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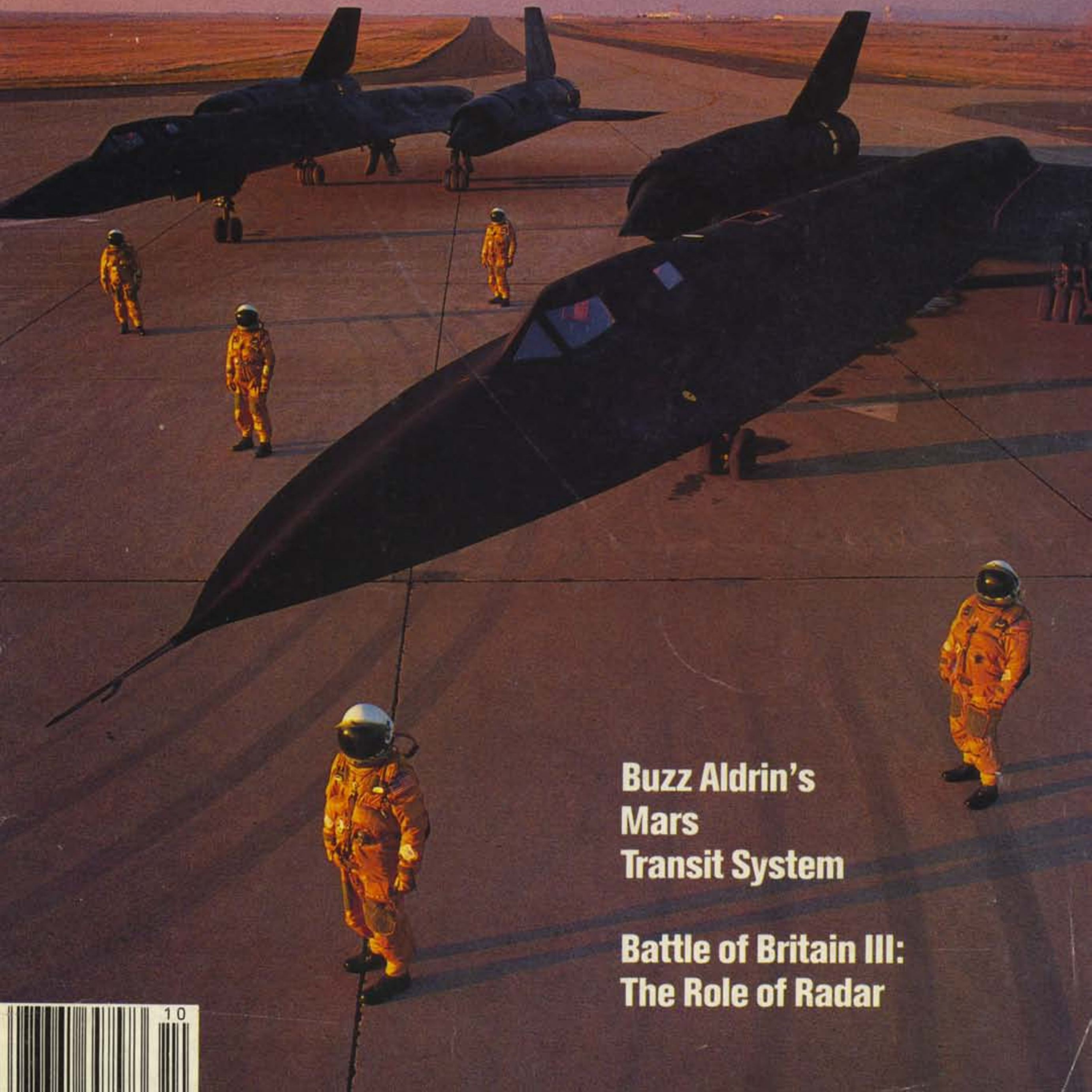

