## After the Moon

# Next step MARS?

Landing humans on the Red Planet is harder and more dangerous than you might think, but it can be done. Here's how.

**by Daniel Pendick**

Earth: NASA & USGS; Mars: USGS

Sending astronauts to explore Mars could be the toughest trip in the history of the human race. Four to six people will live in an aluminum can for up to 6 months on the way to the Red Planet. After a harrowing descent to the surface, the crew will continue to live in cramped habitats for as many as 600 days until Earth reaches the spot in its orbit that will make a homebound journey possible. Finally, the intrepid explorers will blast off from the martian surface only to ride yet another aluminum can back to Earth for 6 months. Their high-speed reentry into Earth's atmosphere — 2½ years since leaving home — will seem anticlimactic.

Lunar journeys include opportunities to abort the mission all along the process, from the launch pad to final approach. Not so for Mars. Once the mission leaves Earth, the crew is committed for the duration. Going to the Moon is like paddling a few miles outside of New York Harbor; going to Mars is like sailing onward to Europe in a barrel.

Tough trip, yes, but impossible? Advocates of Mars exploration think not. Given the money and the commitment to do it on par with the Apollo-era push to go to the Moon, some believe we could put footprints on Mars in a mere decade.

## Why go to Mars?

There is no more passionate cheerleader for human Mars exploration than aerospace engineer Robert Zubrin. He is the founder and president of the Mars Society and author of a 1996 manifesto, *The Case for Mars: The Plan to Settle the Red Planet and Why We Must*. He also was the chief architect of Mars Direct, a mission design he says could get humans on Mars sooner and cheaper than anything NASA has proposed.

For Zubrin and like-minded people, putting footprints on Mars is not a question of whether, why, or how. It's ultimately a must. It's how we'll find out if life once existed, or still exists, on Mars. It will significantly advance aerospace technology and inspire the next generation. And it will expand humanity to another planet. "NASA needs a goal," Zubrin says. "The goal should be sending humans to Mars. Mars is where the science is. It's where the challenge is. It's where the future is. It is the new frontier."

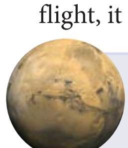
**Daniel Pendick** *is an associate editor of* Astronomy.

**A nuclear thermal rocket (NTR) stage could take astronauts from Earth orbit to Mars. An NTR uses a hot nuclear core to superheat rocket propellant, generating more thrust with less fuel than a chemical rocket engine. In this artist's concept, a separately launched crew vehicle from Earth has docked with the NTR and delivered astronauts to the habitat where they will live and work for 6 months on the way to Mars.** Unless otherwise noted, Mars mission art courtesy John Frassanito & Associates, Inc.

## How do we get to Mars?

In spacecraft, of course. Thanks to Zubrin and NASA, hopeful interplanetary explorers can choose from a menu of options for human flights to Mars.

Science fiction is littered with massive spaceships that zip off to other planets as easily as driving to a convenience store for a gallon of milk. In real interplanetary flight, it won't work that way.



**"Mars is where the science is. It's where the challenge is. It's where the future is. It is the new frontier."**
— Robert Zubrin

**A cargo ship sent to Mars 2 years before the crew departs would land supplies and hardware on the surface. This cargo lander is an automated chemical plant that transforms the martian atmosphere into fuel for the small conical spacecraft, the Mars Ascent Vehicle, mounted on top. At the end of the surface mission, astronauts would leave Mars' surface in the craft.**

Travel to Mars will include three steps. First, lift yourself and your ship from the bottom of Earth's gravity well. Second, accelerate on a trajectory to Mars. Third, descend into Mars' gravity well and land safely on the surface. It's not as easy as it sounds.

Rocket propellant is the problem. You must have enough to get you off Earth, to Mars, and back. The propellant always significantly outweighs the payload. In fact, it's best to visualize any interplanetary spacecraft as a massive gas tank with a tiny payload stuck to the front of it. A journey to Mars traversing hundreds of millions of miles requires a tremendous fuel supply.

One way around this dilemma is adopting a "split-mission strategy." It divides the plan into multiple stages to make the whole enterprise more manageable. The strategy has its roots in a speech President George H. W. Bush delivered in 1989 on the steps of the National Air and Space Museum in Washington, D.C.

