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LET'S ORBIT MARS: A PROPOSAL TO EXPLORE MARS NOW

The Apollo Paradigm

Mars is an exciting target for the human exploration; the next destination toward the ultimate human colonization of the solar system. But the price of proposed missions to Mars is a daunting barrier. Expensive missions make it a slow and difficult process to achieve the political consensus to make a commitment to exploration. In today's deficit-conscious era (and what era is not?), it is as difficult-- perhaps impossible-- task to justify to a skeptical and cost-conscious public the need to invest in exploration. It seems far too easy to postpone exploration into a future that never seems to arrive.

It would be terrific to explore Mars in small steps, where each step makes progress toward human exploration and settlement, and each step also is not only exciting to the public, but also justifiable on its own scientific merits.

The first Apollo missions to the moon-- Apollo 8 and 10-- did not land on the moon, but instead went into lunar orbit without landing. Could the same stepwise approach be used for Mars missions?

Orbit Mars without landing? At first thought it may seem unreasonable to propose that humans should go all the way to Mars, and then return without landing. Yet this is in fact quite sensible. The interplanetary transport itself is easy. It is by far the simplest part of a Mars mission; a transfer habitat will be similar to habitat modules on the space station, and the propulsion needed to boost to Mars can most certainly be done with technologies already existing.

Landing humans on Mars, on the other hand, is a difficult challenge. A human-rated entry vehicle must be designed and developed, a rocket lander must be designed and developed, a Mars habitat must be designed and developed, and finally and a Mars Ascent vehicle to return the crew to orbit has to be designed and developed. Each of these are dangerous steps, and all of these are unique vehicles that in many ways will be very dissimilar to any other space vehicles previously made, that will operate in environments far different from any we have previously experienced.

Living on Mars will require life support technologies that will operate reliably in the hostile environment of Mars, subject to wind, dust and chemical attack as well as thermal cycling and ultraviolet exposure. The space suits for Martian exploration will be used without refurbishment on Earth over surface mission lengths as long as nearly a year, a duration far longer than the space suits used in previous orbital or lunar missions, and will need to be designed specifically for the Mars environment, since Mars space suits do not currently exist.

If we orbit Mars without attempting to land humans on the surface, we have no need to develop a human-rated Mars Lander and Mars Ascent Vehicle, and we can send geologists and biologists on the mission; rather than pilots specially trained to operate complicated rocket landers. A mission to Mars orbit would be much less expensive, possibly as much as ten times cheaper than a human landing on the surface of Mars. And it could be done with the technology we have now, not with future technology not yet developed. It makes sense that the low-cost orbital mission would be done as a logical precursor to any landing.

Given the attractively lower cost, we need to ask: can we do real science missions from Mars orbit? Could such a mission be made exciting to the public?

Human Factors

Quite independent from the cost, a mission to Mars orbit makes sense from safety and human factors.

There is some uncertainty about whether astronauts would be able to accomplish useful activities on the surface of Mars after nine months in microgravity getting to Mars. Surely a Mars mission would use simulated gravity produced by a rotating tether, but it would be useful to demonstrate this on an interplanetary mission before relying on it for a landing mission.

We also don't know enough, yet, about the health hazards of the surface of Mars. Over the course of the landed mission, the space suits will become covered with dust, and EVA operations will bring the Martian dust, along with the space suits, into the habitat. The biological hazard of the extremely fine Martian dust is as-yet unknown.

Science from Orbit

Any human landing site will be to some extent a compromise between safety and scientific interest, and many of the most interesting features of Mars may not be suitable for a human landing site. The landing site for robotic missions has typically taken several years of analysis and argument, and the final sites are always selected with mission safety, and not science, as the dominant concern. Such landing site analysis will be even more stringent for human exploration. Landing sites for a human mission are likely to be scientifically "boring" sites, featuring flat surfaces with an absence of boulders, cliffs, channels, craters, or mountains.

