The Case For Mars

Chapter 1: Mars Direct

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Robert Zubrin

1: MARS DIRECT

The planet Mars is a world of breathtaking scenery, with spectacular mountains three times as tall as Mount Everest, canyons three times as deep and five times as long as the Grand Canyon, vast ice fields, and thousands of kilometers of mysterious dry riverbeds. Its unexplored surface may hold unimagined riches and resources for future humanity, as well as answers to some of the deepest philosophical questions that thinking men and women have pondered for millennia. Moreover, Mars may someday provide a home for a dynamic new branch of human civilization, a new frontier, whose settlement and growth will provide an engine of progress for all of humanity for generations to come. But all that Mars holds will forever remain beyond our grasp unless and until men and women walk its rugged landscapes.

Some have said that a human mission to Mars is a venture for the far future, a task for the "next generation." On the contrary, we have in hand all the technologies required for undertaking within a decade an aggressive, continuing program of human Mars exploration. We can reach the Red Planet with relatively small spacecraft launched directly to Mars by boosters embodying the same technology that carried astronauts to the Moon more than forty years ago.

How can this be? Looking at almost any plan for a human mission to Mars, be it from the 1950s or the 1990s, we see enormous spaceships hauling to Mars all the supplies and propellant required for a mission. The size of the spacecraft demands that they be assembled in Earth orbit—they're simply too large to launch from the Earth's surface in one piece. This requires that a virtual parallel universe of gigantic orbiting "dry docks," hangars, cryogenic fuel depots, power stations, checkout points, and construction crew habitation shacks be placed in orbit to enable assembly of the spaceships and storage of the vast quantities of propellant. Based upon such concepts, it has been endlessly repeated that a mission to Mars would have to cost hundreds of billions of dollars and incorporate technologies that won't be available for another thirty years.

Yet landing humans on Mars requires neither miraculous new technologies nor the expenditure of vast sums of money. We don't need to build *Battlestar Galactica*–like futuristic spaceships to go to Mars. Rather, we simply need to use some common sense and employ technologies we have at hand now to travel light and live off the land, just as was done by nearly every successful program of terrestrial exploration undertaken in the past. Living off the land—intelligent use of local resources—is not just the way the West was won; it's the way the Earth was won, and it's also the way Mars can be won. The conventional Mars mission plans are impossibly huge and expensive because they attempt to take all the materials needed for a two- to three-year round-trip Mars mission with them from Earth. But if these consumables can be produced on Mars instead, the story changes, radically.

Starting in the spring of 1990, I led a team of engineers and researchers at Martin Marietta Astronautics in Denver in developing a plan to pioneer Mars in this way. The name of the plan is "Mars Direct," and it represents the quickest, safest, most practical, and least expensive way to undertake the exploration and settlement of Mars.

Mars Direct says what it means. The plan discards unnecessary, expensive, and time-consuming detours: no need for assembly of spaceships in low Earth orbit; no need to refuel in space; no need for spaceship hangars at an enlarged Space Station, and no requirement for drawn-out development of lunar bases as a prelude to Mars exploration. Avoiding these detours brings the first landing on Mars perhaps twenty years earlier than would otherwise happen, and avoids the ballooning administrative costs that tend to afflict extended government programs.

A rough cost estimate for Mars Direct would be about $30 billion to develop all the required hardware, with each individual Mars mission costing about $3 billion once the ships and equipment were in production. While certainly a great sum, spent over a period of ten years it would only represent about 7 percent of the existing combined military and civilian space budgets. Furthermore, this money could drive our economy forward in just the same way as the spending of $100 billion (in today's terms) on science and technology in the Apollo program contributed to the high rates of economic growth of America during the 1960s.

Conventional wisdom might deem Mars Direct attractive because of its simplicity, but it would also deem it infeasible—the mass of the propellant and supplies needed for a human mission to Mars is much too large to be launched directly from Earth to Mars. Conventional wisdom would be right except for one thing: The required propellant and supplies needed for a Mars mission do not have to come from Earth. They can be found on Mars.