On July 20 of that year, the 20th anniversary of the Apollo 11 Moon landing, Bush announced his Space Exploration Initiative. It called for construction of the space station, returning to the Moon, and, someday, going to Mars.

NASA launched the "90-Day Study" to flesh out Bush's vision. The Mars portion emerged as an elaborate "all-up" mission architecture. Astronauts would assemble a single massive ship at the space station. Upon arrival at Mars, the ship would split into a return vehicle to eventually take the crew home and an "excursion vehicle" to land the crew on the surface and return to orbit at the end of the expedition. This first mission would entail only 30 days on the surface.

## Mars Direct is born

The price of Bush's initiative was estimated at $500 billion, and by 1990 his administration had all but abandoned it. But the episode did stimulate important progress. It spurred Zubrin, then working at Martin Marietta Astronautics, to develop the Mars Direct plan.

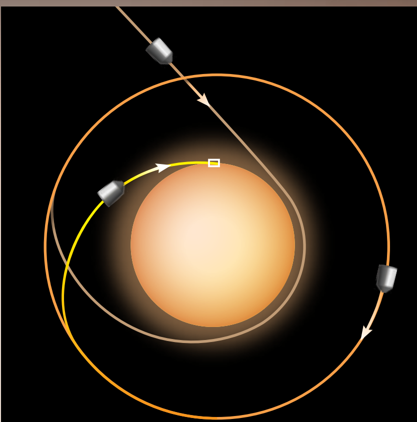
Zubrin was concerned that national "sticker shock" over Bush's proposed initiative would doom future human Mars exploration. He developed the Mars Direct concept with a colleague at Martin Marietta, David Baker. "It was apparent we needed a much quicker, cheaper plan, or there would be no program at all," Zubrin recalls.

# How to land people on Mars

**Proposals for human exploration of Mars require landing payloads of cargo and crew far too heavy for today's technology. Aerospace engineers have started to brainstorm new ways to slow down payloads entering the martian atmosphere at blistering speeds. One leading design relies on a device called a supersonic inflatable aerodynamic decelerator (SIAD). Its broad surface creates air drag.**

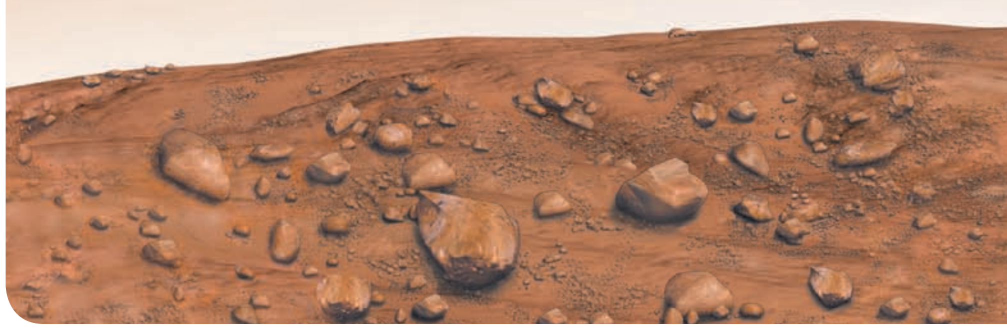
**This illustration depicts the landing of a 40-metric-ton payload. (A metric ton is 1,000 kilograms of mass, or 2,200 pounds of weight on Earth.) The scenario is based on research by graduate students at the Georgia Institute of Technology under the direction of aerospace engineering professor Robert Braun.**