Buzz Aldrin's Mars Transit System

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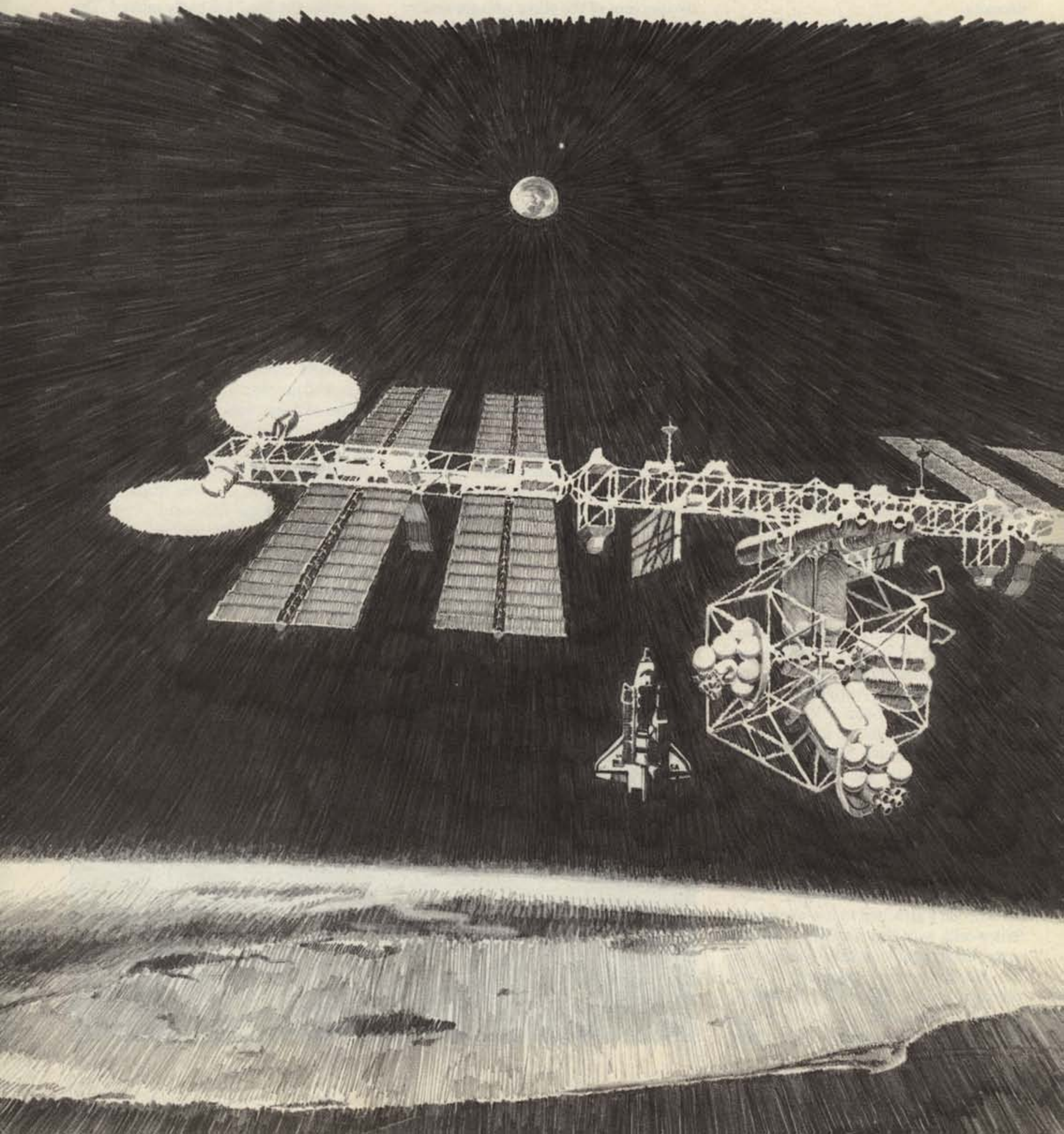
The Mars Transit System



A former astronaut presents his plan to make Mars a destination, not just a goal.

by Buzz Aldrin

Illustrations by Carter Emmart

In the late 15th century, European mariners learned to take advantage of the tropic winds that blow steadily westward toward the equator to move their caravels across the vast, trackless ocean. They relied on another system of easterly winds to return them to their home ports. The new routes did not follow direct courses but instead looped along curving paths that sometimes appeared to carry the mariners away from their objective. These trade winds, however, soon became bridges between continents, making possible the great age of discovery.