From a vantage point of the present, here's how the Mars Direct plan would work:

AUGUST 2020

A new, multistage rocket fashioned from currently existing parts rests on the launch pad at Cape Canaveral, its thin metal skin steaming in the morning sunlight. The booster reminds some of the old Saturn V's, the rockets that carried men to the shores of the Sea of Tranquility. The new Ares booster has about the same heavy lift capacity as the Apollo-era *Saturn V*'s, but at its heart are the workhorses of the past several decades, four Space Shuttle main engines and two shuttle solid rocket boosters. The engines ignite. Flame and smoke describe the signature of a new space age as the Ares hurtles skyward. High above Earth's atmosphere, the Ares upper stage separates from the spent booster, fires its single hydrogen-and-oxygen-burning engine, and hurls an unmanned 45-tonne (45-metric-ton) payload to Mars: the Earth return vehicle. (NB: 1 tonne=2204.6 lb.)

The ERV's name says it all. The vehicle is designed to carry a crew of astronauts back from the surface of Mars direct to a splashdown in Earth's waters. On its journey to Mars the ERV carries a small nuclear reactor mounted atop a light truck, an automated chemical processing unit along with a set of compressors, and a few scientific rovers. The ERV's crew cabin stores a life-support system, food, and other necessities to sustain a four-member crew on an eight-month journey back to Earth. Though its two propulsion stages will consume some 96 tonnes of methane/oxygen bipropellant on the return flight, the ERV arrives at Mars with its fuel tanks essentially empty, carrying just 6 tonnes of liquid hydrogen propellant production feedstock.

FEBRUARY 2021

Traveling across space at an average speed of about 27 kilometers per second, the ERV reaches Mars after a six-month trip. Upon arrival the ERV uses its *aeroshell*—a blunt, mushroom-shaped shield—to plow through the upper reaches of Mars' thin atmosphere. The craft's speed drops, allowing it to brake into orbit. A few days are spent in orbit to allow the flight controllers to perform a final system checkout. Then upon arrival of a clear dawn with low winds and well-defined shadows at the chosen landing site, the craft is targeted back into the atmosphere for final entry. Using its aeroshell again, the ERV decelerates to subsonic speeds until a parachute can pop open and start the spacecraft on a gentle descent toward the surface of Mars. A few hundred meters above the surface, the parachute drops away and small rockets fire up to take the ERV carefully through the last moments before touchdown.

Once settled on the rust-colored soils of Mars, the ERV gets down to the business at hand, making fuel for the return flight home out of thin air—in this case, Martian air. A door pops open on the side of the squat ERV landing stage and a light truck carrying a small nuclear reactor trundles out. Using a small TV camera on board as their eyes, mission controllers in Houston slowly drive the truck a few hundred meters away from the landing site. As the truck wheels along, a power cable snakes off its windlass, keeping the ERV's chemical plant connected to the small reactor. Once the controllers maneuver the truck to an appropriate spot, a winch lifts the reactor from the truck's bed and lowers it into a small crater or other natural depression in the landscape. The reactor kicks in and begins to energize the chemical processing unit with 100 kilowatts of electricity (kWe). Now the chemical plant goes to work, producing rocket propellant by sucking in the Martian air with a set of pumps and reacting it with the hydrogen hauled from Earth aboard the ERV. Martian air is 95 percent carbon dioxide gas (CO_2). The chemical plant combines the carbon dioxide with the hydrogen (H_2), producing methane (CH_4), which the ship will store for later use as rocket fuel, and water (H_2O). This methanation reaction is a simple, straightforward chemical process that has been practiced in industry since the 1890s. As the methanation reaction proceeds, it rids us of a potential problem, that of storing super-cold liquid hydrogen on the Martian surface. The chemical plant continues its work, splitting the water produced by the methanation process into its constituents, hydrogen and oxygen. The oxygen is stored as rocket propellant, while the hydrogen is recycled back into the chemical plant to make more methane and water. Additional oxygen is produced by a third unit which takes Martian carbon dioxide and splits it into oxygen, which is stored, and carbon monoxide, which it vents as waste. At the end of six months of operation, the chemical plant has turned the initial supply of 6 tonnes of liquid hydrogen brought from Earth into 108 tonnes of methane and oxygen—enough for the ERV plus 12 tonnes extra to support the use of combustion powered ground vehicles on the Martian surface. Using Mars' most freely available resource, its air, we have leveraged the portion of our return propellant hauled from Earth eighteen times over.

