperative'. O'Neill's concepts involved designs for enormous habitats in space, where ordinary people would make a living by building equally gigantic solar power satellites that would beam energy to a resources-starved Earth. This would all be made possible by the Space Shuttle and its successors, as they would enable launches costing only a fraction of those of conventional expendable rockets. Rather than the bleak future presented by many scientists in the 1970s, fearing a rapid decrease in resources in combination with overpopulation, O'Neill offered a bright, almost utopian prospect.

Consistent with this, and only a few months before the Space Shuttle would make its first flight, a Dutch television program in 1980 ('*TROS Aktua special: de Space Shuttle*') enthusiastically conveyed NASA's promises for this revolutionary vehicle, which would be flying almost on a weekly basis. According to the presenter, the Shuttle would soon make traditional expendable rockets "join the ranks of old steam locomotives and horse trams," regularly return 'Made in Space' products from orbital microgravity factories to Earth, and help construct giant space solar power satellites that would take on a considerable share of our global electrical power needs by the year 2000. By then, the Shuttle would be replaced by an even more sophisticated, fully reusable, single-stage-to-orbit spaceplane that would provide flights into orbit on a daily basis.

None of this happened, of course. Through the 1980s, the Shuttle proved to be far more expensive, far more complex to re-launch and far less reliable than originally promoted by NASA. The U.S. space agency's policy goal to "optimize the management and operation of the Space Transportation System (STS) program to achieve routine, cost-effective access to space," as worded in the *President's Directive on Commercialization of Expendable Launch Vehicles* in 1983, was not achieved. This brought all the fancy ideas for space colonization to quite a sudden stop, and also put into question the viability of even more complex spaceplanes. The part-rocket, part-airplane launchers that were seriously studied during the late 1980s and through the 1990s all succumbed to the fatal combination of high risks and uncertain economic returns in the early stages of development. With the Space Shuttle retired, we are now back to the days of launching astronauts on top of conventional rockets in rather traditional capsules.

Elsewhere, however, and somewhat under the radar, a different road of spaceflight progress did open up during the late 1960s, and especially in the 1970s: unmanned satellites and robotic space exploration. Thanks to significant developments in electronics, the ability to relay telecommunication signals and conduct Earth observation no longer required the giant space stations with large crews that von Braun had envisioned. This could now be done much more efficiently, and at much less expense, using automated satellites.

The same was true for large space telescopes, which up till the 1970s were expected to require regular servicing by astronauts, or would even need to be put on the Moon to be operated by the crew of a nearby lunar base. Nowadays, very large and complicated space telescopes are designed to operate for many years without any servicing by astronauts, and often keep going for more than a decade. The Hubble Space Telescope *was* serviced and upgraded across several Space Shuttle missions, but taking the huge costs of this into account, it may well have been more economical to launch brand new, upgraded space telescopes instead. In fact, no space telescopes currently in operation, or being planned, incorporate astronaut visits in their mission plan. Hubble's successor, the James Webb Space Telescope, will not receive any visitors.

The story for interplanetary exploration follows a similar narrative. Rather than flying large habitation modules and gigantic (nuclear) spaceships to Mars in order to accommodate a crew of astronauts, relatively small probes like the Vikings, and later the NASA rovers, were sent instead. While astronauts are yet to venture further than the Moon, a mere 384,000 kilometers away, Voyager 1 is currently an incredible 20,520,000,000 kilometers from Earth. That is so far out that it takes Voyager's radio messages 19 hours to reach us, even travelling at the speed of light.

Manufacturing in space never became a success, but weather forecasting, television broadcasting, navigation, astronomy and mapping from space certainly have. Initially seen as merely an additional benefit in the shadow of manned spaceflight, or as paving the way for 'proper' manned exploration, the robotic 'side show' has now become the true driver of spaceflight development and operations, in terms of worldwide effort, budgets and number of launches. It has even led some to consider human spaceflight obsolete and unnecessarily expensive.

Famous astrophysicist James van Allen, for instance, one of the people behind the first U.S. satellite, Explorer 1, has always been skeptical of the usefulness of humans in space. In 2004, he wrote an appraisal in the policy journal *Issues in Science and Technology*, entitled 'Is Human Spaceflight Obsolete?' In it he asked: "Does human spaceflight continue to serve a compelling cultural purpose and/or our national interest? Or does human spaceflight simply have a life of its own, without a realistic objective that is remotely commensurate with its costs? Or, indeed, is human spaceflight now obsolete?"