On July 20, 1989, the 20th anniversary of the first moon landing, I stood on the steps of the National Air and Space Museum with my Apollo 11 crewmates, Mike Collins and Neil Armstrong, listening to President George Bush announce that mankind was about to embark on another great age of discovery. The president proclaimed that the United States would return to the moon and venture on to Mars in the next century.

To undertake a Mars mission in the next 30 years, we have to begin comprehensive planning now. So it's fair to ask what types of spacecraft and flight plans offer the most promise for success on mankind's most ambitious exploration.

Some planners favor a much more massive version of the spacecraft we used in the Apollo mission, which would be assembled at a spaceport in low Earth orbit (LEO) and then propelled beyond Earth's gravity by large, expendable rocket engines. Such a conventional spacecraft would have to decelerate both for landing at Mars and on the

Placing a Starport (center) at space station Freedom would provide a low-Earth-orbit facility for staging missions to the moon and Mars via the Cycler system.

Space Exploration Schedule

1996: Construction of space station Freedom and its Starport begins

1997: First space taxi launches from Earth

1999: Starport complete and in use as taxi base; first lunar landing with taxi

2002: Assemble lunar Starport in low lunar orbit

2004: Develop and use advanced taxis and landers

2005: Transfer lunar Starport to L-2; develop lunar propellants

2006: Test Mars Starport

2007: Transfer Mars Starport to Mars orbit

2009: First manned mission to Mars orbit via non-cycling taxi spacecraft that will henceforth be used as the Semi-Cycler; complete Starport assembly, explore Phobos

2010: First Mars crew reassembles Semi-Cycler for their return to Earth. Second crew tests Cycler at L-2

2011: Cycler departs with manned taxi convoy; complete assembly enroute

2012: Mars lander arrives at Mars orbit as cargo. First Mars landing on this second manned Mars mission; second mission crew returns to Earth

2013: Next Cycler intercept; work on Mars surface base begins on third mission.

2014: Third mission crew returns to Earth

2015: Fourth mission crew departs for Mars on Cycler; a new second Cycler (for speedier returns) leaves L-2 unmanned

2016: Produce propellants at Mars surface base

2017: Crew intercepts second Cycler on its return to Earth; completes assembly of Cycler enroute

return to Earth, requiring a large expenditure of propellant or the use of an atmospheric aerobrake shield.

To optimize use of the heavy aerobraking equipment, the crew and cargo—including Mars landers—would have to be lumped together on a single jumbo vehicle. When prudent equipment redundancies are added to propellant loads, a manned Mars vehicle would weigh thousands of tons, as compared with the Apollo moonship's 40 tons.

Furthermore, no matter how massive these traditional spacecraft are at the outset of the voyage, they must shed their valuable modular stages in order to dump mass and lessen the amount of propellant needed for braking, making them too expensive for sustained Earth-Mars transportation. If we rely on conventional multi-stage spacecraft, we risk limiting human exploration of Mars to a few expensive "footprints and flagpoles" expeditions.

I believe there's a better approach. Several years ago, Tom Paine, the chairman of the National Commission on Space, encouraged me to expand my investigations into the use of spacecraft that would permanently cycle between the orbits of Earth and Mars. The results of these studies were included in the commission's 1986 report, *Pioneering the Space Frontier.* Such cycling spacecraft, one for manned outbound journeys and another for manned return trips, would use gravity assists from flybys of the planets to boost them along their orbits.

The major advantage of this approach is that it involves reusable spacecraft, which I call "Cyclers," on continuous gravity-assisted trajectories. These spacecraft, with their massive crew support equipment, no longer have to accelerate and decelerate off and onto planets because they continuously cycle along their orbits.

With the support of the Jet Propulsion Laboratory in Pasadena, California, I developed a family of Cycler trajectories which take advantage of recurring planetary encounters to permit travel between Earth and Mars with dependable regularity. Since then I have expanded cycling concepts into a blueprint for a relatively inexpensive and reusable Mars transportation system, which includes a family of permanent orbital staging facilities I call "Starports" and a series of smaller spacecraft to taxi crew members to and from these spacecraft and the planets.