This chemical synthesis sequence may appear to some to be rather involved, but it's actually all Gaslight Era technology, utterly trivial by comparison with practically every other significant operation required for a successful interplanetary mission of any kind. Moreover, it is this concept of living off the land that makes Mars Direct possible.

If we attempted to haul up to Mars all the propellant required, we indeed would need massive spacecraft requiring multiple launches and on-orbit assembly. The cost of the mission would shoot out of sight. It should come as no surprise that local resources make such a difference in developing a mission to Mars, or anywhere else for that matter. Consider what would have happened if Lewis and Clark had decided to bring all the food, water, and fodder needed for their transcontinental journey. Hundreds of wagons would have been required to carry the supplies. Those supply wagons would have needed hundreds of horses and drivers, who in turn would have required further supplies. A logistics nightmare would have been created that would have sent the costs of the expedition beyond the resources of the America of Jefferson's time. Is it any wonder that Mars mission plans that don't make use of local resources manage to ring up $450 billion price tags?

SEPTEMBER 2021

Thirteen months following launch, a fully fueled spacecraft—the ERV—sits on the surface of Mars, awaiting the arrival of a human crew. Engineers at NASA's Johnson Space Center have monitored every step of the chemical production process, and, certifying its successful completion, give the go-ahead for the next step in the Mars Direct mission to proceed. The ERV deploys small robots to examine and photograph the terrain in its immediate vicinity. The crew of the first human expedition, skilled and vitally interested in landing site selection, takes an active role in exploring the ERV's neighborhood via these distant explorers. After several months of robotic exploration, an ideal landing spot is identified. One of the ERV robots ambles across the rough Martian terrain and places a radar transponder at the landing site to help guide the crew to a safe touchdown.

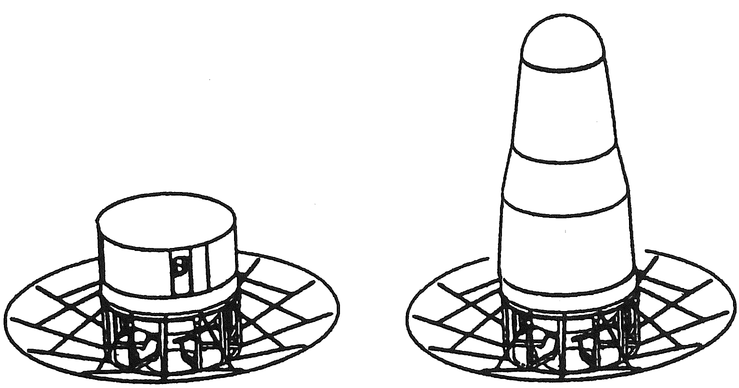
OCTOBER 2022

The Ares 3 launch vehicle, carrying a spacecraft called the *"Beagle"* after the ship of exploration that carried Charles Darwin on his historic voyage, towers majestically over the flatlands of the Cape, moments away from opening a new era of human history. Just a few weeks ago a similar booster, Ares 2, climbed into the skies over Florida. Identical to the first Ares booster and carrying a similar ERV payload, Ares 2 hurtles toward Mars even as crowds gather to watch the launch of the *Beagle*, the ship that will carry the first four humans to Mars.

The primary component of the *Beagle* is a habitation module that looks a bit like a huge drum. The module stands about 5 meters high and measures about 8 meters in diameter. With two decks each with 2.5 meters (about 8 feet) of headroom and a floor area of 100 square meters (about 1,000 square feet), it is large enough to comfortably accommodate its crew of four. The "hab," as everybody calls it, has a closed-loop life-support system capable of recycling oxygen and water, whole food for three years plus a large supply of dehydrated emergency rations, and a pressurized ground car powered by a methane/oxygen internal combustion engine. (See Figure 1.1.)

The four crew members are true renaissance men and women.

FIGURE 1.1
The Mars Direct hab and Earth return vehicles (ERV) within their aerobrakes.