*Astronomy*: Roen Kelly



**1. Aerocapture**

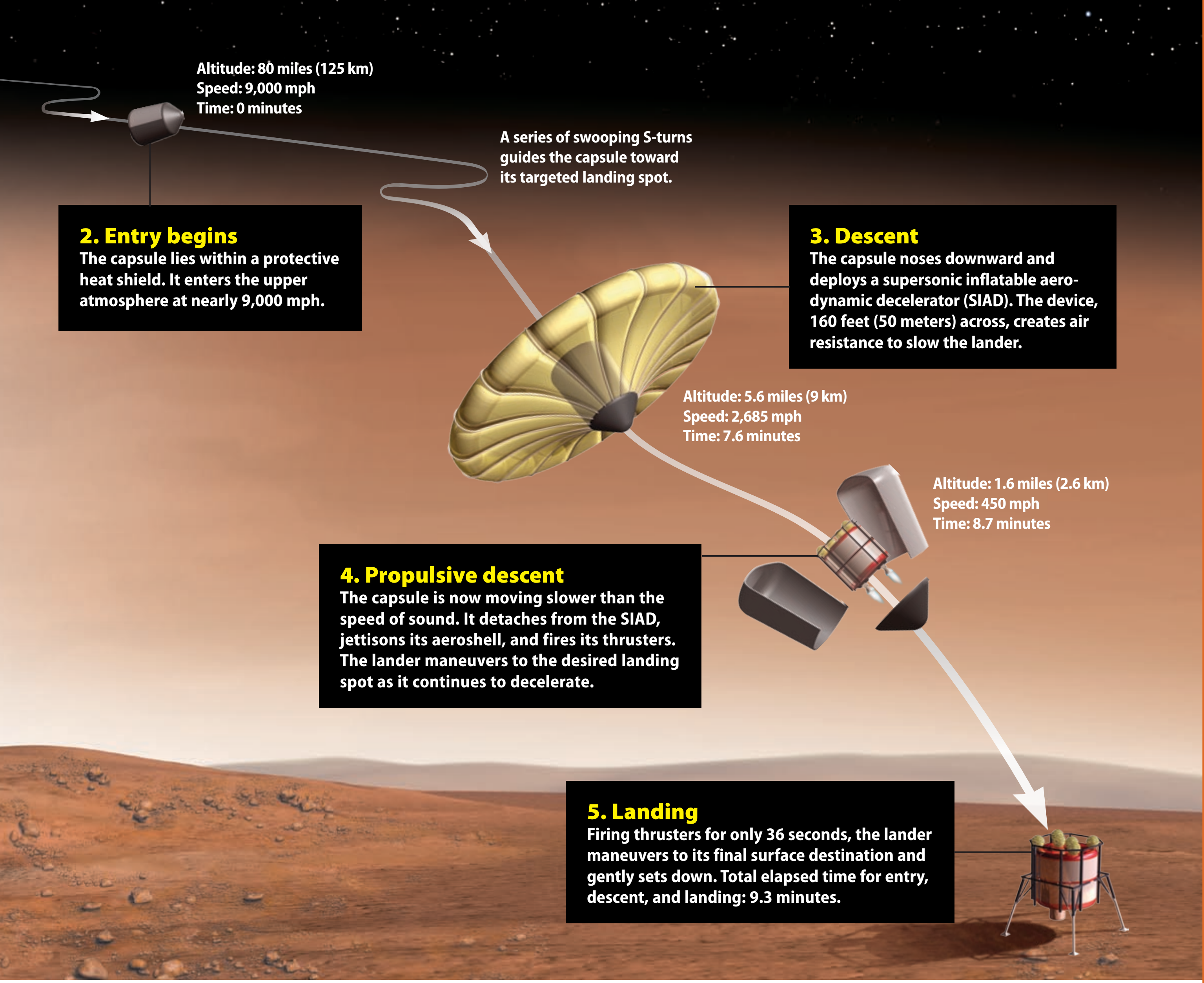
**At arrival, a spacecraft from Earth enters Mars orbit by decelerating through its upper atmosphere — a strategy called aerocapture. This maneuver brings the ship into a circular orbit at an altitude of about 250 miles (400 kilometers).**



Mars Direct diverged radically from the previous all-up strategy. First, a cargo-only vehicle launches into space on a booster comparable to the Apollo-era Saturn 5. It carries an Earth Return Vehicle (ERV) that will eventually bring the astronauts home. The payload goes directly to Mars with no stopover in low Earth orbit for assembly or fueling. This is the "direct" part of Mars Direct.

The Earth Return Vehicle lands on Mars unfueled for the return flight. Instead, it carries in-situ resource utilization (ISRU) hardware. This includes an automated chemical processing plant, a nuclear electric generator, and liquid hydrogen "feedstock" (raw material to kick off the manufacturing process). The ISRU plant then combines the feedstock with carbon dioxide from the martian atmosphere to produce methane and oxygen for rocket fuel.