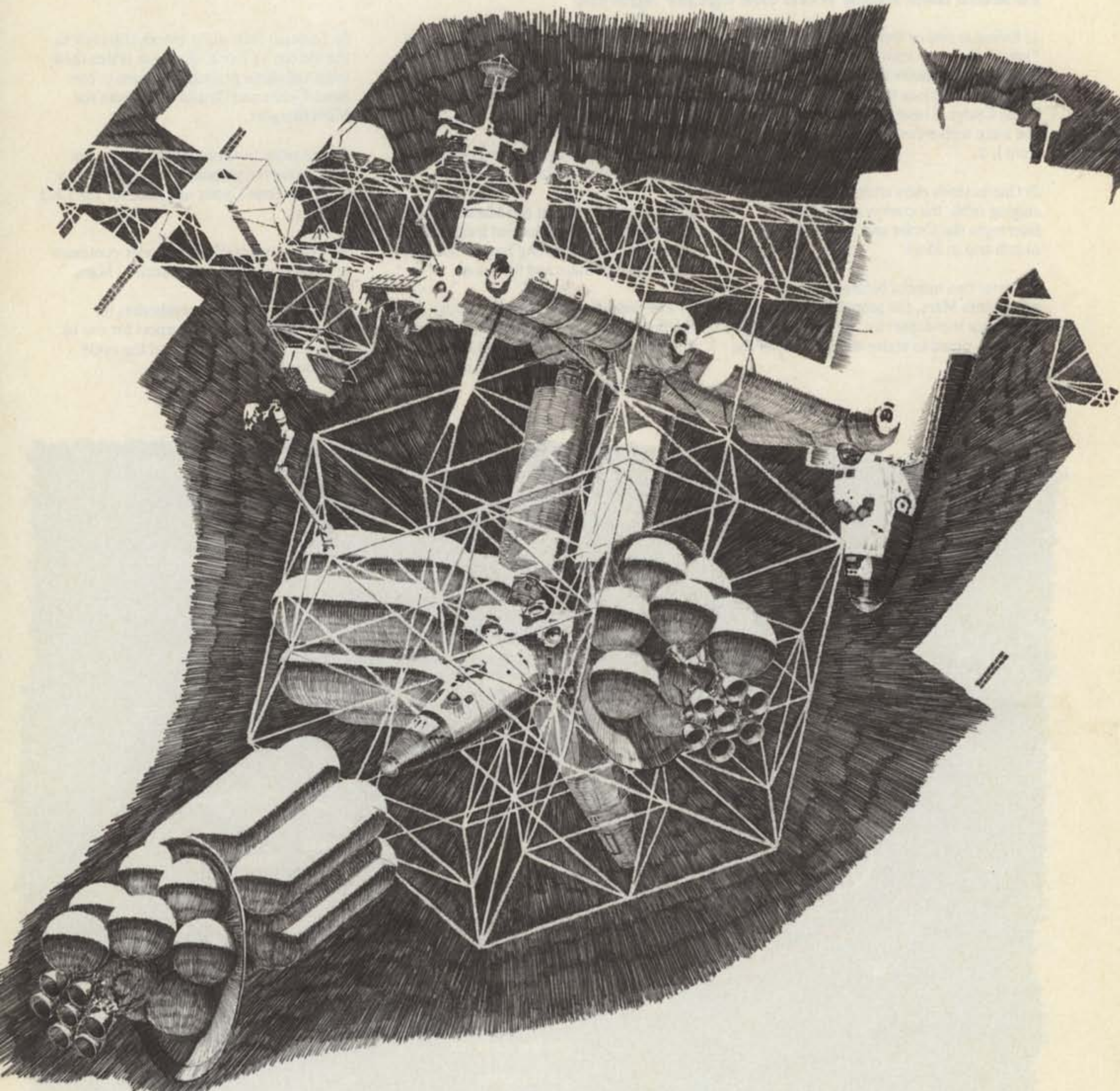
The mechanics governing the cycling orbits are both beautifully simple and dauntingly complex. Earth and Mars occupy nearly circular orbits. An Earth year, or revolution around the sun, is approximately 365 days, while a Mars year takes 687 days. With the Earth orbiting nearly twice as fast as Mars, a complete alignment of the two planets with the sun occurs every 26 months, or in just a bit more than two Earth years.