Given the nature of their mission—exploration far from home—all are cross-trained in several disciplines. At heart, though, they are a crew of two field scientists and two mechanics. A biogeochemist and a geologist will complement a pilot who is also a competent flight engineer. The last crew member, a jack-of-all-trades, is primarily a flight engineer, but can also provide common forms of medical treatment and understands the broad means and objectives of the scientific investigations. This person backs up all the specialists in their functions, and provides one more—he or she will be the mission commander.

On board the *Beagle,* four men and women prepare themselves for a journey that will take them to another world and return them home in the span of about two and one half years—about the same amount of time it took explorers centuries before to circumnavigate the globe. Miles distant from their small ship, more than a million people camped around Cape Canaveral gaze in anticipation as the countdown clock approaches zero. The lower-stage engines of the booster erupt, pouring out a sea of flame. A cheer louder than any this country has heard in years sweeps the crowd as the Ares 3 lifts off the pad. The rocket accelerates, propelling the upper stage and its payload through the atmosphere. The upper stage fires its own engines and breaks away, driving the hab to trans-Mars cruise velocity. Four humans are on their way to Mars.

The pilot of the hab directs it to pull away from the burnt-out upper stage of the booster, releasing it on a tether 330 meters long as it goes. A small rocket engine on the hab fires, causing the tethered combination of hab and upper stage to now revolve at 2 revolutions per minute. This generates enough centrifugal force to provide the astronauts in the hab with artificial gravity en route to Mars equal to that found naturally on the Red Planet.

APRIL 2023

On the 180th day of flight, the hab arrives at Mars. The vehicle drops the tether and upper stage, and then aerobrakes into orbit. The crew intends to set the *Beagle* down at the landing site hard by the ERV that flew out to Mars in 2020. A radio beacon in the Ares 1 ERV, detailed photos and maps of the landing site, a landing pad radar transponder, and the crew's expert handling of the ship virtually guarantee a precision landing. In the unlikely event that the *Beagle* misses the landing site, the crew has three backup options available. In the first place, they have on board the hab a fueled pressurized rover boasting a one-way range of nearly 1,000 kilometers. So long as they're within that distance of the landing site, the crew can still get to their ERV by driving overland. If some disaster causes the *Beagle* to miss the mark by more than a thousand kilometers, the second backup can be brought into play. This is the ERV launched by Ares 2, which, since it was launched on a slower trajectory than the *Beagle,* is now following the crew to Mars. Even if the crew lands the hab on the wrong side of the planet, this second ERV can be maneuvered to land near them. Finally, as a third-level backup, the crew arrives at Mars with sufficient supplies for three years—if worse came to worst, the four could just tough it out on Mars until additional supplies and another ERV could be sent out in 2024.

The landing, however, is right on target. Though they have studied the landing site in detail, seen it from images captured by rovers and relayed to Earth, nothing can prepare the crew for the sight of the Martian landscape stretching before them. The soils are rust colored, littered with sharp-edged rocks, large and small. In the distance are small hills and dunes. The landscape is akin to the deserts of America's southwest, save for the skies, which are a ruddy, salmon color. There's an immense amount to be done just after touchdown, but they take the moment to gaze out at Mars, to savor the fact that no creature with eyes to see has ever gazed out on this vista in the four-billion-year history of Mars and Earth.

With the *Beagle* safely down at the landing site, the Ares 2 ERV lands some 800 kilometers away, where it begins the process of filling itself with propellant. It will be used as the ERV for the second human expedition, which will arrive at its site in Hab 2 in 2024, along with another ERV that will open up Mars landing site number three. As the missions proceed, a network of exploratory bases will eventually be established, turning large areas of Mars into human territory.