According to van Allen, human spaceflight supporters "defy reality and struggle to recapture the level of public support that was induced temporarily by the Cold War." He argued that the highly expensive Space Shuttle mission program contributed little to science and space technology development, while "almost all of the space program's important advances in scientific knowledge have been accomplished by hundreds of robotic spacecraft in orbit about Earth and on missions to the distant planets Mercury, Venus, Mars, Jupiter, Saturn, Uranus, and Neptune."

Skeptical of the use of "false analogies to Christopher Columbus, Ferdinand Magellan, and Lewis and Clark, or with visions of establishing a pleasant tourist resort on the planet Mars," in van Allen's opinion, "the only surviving motivation for continuing human spaceflight is the ideology of adventure." Inevitably, he asked the question of whether that was sufficient reason to spend hundreds of billions of dollars on it. It will come as no surprise that he thought not.

A little less scathing is Louis Friedman, space engineer, space advocate and co-founder of The Planetary Society, in his recent book *Human Spaceflight: from Mars to the Stars.*

Observing how robotic space technology has evolved tremendously over the last 50 years while human spaceflight is hardly advancing, he points out: "If we characterize the space race as a race between humans and robots, the robots are clearly winning." He does envisage humans eventually reaching Mars, for the primary reason of establishing another home to avoid total annihilation in case of a catastrophe on Earth, but going no further. By the time we get to Mars, Friedman believes that our technology will be so advanced that robotic space probes will enable us to be virtual explorers in virtual recreations of the worlds our robots visit, as with the Holodeck of the fictional starships in *Star Trek*: "Holograms will allow us to virtually cut a hole in the ice of Europa, moving underneath and sampling its constituents, just as if we were physically there."

Technological developments are indeed moving quickly in this respect. A team from NASA JPL, for instance, has recently developed a virtual reality planning tool that allows Mars rover mission operators to step into a virtual Martian landscape, based on images sent by the rover, and identify features for the rover to investigate. Merely pointing towards it could command the robot to go to the intended location. Such tools can probably be converted fairly easily into systems that allow anyone to join a rover on its journey remotely.

In this respect, it is interesting to note that while Krafft Ehricke's 1966 forecast for spaceflight in the year 2000 was far too optimistic in terms of human spaceflight developments, it has proven to be not that far from the truth with regard to robotic space exploration. His predictions read: "Unmanned probes have approached the Sun as close as 0.15 AU. Large and very advanced unmanned probes have reached out as far as the planet Pluto, and at this moment rove the vast, dark regions of trans-Pluto and interstellar space." In fact, it was only ten years after these predictions, in 1976, that the Helios 2 satellite flew by the Sun at a record close distance of 0.29 AU (Astronomical Unit: 1 AU is the average distance between Earth and the Sun). By the year 2000, four space probes had already made it well beyond the orbit of Pluto (Pioneer 10, Pioneer 11, Voyager 1 and Voyager 2), although the dwarf planet itself was not visited until NASA's New Horizons probe arrived in 2015.

Ehricke was even more on target with his 1966 vision of the future use of Earth-orbiting satellites, describing the developments from that year up to 2000 as follows: "Satellites of many nations began to form a virtual super-structure above the surface of our planet; forestry, plant disease detection, weather observation, communication, air and sea traffic control have become matters of global concern…"

Despite the fact that those grand visions of human spaceflight from the 1960s to the 1980s have yet to become reality and are unlikely to do so for the foreseeable future, and even in the face of the much more rapid progress of unmanned satellites and space probes, NASA, ESA and other space agencies typically tend to try and stick to some form of the 'von Braun paradigm'. Robotic space exploration is fine and worthwhile in its own right, they argue, but it should eventually (sooner rather than later) be followed by humans. People are deemed to be more versatile, adaptable and better able to convey discoveries back to Earth, and supposedly will remain so in the future. Their targets remain the Moon or Mars, not surprisingly, because these are the only large bodies on which we can imagine landing humans in the near future.