To bridge the gap between the two planets' orbits, a cycling spacecraft could be launched on a modified elliptical orbit, coming close enough to Earth or Mars to use the planet's gravity to bend its trajectory. On the next high-speed flyby of the other planet, this gravitational slingshot effect would be repeated. Eventually, the Cycler's elliptical orbit would rotate back to its starting place, which it would continue to reach at regular 26-month intervals. This permanent cycling trajectory would need only minor course corrections.

Like a ship sailing the trade winds, a cycling spacecraft would not follow a linear route between Earth and Mars. When the planets are aligned, the spacecraft would accelerate away from Earth and then loop outward, swinging close to Mars about five months later. But instead of expending propellant or using atmospheric drag to brake into Mars' orbit or to land, the Cycler would discharge smaller manned vehicles and a cargo pod. Then the Cycler itself would glide majestically on, using the boost of Mars' gravity to curve outward for eight more months, reaching its maximum distance from the sun before swinging back toward Earth. This unmanned return trip from Mars would take 21 months. In a sense, the vehicle would become a permanent, man-made companion of Earth and Mars, sharing with the asteroids and comets the free and inexhaustible fuel supply of gravity to maintain its orbit.

The simplicity of gravity-assist trajectories has already been demonstrated on a smaller scale by the unparalleled success of the unmanned Voyager 2 spacecraft, which used the slingshot assist of Jupiter to accelerate onto a trajectory that led it past Uranus and Neptune. Presently, the Galileo probe is completing a multi-pass Venus-Earth-Earth gravity-assist acceleration to loop it out to the orbit of Jupiter.

However, the discovery of convenient gravity-assist routes linking Earth and Mars—like the knowledge of the trade winds—is useless, arcane data unless we use ingenuity to develop practical hardware to exploit the potential of the Cycler. We need a Space Age caravel to ply the solar system's gravity ocean.



As with the other Starports in the Cycler system, the low-Earth-orbit facility would contain a central pressurized command module surrounded by berthing ports for small transfer taxis and propulsion stages.

To Mars and Back With the Cycler System

1) Riding in two or three small transport "taxis," the crew leaves the low-Earth-orbit Starport. They enter a staging orbit around Earth that positions them properly relative to the Cycler. These vehicles rendezvous and mate with refueled propulsion stages from L-2.

2) One to three days after leaving the staging orbit, the convoy of vehicles intercepts the Cycler and begins the five-month trip to Mars.

3) About two months before the Cycler encounters Mars, the propulsion stages for the return trip depart for the orbiting Mars Starport, timed to arrive safely ahead of the crew.

4) Shortly before encountering Mars, the crew leaves the Cycler in their taxis for a one- to three-day journey to aerobrake into Mars' atmosphere and then rendezvous with the Mars Starport.

5) The unmanned Cycler continues on a 21-month loop back to Earth.

6) The crew arrives at the Mars Starport, which serves as a permanent facility for servicing and dispatching landers for the exploration of Mars and its moons.