Use of telerobots lowers risk, and thereby allows dangerous exploration. Valles Marineris, for example, is a geological section through layers representing many millions of years of Martian geological history, yet the unstable cliff tops and fragile walls mean that human exploration of such canyons would be extremely dangerous. A robot could rappel down the cliffs of Valles Marineris and examine the layering in detail, without worrying that the nearest hospital is a hundred million miles away.

Tele-exploration from Mars orbit also allows possible investigation a wide variety of locations. With an orbital base controlling surface telerobotic, human explorers are not stuck with one base location, but can investigate locations all over Mars. They can investigate the polar caps and also near-equatorial canyon regions. This frees the mission from landing site constraints.

With no need to select a “grab bag” site that contains a large number of geologically diverse features at or near a single location; it is now possible go to all the best sites-- ancient lake bed sites, dry river channels, volcanic calderas and lava tubes, layered terrain, canyons, possible shoreline features, the North and South poles.

Protecting Earth-- and Mars

Exploring from orbit will reduce biological risk by keeping humans from exposure to possible Mars microbes. A telerobotic mission avoids the difficult human question of how to isolate Mars mission astronauts infected by Martian microorganisms until after a thorough scientific search for such microorganisms has been conducted. While many biologists would argue that any life that was well adapted the extreme conditions of Mars could have no possibility of infecting terrestrial life, the "scare factor" of Martian microbes invading Earth is very real. The Apollo astronauts, as an example, were kept in isolation after returning from the moon despite the absurdity of any possible contamination.

Protecting Mars is a significant constraint on human exploration. One of the most significant scientific questions to be answered on Mars is: does Mars have present, or past, life? Addressing this question requires exploration of multiple sites to collect biologically pristine samples, with no terrestrial organic contamination. But space suits, and habitats, may very well be leaky. At a minimum, adding a requirement that after donning their spacesuits, each astronaut must then sterilize the entire outside surface of the suit, will greatly increase the complexity (and cost) of the mission. Exploration by telerobotics will allow us to keep the landing site uncontaminated by human habitat effluvia, so when we discover evidence of biological activity, we can have a higher likelihood that it is not microbes that originated from the human explorers.

Since present day life could exist on Mars, planetary protection is also needed to preserve the (possible) fragile Mars biosphere from competition from ferocious Earth life. Isolated biospheres on Earth have been devastated when they have been exposed to alien life forms introduced—accidentally or deliberately-- from another continent. If there is life on Mars, we will wish to protect it from competition by introduced Earth biota.

Telerobotics: Just Like Being There?

In the telerobotic exploration scenario, the humans remain in an orbital habitat, and use teleoperation to rove across the surface of Mars and explore. Tele-robots controlled by humans in a Mars-orbital habitat will be essentially operated on "real time" operation with minimum time delay, giving a virtual presence on the surface. Such robots could give Mars explorers truly immersive virtual presence on Mars.

Roboticists distinguish between teleoperated and remotely operated robots. A teleoperated rover, has a real time operator interface, such as the joystick control that is routinely used for operating underwater vehicles. Often, teleoperation is assumed to include an immersive "virtual" environment, so that the human views the scene from the robot's point of view. On Mars, true teleoperation requires humans to be close enough to the robot that the speed-of-light delay is short enough that the human can operate the rover in real time.

A bipedal robot body would present the highest fidelity virtual presence, allowing Mars explorers to walk around Mars just like they now walk around the Earth The technology for bipedal robots is being developed by many laboratories, for example, by researchers at Honda, who have developed a bipedal robot "Asimo" that can duplicate much of the flexibility and balance of a human. But it is not necessary that the robotic body mimic a human in all ways, and wheels might be a simpler solution. Wheeled vehicles are stable, and the wheel is a technology that has thousands of years of history. A humanlike interface could be used on a wheeled body, as shown in the "Centaur" concept for robotic exploration proposed by Ambrose and co-workers.