However, geopolitical positioning generally seems to be more important for human spaceflight than science. It was a major propaganda tool during the Cold War, and continues to have a strong symbolic function, showing off national capability and generally gathering more public interest than robotic missions. China's human space missions serve as a strong symbol of that country's technical and economic progress, undeniably stating that China is now part of the "major spacefaring nations" club.

Human spaceflight does have its diplomatic uses, in that it offers the possibility to fly guest astronauts of other countries, resulting in tighter bonds between nations. The Soviet Union, for example, had its Interkosmos program for communist and sympathetic socialist nations, while the U.S. flew astronauts from allied nations across the world onboard the Shuttle. Today, the International Space Station (ISS) ensures that Russia, the U.S. and Europe at least maintain cooperation in space, even though their terrestrial disputes have led to communication breakdowns, sanctions and boycotts in other areas. Maintaining at least some kind of human spaceflight endeavor also preserves jobs, perishable skills and expertise in high-tech industry.

Several U.S. presidents have thus come up with new, bold plans in the spirit of the 'von Braun paradigm', such as Ronald Reagan's National Aero-Space Plane and the space-based part of his Strategic Defense Initiative ("*Star Wars*") of the 1980s; George W. Bush's manned Mars plans for the 1990s; and George W. Bush Junior's Constellation lunar plans for the 2000s. All of them were cancelled in the early stages of development.

Lately, the debate surrounding such ambitious space exploration has centered on whether they should happen through classical government space programs, or via some form of NewSpace commercial developments and public-private partnership. But human space exploration remains the focus. It is almost a religion, with its own 'bibles' in the writings of Konstantin Tsiolkovsky, Hermann Oberth, Robert H. Goddard, Wernher von Braun and other space pioneers, in which astronauts assume the role of saints.

Human space exploration is seen as something inevitable, a logical outcome of evolution and the restless need to explore that Mother Nature instilled in us. Moreover, if the universe is mostly empty and seemingly devoid of intelligences other than ours, wouldn't it be a waste of all that space if we were not to make use of it? Isn't it all out there for us to expand into, and in fact don't we have an obligation to do so?

In reality, there is no scientific proof that intelligence, let alone human or robotic space exploration, is a fundamental result of natural, Darwinian evolution. Nature doesn't have a 'direction', and the universe doesn't care whether life on Earth manages to leave its planet or remains at the single cell stage in a tidal puddle somewhere; whether we colonize the galaxy or blow ourselves up in a nuclear Armageddon. As space popularizer Carl Sagan put it: "The universe seems neither benign nor hostile, merely indifferent."

There is also no guarantee that once we colonize space, we will find ways to make it economically justifiable, whether that is by mining the Moon and asteroids, Space Solar Power, zero-g manufacturing, spin-offs or whatever. Some space enthusiasts seem to be certain of this, but once again according to Sagan: "The universe is not required to be in perfect harmony with human ambition."

Hard lessons have been learned. The first one is that erroneous predictions are not the exception but the rule for spaceflight developments; mostly too conservative until around the launch of Sputnik, and way too optimistic ever since Apollo 8. We are still waiting for giant-wheel space stations, efficient aircraft-like operable spaceplanes and Mars bases. Only computers have evolved much faster than predicted by von Braun, although they are still not as smart (or dangerous) as the HAL 9000 of *2001, A Space Odyssey*.

Another thing we have found out is that there is nothing inevitable about space exploration. Political needs, such as demonstrating the power and success of one's economy and technology, are major drivers for human spaceflight, but the rapid decline in NASA's budget following the successful lunar landing of Apollo 11 shows that changing priorities and government administrations can quickly curtail any dreams for human expansion into the cosmos. In his testimony to the U.S. Senate, space popularizer Neil deGrasse Tyson passionately argued that "after we stopped going to the Moon, we stopped dreaming about tomorrow."

Changing priorities and constraints can even lead to the loss of capabilities. From 1981 until 2011, we had, in the Space Shuttle, a partly reusable launch vehicle capable of flying a variety of payloads and astronauts into orbit, and which could function as a crewed space laboratory for weeks on end. It was effectively the first element of the 'von Braun paradigm'; a reusable winged vehicle giving routine access to low Earth orbit and enabling the construction of a large, modular space station, the ISS. But the Space Shuttle system turned out to be very expensive, costing more per flight and per kilogram-payload-to-orbit than any other launcher. It was overly complex and neither very reliable nor safe. When the Space Shuttle was mothballed, however, we lost a set of unique capabilities that only a Shuttle-like system can provide. The Soviets developed their own Shuttle, launched it once, then gave up.