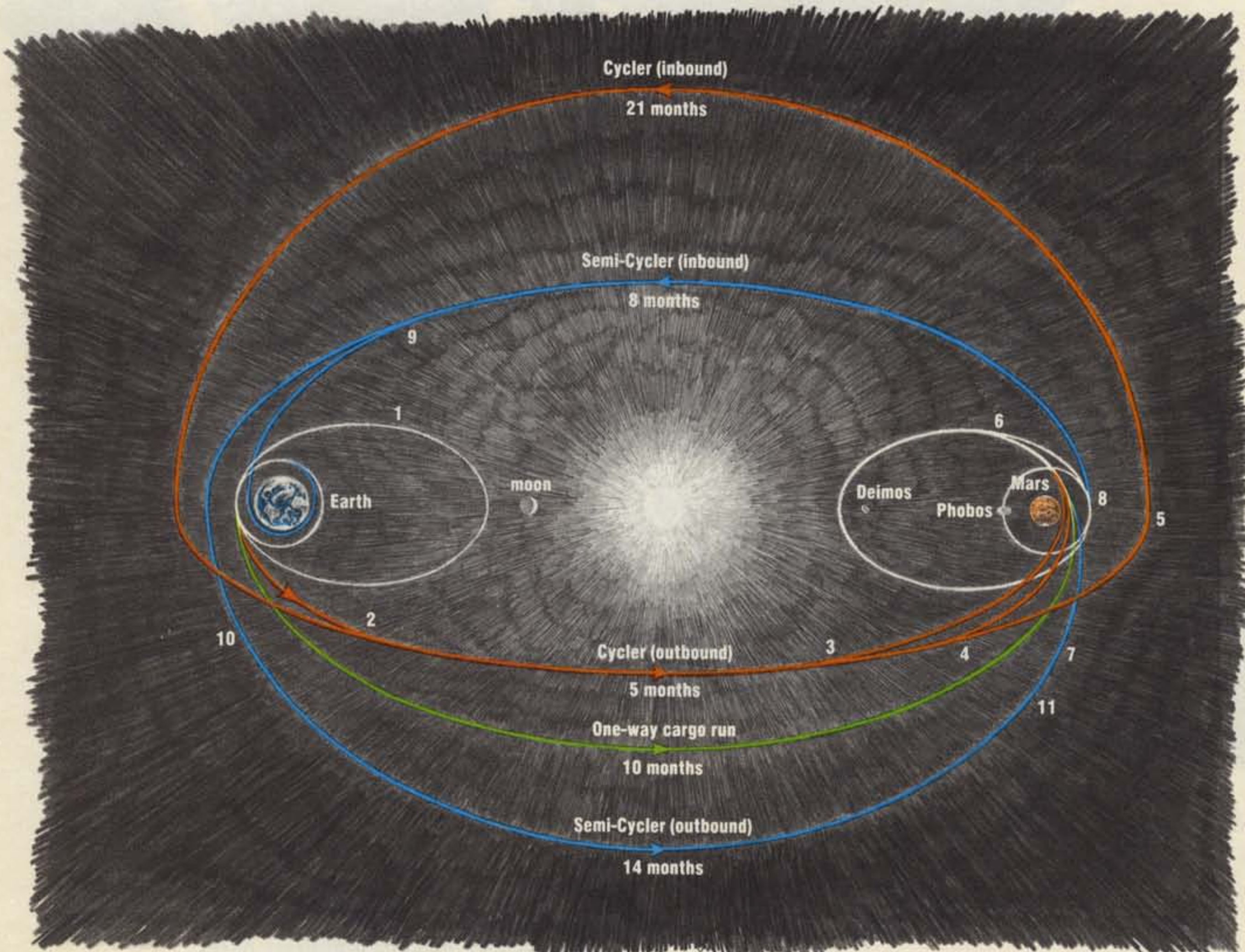
7) The Semi-Cycler, returning on the Earth-to-Mars leg of its journey, aerobrakes into Mars orbit about 16 months after the crew's arrival at Mars and four months before their departure.

8) To begin their eight-month trip back to the vicinity of Earth, the crew mates their taxis and three propulsion stages to the Semi-Cycler and thrusts away from the Mars Starport.

9) Just prior to encountering Earth, the crew taxis and propulsion stages separate from the Semi-Cycler and head for the LEO Starport.

10) The unmanned Semi-Cycler continues on, making a 14-month return to Mars.

11) The Semi-Cycler aerobrakes for recovery at the Mars Starport for use by the next mission's crew, and the cycle continues.



How would the Mars Cycler system work on this practical level?

Once we accept the Cycler principle, the fundamental support structure for Mars missions changes. The most massive components of this system are no longer repeatedly accelerated and decelerated—or discarded. Regular, predictable planetary flybys, not "planetfalls," become paramount. The Cycler system in effect creates an entirely new economic and philosophic approach to the Mars mission.