**The crew lands, lives, and works in multilevel habitat landers. In an early Mars mission design, NASA would send one of the habitat landers on a robotic cargo flight. The crew would follow in a later launch, landing in the second habitat near the one already on Mars.**




At the next favorable Earth-Mars alignment for a launch — 26 months after the cargo flight — the crew will depart Earth. But they will leave only after confirming the ISRU hardware has fueled the return ship. The crew ship is the equivalent of a small cottage with rocket propulsion. It carries a methane-burning rover, a crew of four, and everything they will need to live for 3 years.

The trajectory Mars Direct uses for the outbound and return flights minimizes the propellant required, but at the cost of an extended stay on the planet. After the 6-month cruise to Mars, the astronauts must remain there for about 600 days until Earth swings around to an orbital position that requires the least amount of fuel to reach home.

As the crew ship departs for Mars, a cargo flight blasts off to deliver a second Earth Return Vehicle into Mars orbit. This provides a safety margin: If the ERV sent earlier fails, the astronauts can still get home using the second one. And if the crew ends up not using the backup ERV, it will be waiting when the next crew arrives from Earth to explore Mars.

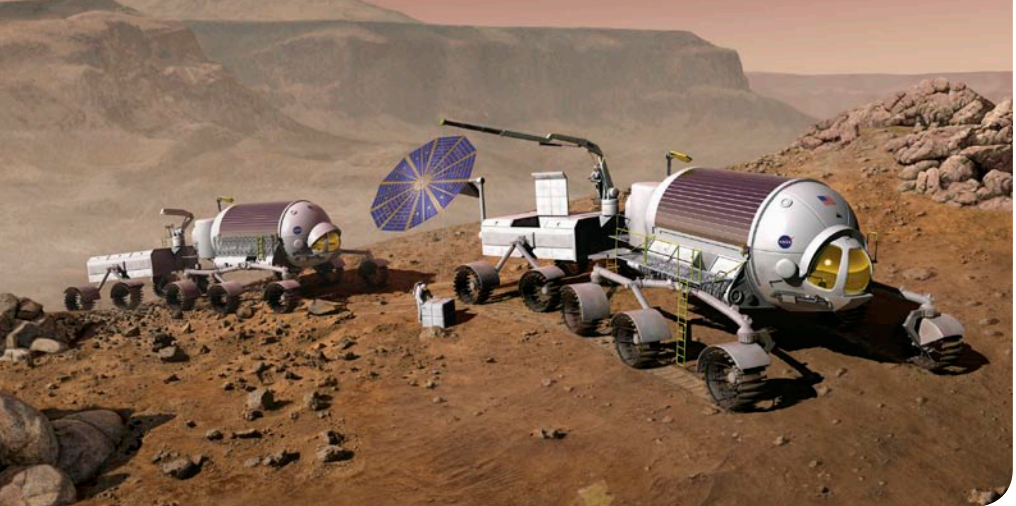
With every mission, the number of crew habitats and other equipment left on the surface increases. This provides the basis for a permanent human presence and perhaps colonization.

The price tag for Mars Direct was a key selling point. Zubrin's original estimate claimed it would take $20 to $30 billion and 10 years to develop the hardware plus $1 to $2 billion for subsequent piloted flights to the growing Mars outpost. Today, he says, it would cost in the neighborhood of $30 to $40 billion and $2 to $3 billion per additional visit.

## NASA responds to Mars Direct

NASA followed Zubrin's lead with its Design Reference Mission (DRM), drawn up in the 1990s by scientists and engineers at Johnson Space Center. The DRM, like Mars Direct, is not a detailed set of spacecraft designs and procedures. NASA bills it as a general framework for developing, comparing, and improving architectures for a future Mars mission.

The DRM adopts Mars Direct's split-mission strategy and the "live off the land" philosophy that uses ISRU technology to manufacture propellent. An important difference, however, is that NASA's plan separates the return trip into two legs. The crew would blast off from the martian surface in a Mars Ascent Vehicle (MAV) and then transfer to a waiting interplanetary vehicle placed in orbit by a previous cargo flight.