The crew of the *Beagle* will spend five hundred days on the Martian surface. Unlike conventional Mars mission plans based upon orbiting mother ships with small landing parties, Mars Direct places all the crew on the surface of Mars where they can explore and learn how to live in the Martian environment. No one has been left in orbit, vulnerable to the hazards of cosmic rays and zero-gravity living. Instead, the entire crew will have available to them the natural gravity and protection against cosmic rays and solar radiation afforded by the Martian environment, so there is no strong motive for a quick departure. For a crew left in orbit during a conventional mission, there's little to do but soak up cosmic rays, and that tends to create a strong incentive to limit the time allowed for surface exploration, generally to thirty days or so. This leads to spectacularly inefficient missions. After all, if it takes a year and a half for a round trip to Mars, a stay of only thirty days is rather unrewarding. Worse yet, the rush to get back home forces conventional missions to follow trajectories that require far more propellant. But that extra propellant alone won't get a spacecraft back to Earth directly. Because Earth and Mars are constantly changing their positions relative to one another, "quick return" flight plan trajectories have to get a gravitational boost by swinging past Venus—where the Sun's radiation is twice that at Earth.

Even with such a substantial amount of surface time, the crew's days will be filled with projects that will vastly expand our knowledge of the planet and pave the way toward future exploration and, eventually, human facilities and settlements. There will be the geologic characterization of Mars, which will begin to tell us the story of Mars' past climatic history, how and when it lost its warm and wet climate, key clues to reviving Mars and perhaps saving the Earth. Geologic investigations will also include searches for useful mineral and other resources. Above all, astronauts will seek out easily extractable deposits of water ice or, better yet, subsurface bodies of geothermally heated water. Ice or water is key, because once water is found, it will free future Mars missions from the need to import hydrogen from Earth for rocket propellant production, and will enable large-scale greenhouse agriculture to occur once a permanent Mars base is established. Experimentation with agriculture is another item high on the priority list, and an inflatable greenhouse will be brought along for this purpose. The area of exploration that will seize the attention of the people of Earth, though, will be the astronauts' search for Martian life.

Images of Mars taken from orbit show dry riverbeds, indicating that Mars once had flowing liquid water on its surface—in other words, that it was once a place potentially friendly to life. The best geologic evidence indicates that this warm and wet period of Mars' history lasted through the first billion years of its existence as a planet, a period considerably longer than it took life to appear on Earth. Current theories of life hold that the evolution of life from nonliving matter is a lawful, natural process occurring with high probability whenever and wherever conditions are favorable. If this is true, if the theories are indeed correct, then chances are life should have evolved on Mars. It may still lurk somewhere on the planet, or it may be extinct. Either way, the discovery of Martian life, living or fossilized, would virtually prove that life abounds in the universe, and that the billions of stars scintillating in a clear, dark night sky mark the home solar systems of living worlds too numerous to count, harboring species and civilizations too diverse to catalogue. On the other hand, if we find that Mars never produced any life, despite its once clement climate, it would mean that the evolution of life is a process dependent upon freak chance. We could be virtually alone in the universe.

Given the importance of the question, the search for life past or present will be intensive, for there are many different places to look. There are dry riverbeds and dry lake beds that may have been the last redoubts of the retreating Martian biosphere, and thus promising places to look for fossils. Ice sheets covering the planet's poles may hold well-preserved frozen remains of actual organisms, if there were any. There is a high probability that subsurface ground water, geologically heated, may exist on Mars. In such environments living organisms may yet survive. What a find such organisms would be, for they may well be very different from anything that has evolved on Earth. In studying them, we would discover what is incidental to Earth life, and what is fundamental to the very nature of life itself. The results could lead to breakthroughs in medicine, genetic engineering, and all the biological and biochemical sciences.

The search for life and resources will necessarily involve a bit more than ambling a few meters along the Martian landscape and drilling a hole or two. The first explorers to Mars will have to range across the Martian landscape, beyond the horizon of their small base. The pressurized ground rover, which provides a shirtsleeve environment for astronauts, will allow the astronauts to explore far and wide on week-long sorties from their base. The rover burns methane/oxygen fuel, the same as the ERV. Ten percent of the stockpile of the methane/oxygen fuel produced by the ERV chemical plant will be allocated to support ground exploration. With this much fuel to run their car, the astronauts will be able to explore a vast area around their base, racking up over 24,000 kilometers on the vehicle odometer before the end of the first mission. As the rover crew travels, they will leave behind them small remote-controlled robots which will allow the base crew, and those of us on Earth, to continue to explore a multitude of sites via television.