Robots can have expanded senses. A robot can easily have radar, infrared, and gamma-ray eyes, and so in principle a robot can see far more than a human can.

This type of exploration will require a high-fidelity, high-bandwidth connection to give the humans a fully-detailed virtual presence in the robotic body.

Tools for human telepresence in orbit are already being developed, such as the "Robonaut" concept being developed at NASA Johnson Space Center for the telerobotic operation on the International Space Station. The concept uses a humanoid interface, allowing the operator to use the telerobot in the same way that the human body operates. Robonaut, for example, is explicitly designed to mimic a human's viewing and manipulating capabilities. It incorporates human-scale arms with dexterous five-fingered hands, each incorporating a force sensitive glove. This glove serves as the hand's skin, detecting where the hand has made contact with an object. The inset shows a prototype of that glove, with the index finger incorporating force sensors embedded along the inner surfaces. The glove transmits the sensation of holding an object to the operator's hands. Picking up a rock with an advanced version of the force-sensitive hand would feel like picking it up in your own hands,

It is a cheaper, simpler, and safer way to explore, and hence it will be a faster way to explore. Indeed telerobotics has at least as high human engagement factor as direct astronaut exploration: video games, robots, and virtual reality excite children. It has all the excitement of being there, at a fraction of the price.

Exploration Scenario

Selecting the orbit for a human habit for telerobotic exploration presents an interesting design exercise.

If interesting landing sites can be found in the near-equatorial regions, then an areosynchronous orbit would be an obvious choice. With a period of 24 hours and 39.5 minutes, synchronous with the rotation of Mars, an areosynchronous orbit will stay over a constant spot on the Martian equator. Due to the lower gravity of Mars, aerosynchronous orbit is about three times closer to the Martian surface than the similar geosynchronous orbit is to the Earth's surface. This has the advantage of reducing the round-trip lightspeed delay compared to the nearly quarter-second delay experienced on Earth geosynchronous communications. It has a disadvantage, however, of meaning that the amount of Mars surface viewed from aerosynchronous orbit is slightly less than the comparable view from Earth orbit.

Such a stationary orbit would be in constant line of site communications with the landing site, allowing direct telerobotic control at all times.

The Meridian landing site of the Mars Exploration Rover "Opportunity," for example, is an exciting location with a plethora of water-related features. The Valles Marineris canyon system is also located close enough to the equator to be viewed from stationary orbit, as are many other sites of interest.

An inclined synchronous orbit has some advantages for exploring sites off of the equator. Such an orbit would have a ground-track of a figure 8, dipping above and below the equator, and would cross the same point on the ground time at the same local time. This ground track could be synchronized to the crew's work schedule.

High latitude polar exploration sites will need to be operated from a nearly Mars-polar orbit to allow direct line-of-sight communications for surface teleoperation. A near-polar inclination synchronous Mars orbit, for example, will put the orbital station in line-of-sight of a given region for about 8 hours per day-- one teleoperation shift.

An alternative would be to put the habit into a lower orbit with a period of exactly half a Mars day. A habitat in a half-synchronous orbit will result in the habitat moving over different points on Mars, but returning to the same ground location at the same time each Mars day, allowing a telerobotic operator to return to the same site at the same time of day for a work shift.

Relay satellites in Mars orbit increase the complexity of the system, and slightly increase the speed of light delay, but the gain in flexibility is likely to be more than the added cost of the relay satellites.

A final possible choice would be to place the habitat to be on Deimos or Phobos, one of the Martian moons. In this location the habitat could be buried under regolith from the moons to shield from radiation. And a mission to Deimos or Phobos would be the first human landing on a body beyond Earth orbit-- which may be of scientific interest in its own right, as well as an accomplishment of significant public interest.