**The surface mission** would last about 600 days. This provides ample time for exploration in far-ranging pressurized rovers. Astronauts will collect geological samples, study the atmosphere and weather, and maintain a stable of robotic helpmates. NASA artwork by Pat Rawlings/SAIC

In a 1998 update to the DRM, NASA planners abandoned the direct-to-Mars launch approach, opting for a strategy sometimes called Mars Semi-Direct. Doing so would eliminate the need to develop an expensive new launcher that could send NASA's heavy 200-ton-plus payloads hurtling to Mars. An 80-ton launcher would lift payload and propulsion stages into low Earth orbit, where they would dock and leave for Mars. This would require a minimum of six launches to get the first crew on Mars.

The NASA mission to Mars involves more and heavier hardware than Mars Direct, but it takes essentially the same approach. And like Mars Direct, the DRM helps make Mars exploration look a lot more feasible. NASA offered no official cost estimate for the DRM, but most likely it would be less than the $500 billion Bush initiative.

## Landing on Mars

Mars Direct and the NASA reference mission are rough outlines. Many devilish details remain to be worked out. One of the most crucial ones is how to land heavy payloads in one piece. Aerospace engineers call the process EDL, or "entry, descent, and landing."

Right now, NASA does not officially fund research on human spaceflight to Mars. But scientists and engineers within and outside the agency continue to explore the challenge of martian EDL. It's a terrific test case for their students, and it may have applications for coming robotic missions to the Red Planet. The basic challenge of EDL is to slow down from hypersonic speed to a standstill in less than 10 minutes. Failing in this task could end with the payload at the bottom of a new crater on the martian surface.

> **"You have very high energy in orbit that you have to reduce to a tiny fraction."** — Robert Manning

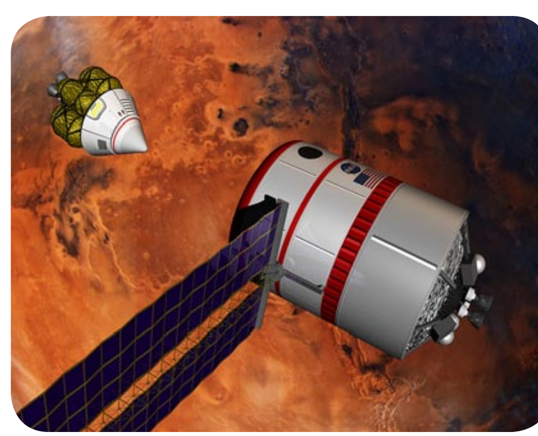
Most of the hard work occurs in the middle stage of the process, descent. "You have very high energy in orbit that you have to reduce to a tiny fraction of that — less than 1 percent — before you are even close to being able to choose how you touch the ground," says Robert Manning, chief engineer for the Mars Exploration Program at NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California.

The touchdown of the Mars Phoenix Lander in May 2008 displayed the current state of the art for Mars landings. The craft's so-called "7 minutes of terror" started at the top of the martian atmosphere, about 80 miles (125 kilometers) above the surface. Phoenix entered from space at about 12,500 mph (20,000 km/h). Air resistance against its heat shield slowed the craft to about 900 mph (1,400 km/h). Then a parachute took the speed down to 250 mph (400 km/h). After a brief freefall, the craft fired thrusters at 3,200 feet (975 meters) and touched down — all in about 7 minutes.

Current EDL technology will reach its limit in 2011 with the planned landing of the Mars Science Laboratory (MSL). Its mass on the ground will be 1,984 pounds (900 kilograms). Conventional combinations of heat shields, parachutes, and thrusters are not up to the task of landing anything heavier than the MSL rover.

But Mars Direct and the NASA DRM envision payloads ranging from 30 to 60 metric tons. (A metric ton is 1,000 kilograms of mass, or about 2,200 pounds of weight on Earth.) With current EDL technology, we can't land a Cooper Mini on Mars — curb weight with manual transmission 2,524 pounds (1,145 kg) — much less a capsule with astronauts.

Manning and other EDL experts say a human landing will take new technolo-



> **At the end of their visit,** astronauts will leave in a Mars Ascent Vehicle and rendezvous with a spacecraft waiting in orbit to take them home.