The enormous amount of exploring the astronauts will undertake will necessarily result in a staggering amount of information, all of it new, undoubtedly unique, and certainly more than any one crew member could digest. Each astronaut will confer regularly with panels of the world's top experts in his or her assigned fields, creating a massive flow of information between Earth and Mars. Of course, crew members will also send and receive personal messages, but because there is a time lag in the transmission of radio waves between Mars and Earth, they will have to put up with delays of up to forty minutes before they get their answer. That will be troublesome for people accustomed to telephone conversations, but no problem at all for those who still know how to write a decent letter.

SEPTEMBER 2024

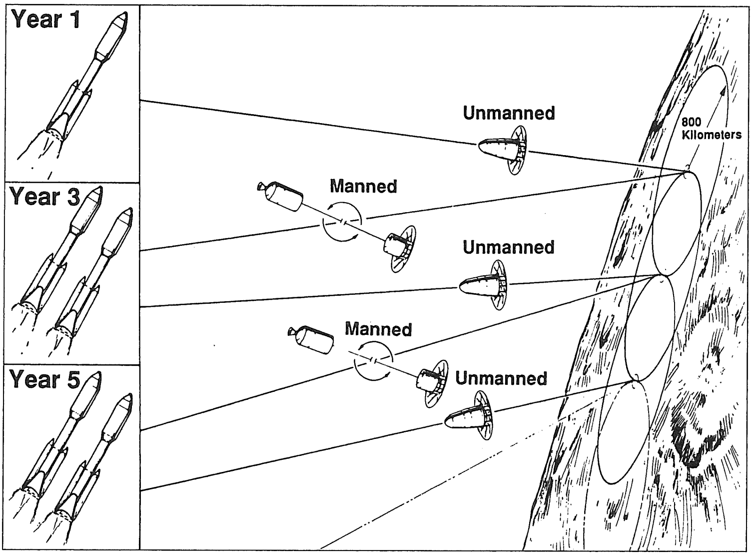
At the end of a year and a half on the Martian surface, the astronauts clamber aboard the ERV and blast off to receive a heroes' welcome on Earth some six months later. They leave behind Mars Base 1, with the *Beagle* hab, a rover, a greenhouse, power and chemical plants, a stockpile of methane/oxygen fuel, and nearly all of their scientific instruments. In May 2025, shortly after the first crew reaches Earth, a second crew arrives at Mars in Hab 2 and lands at Mars Base 2. The crew of the second mission will spend most of their time exploring the territory around their own site, but they will probably drive over at some point and revisit the old *Beagle* at Mars Base 1, not just for sentimental reasons, but to continue necessary scientific investigations in that region.

Thus every two years, as shown in Figure 1.2, two Ares boosters will blast off the Cape, one delivering a hab to a previously prepared site, the other an Earth return vehicle to open up a new region of the Red Planet to a visit by the next mission. Two boosters every two years: That's an average launch rate of just one launch per year—12 percent of our heavy-lift launch capability—to support a continuing and expanding program of human Mars exploration. This is certainly affordable and thus sustainable. As an added bonus, the same Ares launch vehicles, habs, and Earth return vehicles (fitted with only one propulsion stage) used in the Mars Direct plan can also be used to build and sustain lunar bases. While Moon bases are most emphatically not needed to support Mars exploration, they are of considerable value in themselves, most notably as sites for superb astronomical observatories. By using common transportation hardware for both lunar and Mars exploration, the Mars Direct approach will save tens of billions of dollars in development costs.

Mars Direct is not without risk. The consequences of extended exposure to Mars' gravity—38 percent that of Earth—are unknown. However, experience with the more severe deconditioning of astronauts in orbiting zero-gravity facilities indicates that most of the ill effects are temporary. Then there is space radiation, which on the six-month transit trajectories necessitated by current or near-term propulsion technology will give the astronauts doses sufficient to cause an additional 0.5 to 1 percent probability of a fatal cancer at some point later in life. This is nothing to scoff at, but those of us who stay home all face a 20 percent risk of fatal cancer anyway.