Robotic Spin-offs

A final benefit of telerobotic exploration from orbit is the spin-off development of technology. Telerobotic technology is widely discussed, but a high-fidelity human-capable robot has not yet been developed. Likewise, the high-fidelity full-immersion virtual reality has yet to be fully developed.

Developing this technology would be a valuable goal for NASA, and would enrich missions to other planets beyond Mars. It is also technology with applications on Earth. Cross-fertilization of ideas and technologies between Earth and space applications could be leveraged to the commercial advantage of both. A common justification for exploring space is that technology development for space also has spin-off applications here on Earth. And pushing the limits of technology enhances the economic strength of the country developing the technology.

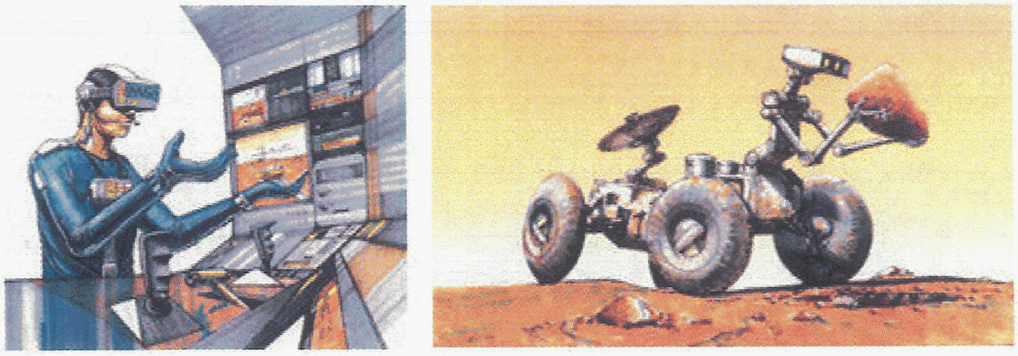
By choosing telerobotics as the technology to develop, applications (many of them not even yet conceived) will be developed. The economic benefits of this are likely to be far greater than the cost.

CONCLUSIONS

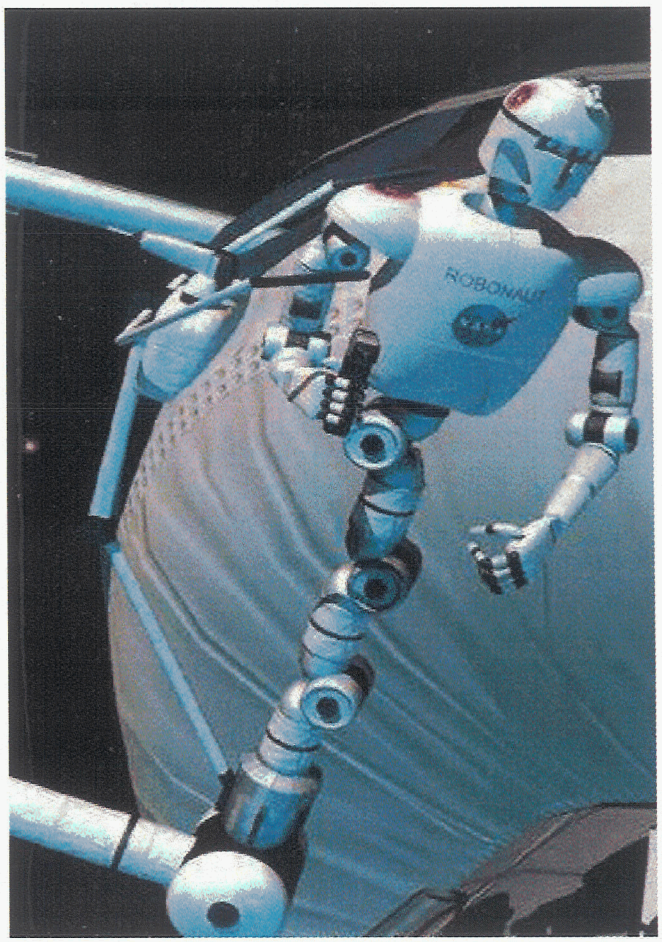
To be successful, a Mars exploration program should proceed in steps, with each step developing technology toward an eventual human mission to the surface of Mars, and also each step being both scientifically justifiable and also interesting to the public. One such step in the exploration of Mars should be the exploration of Mars by telerobotic agents operated by humans in Mars orbit.