Now we are back to wingless, parachute-equipped capsules atop rockets that can trace their heritage directly to the spaceships of the 1960s, rather than the logical next step on from the Shuttle in the form of truly reusable, versatile and highly efficient spaceplanes. In 1969 we had the equipment to land people on the Moon; from 1973 on we no longer did.

Today we have the large International Space Station which, while it could be viewed as the second step in von Braun's original master plan, no longer has the reusable Shuttle for logistics support. However, unlike von Braun's large space station concept, the ISS is unsuitable for use as a staging point for missions to the Moon or Mars. It is in the wrong orbit for that (too high an inclination) and moreover it is not equipped, in terms of hardware and astronaut manpower, to act as a "space garage" for assembling and maintaining large interplanetary spacecraft. The ISS is set up to house six people, not the large crews von Braun envisaged.

There are also no guarantees that the ISS will lead to larger, multiple, or even just a single follow-on space station when it is inevitably decommissioned, probably sometime in the 2020s. The ISS has not led to fundamental breakthroughs in terms of science and certainly not in terms of economics. There is no large and powerful community of scientists demanding better and larger space station facilities, nor investors ready to bankroll in-orbit factories.

Many other roles von Braun envisioned for his space station, such as Earth observation, telecommunication and astronomy, have today been totally taken over by unmanned satellites. It is not even obvious anymore that the continuation of human space exploration, with missions to the Moon or Mars, will even require an Earth-orbiting space station.

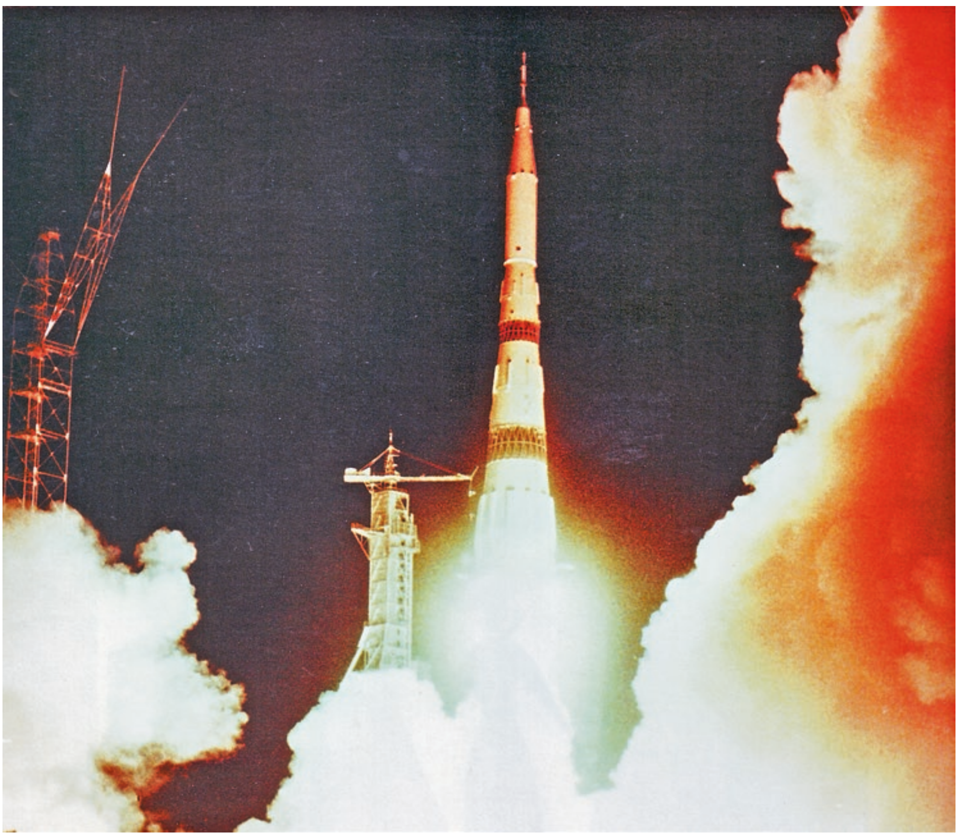
There is no direct road from the ISS to von Braun's giant wheel-shaped space base and on to O'Neill's space colonies. Instead, that road is winding, full of crossroads, without indications of the direction, and with some streets leading to dead ends. Moreover, we are having a very hard time keeping ourselves on it.