The Martian environment itself may hold some surprises, yet both the 1970s vintage *Viking* landers, and the more recent Mars Exploration Rovers *Spirit* and *Opportunity,* none of which were designed for ninety days of operation, all functioned without hindrance on the Martian surface for years, unaffected by cold, wind, or dust. The biggest mission

FIGURE 1.2
The Mars Direct mission sequence. The sequence begins with the launch of an unmanned Earth return vehicle (ERV) to Mars, where it will fuel itself with methane and oxygen manufactured on Mars. Thereafter, every two years, two boosters are launched. One sends an ERV to open up a new site, while the other sends a piloted hab to rendezvous with an ERV at a previously prepared site.



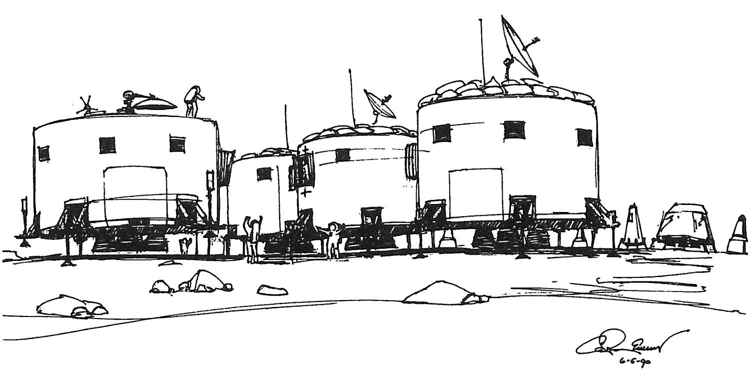
risk arises from possible failures in critical mechanical or electrical systems. Multiple backups for all important systems can minimize the risk, as can the presence of two ace mechanics during the mission. Any way you slice it, though, going to Mars the first time will involve a certain level of risk. This will be true whether we make the attempt with Mars Direct in 2022 or leave it for another generation to try. Nothing great has ever been accomplished without risk. Nothing great has ever been accomplished without courage.

MAY 2033

Over time, many new exploration bases will be added, but eventually it will have to be determined which of the base regions is the best location to build an actual Mars settlement. Ideally this will be situated above a geothermally heated subsurface reservoir, which will afford the base a copious supply of hot water and electric power. Once that happens, new landings will not go to new sites. Rather, each additional hab will land at the same site. In time, a set of structures resembling a small town will slowly take form. The high cost of transportation between Earth and Mars will create a strong financial incentive to find astronauts willing to extend their surface stay beyond the basic one and a half year tour of duty. As experience is gained in living on Mars, growing food, and producing useful materials of all sorts, astronauts will extend their stay times to four years, six years, and more. As the years go by, the transportation costs to Mars will steadily decrease, driven down by new technologies and competitive bids from contractors offering to deliver cargo to support the base. Photovoltaic panels and windmills manufactured on site and new geothermal wells will add to the power supply, and locally produced inflatable plastic structures will multiply the town's pressurized living space. As more people steadily arrive and stay longer before they leave, the population of the town will grow. In the course of things children will be born, and families raised on Mars—the first true colonists of a new branch of human civilization.

It is possible that someday millions of people will live on Mars, and call it their home. Ultimately, we can employ human technologies to

FIGURE 1.3
Linking Mars Direct habs to establish the beginnings of a Mars base. (Artwork by Carter Emmart)



alter the current frigid, arid climate of Mars and return the planet to the warm, wet climate of its distant past. This feat, the transformation of Mars from a lifeless or near lifeless planet to a living, breathing world supporting multitudes of diverse and novel ecologies and life forms, will be one of the noblest and greatest enterprises of the human spirit. No one will be able to contemplate it and not feel prouder to be human.

That is for the future. Yet we today have a chance to pioneer the way. We can land four men and women on Mars within a decade, and begin the exploration and settlement of the Red Planet. We, and not some distant future generation, can have the eternal honor of opening this new world to humanity. All it takes is present-day technology mixed with some nineteenth-century chemical engineering, a dose of common sense, and a little bit of moxie.

FOCUS SECTION—LIVING OFF THE LAND: AMUNDSEN, FRANKLIN, AND THE NORTHWEST PASSAGE

History has shown time and time again that a small group of people operating on a shoestring budget can succeed brilliantly in carrying out a program of exploration where others with vastly greater backing have repeatedly failed, provided that the small group makes intelligent use of local resources. It is a lesson that explorers of the past have ignored at their peril.