An argument might be made that, once humans travel all the distance to Mars orbit, it would be a major disappointment not to the small step down to the surface. But small thought it is, that last step is the hard one. In a real-world future of limited budgets and difficult political choices, it may not be a choice between a human mission to orbit Mars or a mission to land on Mars, but instead a choice between a mission to orbit Mars now, or a postponement of any exploration to a distant and indefinite future.

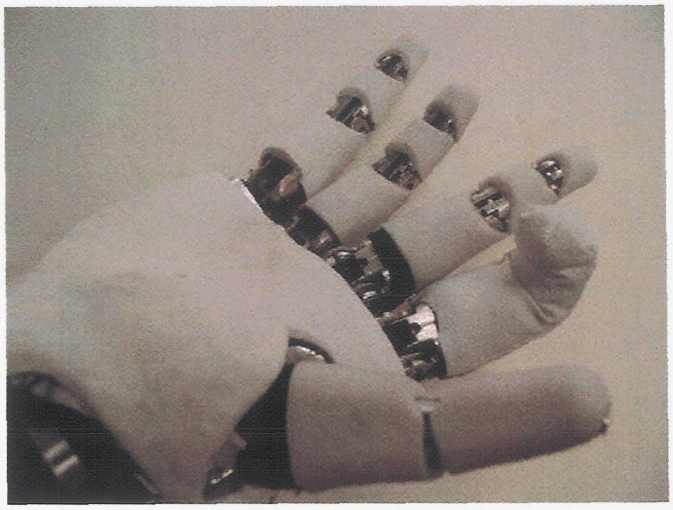
Next stop, Mars orbit! Why wait? Let's start the exploration of Mars now.



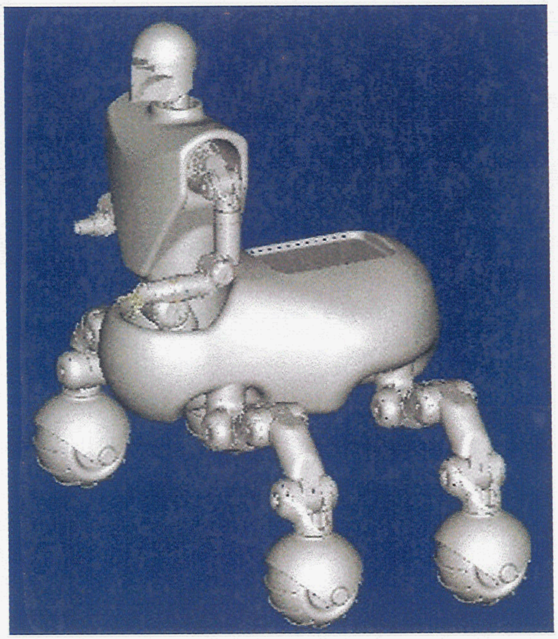
Conceptual view of an astronaut exploring the surface of Mars by virtual telerobotic operation. (Painting by Carter Emmart, courtesy NASA Ames Research Center).



"Robonaut," a system being developed for astronaut-operated tele-robotics for EVA on International Space Station (visualization by John Frassanito and Associates, courtesy NASA)



"arm" and "hand" manipulators for telerobot, developed for Robonaut project (photos courtesy Robonaut project, NASA Johnson Space Center).



"Centaur," a concept for mobile telerobotic exploration of planetary surfaces using "Robonaut" technology (as visualized by Ambrose and co workers at NASA Johnson Space Center.)