>> **A fully fueled return ship** (far right) has waited in orbit for its precious cargo since being launched on a robotic cargo flight. Return trips from Mars could take 130 to 180 days, depending on the orbital geometry between Mars and Earth at departure time.

gies. Mars Direct and the Design Reference Mission both rely on parachutes for the descent. But the Red Planet's thin atmosphere means parachutes would need to be extremely large and able to deploy quickly at supersonic speeds without tangling or shredding. "You would need a parachute about a football field across," Manning says. "It would easily, when flattened out, be a nice canopy for the Rose Bowl."

Apollo-style landings entirely on thrusters are problematic, too. Decelerating from Mars orbit and landing using rockets would require a huge amount of propellent. Also, firing rockets in the martian atmosphere at hypersonic speed can create aerodynamic drag and instability that are hard to predict.

EDL experts at NASA and in the aerospace research community have brainstormed new options for the descent stage of a human landing on Mars. A leading contender is called the supersonic inflatable aerodynamic decelerator, or SIAD. Imagine a giant airbag in the shape of a badminton shuttlecock, and you get the general idea.

Aerospace engineer Robert Braun and his students at the Georgia Institute of Technology in Atlanta have worked out scenarios for landing heavy payloads with SIAD technology. They have developed detailed plans for how to land 20 metric tons of cargo mass — about 8.3 tons of weight in martian gravity — with an inflatable decelerator and thrusters.

The decelerators are still pretty big — up to 160 feet (50m) across — but the basic engineering is plausible. The inflatable slows the craft to about 450 mph (720 km/h), a speed at which it's possible to use rocket thrusters to maneuver the payload to the final landing site and decelerate to a soft landing.

The landed payload masses cited in the original NASA DRM were as much as 65 metric tons. Braun remains skeptical that such a landing is possible with any method he can currently imagine. "To land 65 metric tons — 100 times what we have accomplished with robotic landers — is a very large stretch," he says.

Braun would reduce each payload. "You'd be better off landing payloads of 15 metric tons," he says. That would reduce the size of the SIAD and make other EDL options more feasible.

**After nearly 1,000 days away,** Mars explorers return to Earth the same way astronauts have for half a century — in a cramped capsule. In this artist's rendering, the 5.5-ton capsule rides a steerable parafoil to a relatively soft landing on the ground. After the grueling, risky Mars mission, the crew won't mind a few bumps.

## Insert miracle here

The challenge of landing heavy payloads on the martian surface is just one of the multiple leaps in technology required to carry out Mars Direct and the NASA reference mission. "There are a few 'miracle occurs' steps that we have to invent," Manning concedes.

Quickly inflating an SIAD — nearly the wingspan of a Boeing 747 — at several thousand miles per hour is among the major "insert miracle here" steps that stand in the way of getting to Mars. But don't despair, Manning says: "It's not impossible; it's just a challenge. Put this on your list of things to do, America."

On the extreme of Mars mission skepticism sits Donald Rapp, a retired JPL engineer who has performed detailed analyses of human spaceflight to Mars. In his 2007 book, *Human Missions to Mars*, Rapp dissects the underlying assumptions of the NASA Design Reference Mission on a cellular level.

Rapp credits the important role of Mars advocates like Zubrin. But he criticizes enthusiasm that may exceed reality. "They're visionaries," Rapp says. "People like Zubrin can look across the desert and see the greenery of the orchids beyond. But you still have to get across the desert, and they tend to underestimate grossly what it takes to do that."

Rapp says $10 billion a year for up to 30 years might get us to Mars. Factoring in the delay of NASA's plan to return to the Moon and all the unsolved challenges, he says it could take NASA until 2080 to get boots on the martian surface.

Zubrin has heard all this before. But he remains immune to naysayers and unrepentant in his belief in the importance of going to Mars. For him, the dream dates to the Kennedy-era rhetoric that inspired him to join the aerospace industry in the first place. Cue sound byte: We go to Mars not because it's easy, but because it is hard.

"Relative to our technology today, a mission to Mars is much less challenging than a mission to the Moon was in 1961," Zubrin says. "For us to throw up our hands at these problems and say we just can't do it is really saying we've become less of a people than we used to be."

**Learn more about human spaceflight to Mars at www.Astronomy.com/toc.**