At midnight on June 16, 1903, Roald Amundsen and his crew of six sailed out under the rain-lashed skies of Christiania, Norway, bound for the Canadian Arctic and the Northwest Passage. The Passage hung before Arctic explorers as an elusive prize—nearly three centuries of effort by literally hundreds of expeditions had failed to conquer the fickle ice packs, channels, and waters of the far north.

Amundsen chased the ghost of a boyhood hero, Sir John Franklin, one of the great and ultimately tragic names of Arctic exploration. Franklin had sailed in search of the Passage nearly sixty years earlier. But whereas Amundsen sailed in a thirty-year-old sealing boat bought with money borrowed from his brother and with creditors nipping at his heels, Franklin had set off with the backing of the British Admiralty.

He commanded two ships, the *Erebus* and *Terror*, both displacing well over 300 tonnes, crewed by a complement of 127 men. In the words of historian Pierre Breton, the ships carried ". . . mountains of provisions and fuel and all the accouterments of nineteenth-century naval travel: fine china and cut glass, heavy Victorian silver, testaments and prayer books, copies of Punch, dress uniforms with brass buttons and button polishers to keep them shiny . . ."[1] In a word, Franklin carried all that he needed, save for what he would need to survive.

The *Erebus* and *Terror* set sail on the 19th of May 1845, their commander expecting to discover the Northwest Passage and that feat's attendant glory, but finding only oblivion in the end. Whalers out of Greenland spotted the Franklin expedition's ships tethered to an iceberg on June 25. That was the last any European ever saw of the expedition. Franklin and his ships, his men, all his supplies, sailed into the Arctic wilderness and vanished.

Between 1848 and 1859 more than fifty expeditions set out to discover what befell the expedition. From what could be pieced together in the years that followed—from two brief messages left behind; from the frozen, twisted remains of some of the crew; from bits and pieces of European civilization native Eskimos picked up from the ice or looted from the ships—it became apparent that the expedition ended in disaster because, as one contemporary put it, Franklin had carried his environment to the Arctic.

Trapped in ice near King William Island in the autumn of 1846, Franklin and his men attempted to survive on their provisions of salted meat. The expedition carried meat aplenty, but none was fresh, and salt meat could not protect men from scurvy. Previous explorers had noted the anti-scurvy qualities of fresh meat, but Franklin paid no heed. He was no hunter—the expedition carried shotguns, good for partridge in the British heath perhaps, but not very useful on the Arctic ice—and chose to rely instead on rations of lemon juice. One by one the members of the expedition weakened and died, Franklin apparently on board ship in June 1847. Others, hoping to find a rescue party to the south, abandoned the ships, but literally dropped in their tracks as they dragged heavy iron and oak sledges across the Arctic wastes. All hands died.

Amundsen would follow in Franklin's footsteps, but he would not follow him to his grave. Instead of importing his home environment, he embraced the local environment and adopted a live off the land strategy. He learned about the anti-scurvy qualities of caribou entrails and uncooked blubber. He learned the Eskimo way of Arctic travel, dog sled, which gave him the mobility required to hunt big game. He learned the Eskimo way of building shelters out of ice and chose the deerskin clothing of the Eskimo over the woolens that the British insisted upon.

Amundsen and his crew of six aboard the *Gjoa* were also frozen in, and as a result spent two winters in a small harbor on the southeast corner of King William Island, not far from where Franklin's expedition met disaster, but they did not starve. Making good use of their dog-sled-given mobility they traveled hundreds of kilometers over land to hunt and explore, in the process not only surviving but also making the important geophysical discovery that the Earth's magnetic poles move. The crew of the *Gjoa* thrived in the same environment that destroyed Franklin's expedition. Finally breaking free of the ice in August 1905, the *Gjoa* set sail from King William and within weeks had forced the Northwest Passage. It took another four months of travel for Amundsen to reach an outpost where he could telegraph news of his success to his main backer in Norway, which he did, charges reversed. Six years later Amundsen would use what he had learned on King William to become the first to reach the South Pole.