What is technically possible does not automatically become reality, because having the technological capability is only part of the story. Economics, politics, culture and public interest are all major factors at play, growing in importance with the size of the endeavor. Ignoring the intricate mix of the many non-technical factors that greatly influence large space projects amounts to self-delusion. The Apollo Moon missions, for example, would not have happened without the Cold War context, a booming economy and a charismatic president setting the U.S. a challenge.

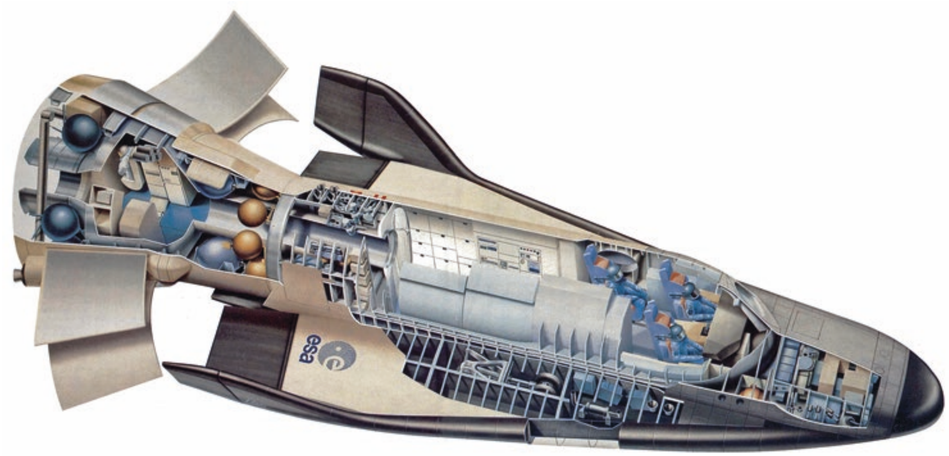
President Kennedy addresses the nation's space effort at Rice University and announces: "We choose to go to the Moon." [NASA]

In the 1960s, the mix was just right, not only for President John F. Kennedy to announce the daring plan for "landing a man on the Moon and returning him safely to the Earth," but also for actually getting it done. An explanation often offered as to why the Moon landings ended in 1972 is that Apollo was ahead of its time. However, before the 1960s the technology was not there, while after that turbulent decade the political necessity as well as the economic prosperity to back it up financially were missing. As such, Apollo came exactly at the right time, seizing a window of opportunity that did not last long and that has not been repeated since. This at least partly explains why the various ambitious space plans boldly announced by U.S. presidents since then have all failed to materialize. The Soviet manned Moon landing program started too late and was too poorly organized and underfunded to be able to catch up with Apollo. It was effectively terminated in 1974.

In the early 1990s in Europe, increasing cost predictions, and the expenses West Germany suddenly faced due to the unification with East Germany, led to a radical diminution of ESA's ambitious Columbus program. The Man-Tended Free Flyer space station and the Hermes mini-shuttle were cancelled, and all that remained was the Columbus laboratory module (of reduced size) that was eventually installed on the ISS and the large, unmanned Earth observation satellite, Envisat.



Lift-off for a Soviet N1 moon rocket prototype, the equivalent to Apollo's Saturn V.



Artist's impression of ESA's Hermes shuttle in orbit. It would have been launched on top of an Ariane 5 rocket. [ESA]

Even purely economically-driven satellite projects are not safe, as demonstrated by the rapid developments in terrestrial mobile phone networks which killed off the ambitious communication satellite constellations in the late 1990s, before they could even be fully deployed. Currently, it even looks like we may one day choke in an Earth-enveloping cloud of self-created orbital debris, which already renders satellite-based applications ever more risky and might ultimately lead to an increased dependency on ground-based technology.

One day we may be a multi-planet species able to reach other solar systems, but this is not bound to happen by itself.

A third lesson, already learned way before Sputnik 1, is that history and technological development do not follow a linear, predictable, or even fully rational path. All kinds of developments that are currently hard to foresee may take place. The fact that unmanned satellites, rather than astronauts, would play the starring role in exploration and the economic use of space was not foreseen by von Braun and his contemporaries.

Private venture plans for 'space tourism' led astronaut and second man on the Moon, Buzz Aldrin, to express the opinion in 2001 that "… we will not be able to afford a political decision to return to the Moon or go to Mars with NASA explorers, or whomever, until we get the people behind it and we start doing adventure travel." While it may not exactly be 'space tourism' that has led to the recent success of SpaceX, this 'NewSpace' company did grow out of a similar idea, of providing low-cost commercial transportation of cargo and astronauts to orbit, revolutionizing this business and forcing established launch providers like Arianespace and ULA to scramble to come up with new, more cost-efficient launchers.

These are the kind of unforeseen and unexpected developments that could suddenly drive completely new directions in the future. Who had foreseen the iPhone, Facebook, mobile phones, satellite navigation, or suborbital space tourism, for example?

In fact, several types of missions that were traditionally expected to require very large spacecraft may instead soon be done with very small ones. Constellations of hundreds of mini-satellites could work together instead of single large communication satellites, or swarms of tiny insect-like robots could explore Mars rather than big rovers or astronauts. Feather-like light-sails might fly to the stars on powerful laser beams, taking humanity on a virtual trip into the Universe instead of on gigantic star ships with hibernating crews and hypothetical propulsion systems, as proposed by Louis Friedman in his book *Human Spaceflight: From Mars to the Stars*. Such ideas are fairly recent, and have only been made feasible by the leap in electronics miniaturization in the last few decades; you will not find them in the traditional 'spaceflight bibles' of Tsiolkovsky, Oberth, Goddard and von Braun. The way we saw the future half a century ago is not necessarily the same as the future we foresee today, which in turn is not likely to be identical to the future we will actually encounter. As Yoda would say, "always in motion, the future is."

New developments, however, can also revive older concepts that were becoming obsolete. Ocean liners were rendered outdated by the airplane, but then holiday cruises meant a new business for large and slow passenger ships. Traditional trains could hardly compete with cars and cheap airline tickets, until new technology led to high speed trains that can take you across Europe faster than a car and about as quick as a plane – without the queuing and annoying security checks at the airport.

New technology and business concepts can even give new chances to futuristic ideas from history that never materialized because they were lacking the need or the means. For a very long time, electric cars were too complex and too expensive to compete with cars equipped with ordinary combustion engines. The small tablet computers of *2001, A Space Odyssey* and *Star Trek* took nearly four decades to become part of everyday life. The increasing demand for low-cost satellite launches means that innovative launch provider SpaceX, as well as DARPA, who are responsible for the development of emerging technologies for the U.S. military, now see a market in (partly) reusable launch vehicles, an idea that is about as old as space rocket technology and has been a staple of science fiction stories for nearly a hundred years.

It is impossible to write a book about unforeseen large-scale concepts and technologies; the 'unknown unknowns' (this is in contrast to the 'known unknowns', where you can at least point out the things you have no clue about). Therefore, this book focuses on ambitious spaceflight ideas that have already been put forward, and sometimes even developed to a certain extent, but which have failed to fully materialize up till now. Of course, not everything discussed in this book was intended to be implemented exactly as described, or according to the schedules projected by their initiators. Many were merely intended to express a vision, to show what could be done and to initiate necessary technology developments and mold public opinion. Nevertheless, such broadly-outlined projects remain illustrative for the way spaceflight was expected (sometimes almost demanded) to develop.

What are the problems that forestall the advancement of particular ambitious space programs, projects and general concepts? Are these issues technical in nature, or financial, or maybe social? What are the chances that in the future these concepts can be re-invented because of new technology or new money becoming available? Which ideas can be relegated to the scrapheap of obsolete concepts, alongside the steam-powered car, the giant flying boat and the nuclear-powered airplane? And which may yet become a reality, as originally intended or possibly serving a very different purpose? What would be required to save these concepts? These questions are explored in the following chapters.