As would be impossible with a single massive spacecraft, the transportation requirements of crew and cargo would be separated, with the cargo traveling independent of the crew, who would ride in small, relatively low-mass "taxis" that join and depart the Cycler. Therefore, these manned vehicles must have permanent ports of departure and arrival orbiting Earth, the moon, and Mars.

We could begin by modifying the proposed U.S. space station Freedom to include a Starport vehicle processing facility. The design I like for this LEO Starport, as well as for those facilities that will orbit the moon and Mars and for the cycling spacecraft itelf, is an octo-tetrahedron, an adaptation of the system of construction devised by Buckminster Fuller, the innovative engineer and architect who developed the geodesic dome.

Built of lightweight but super-strong composite material beams, this first Starport would be attached to the space station's keel. The facility would consist of six concave pyramidal berthing ports, separated by eight tetrahedrons, all connected at the apex to a central pressurized command module with multiple ports. Some berthing ports could be enclosed for protection from heat and meteorites.

Highly flexible in design, the Starport would provide a single facility for translunar vehicle assembly, repair, checkout, and refueling. All these operations would be supported from the pressurized central command module. The Starport's modular construction also allows for easy expansion.

The Starport that would orbit the moon would provide storage, maintenance, and refueling capability at a single facility with a central manned habitat-workshop. During the initial phases of a moonbase buildup, this Starport could be kept in low lunar orbit. During this time, we could also test artificial gravity principles on the Starport by using centrifugal rotation (see "Life Beyond Gravity," December 1989/January 1990), a technique that could be adapted for the Mars Starport and the Cycler itself.

Later, the lunar Starport could be boosted out to the L-2 libration point, one of five such points in the Earth-moon system (L-2 is on the far side of the moon) where the planets' gravitational fields coalesce to form a neutral zone. Objects can remain in a stable orbit at L-2 without significant expenditure of energy. Positioned there, the lunar Starport could serve both as a support base for moon surface operations and as the "staging port" for crew and cargo about to embark on a Cycler mission to Mars.

During this period, vehicles used for lunar landing and orbital transfer and sharing a common basic design would be adapted for service as Mars landers and as taxis connecting the Starports and the Cycler.

Before we send humans to Mars, a Martian Starport, based on similar structural concepts, could also be assembled and tested at L-2. Then, using recoverable propellant stages, the unmanned Martian Starport could be dispatched to Mars, perhaps in several packages, and placed in orbit, through the use of either propulsion or by aerobraking, near the Martian moon Phobos. Since the cargo would travel independent of a crew, these freight runs could be low-velocity, low-propellant, 10-month cruises that take advantage of favorable planetary alignments. Following the placement of an automated plant on Phobos to convert surface material into propellant, the stage would be set for the Cycler's first manned voyage.

Because the function of the Cycler is essentially similar to the functions of the LEO, Lunar, and Mars Starports, the Cycler's configuration would be a direct outgrowth of these facilities. The Cycler's core would be an adaptation of the octo-tetrahedron radiating out from a central command module.

But the special requirements of deep-space, long-duration missions would dictate unique features for the huge vehicle. Artificial gravity would be needed because the Cycler would carry crews on voyages lasting many months. Also, because the Cycler would operate far from the sun, it could use a nuclear power plant, rather than the Starports' solar power cells.

These special requirements actually complement each other. I've designed a three-component Cycler consisting of a central Starport hub, a habitation module shielded from solar flares by a "storm shelter" of water tanks, and a nuclear power plant. Like beads on a necklace, these three components would be connected by long, multi-cable tethers. The entire assembly could be spun up to rotate around the core of the Starport, the centrifugal force simulating gravity in the two end "beads." Adjusting the length of the tethers would vary the amount of gravity, from zero G in a compressed configuration to 1 Martian G (about a third of Earth gravity) when the spacecraft is elongated. Incidentally, the Mars Starport could also evolve into this standard three-component configuration and be spun up to create artificial gravity.

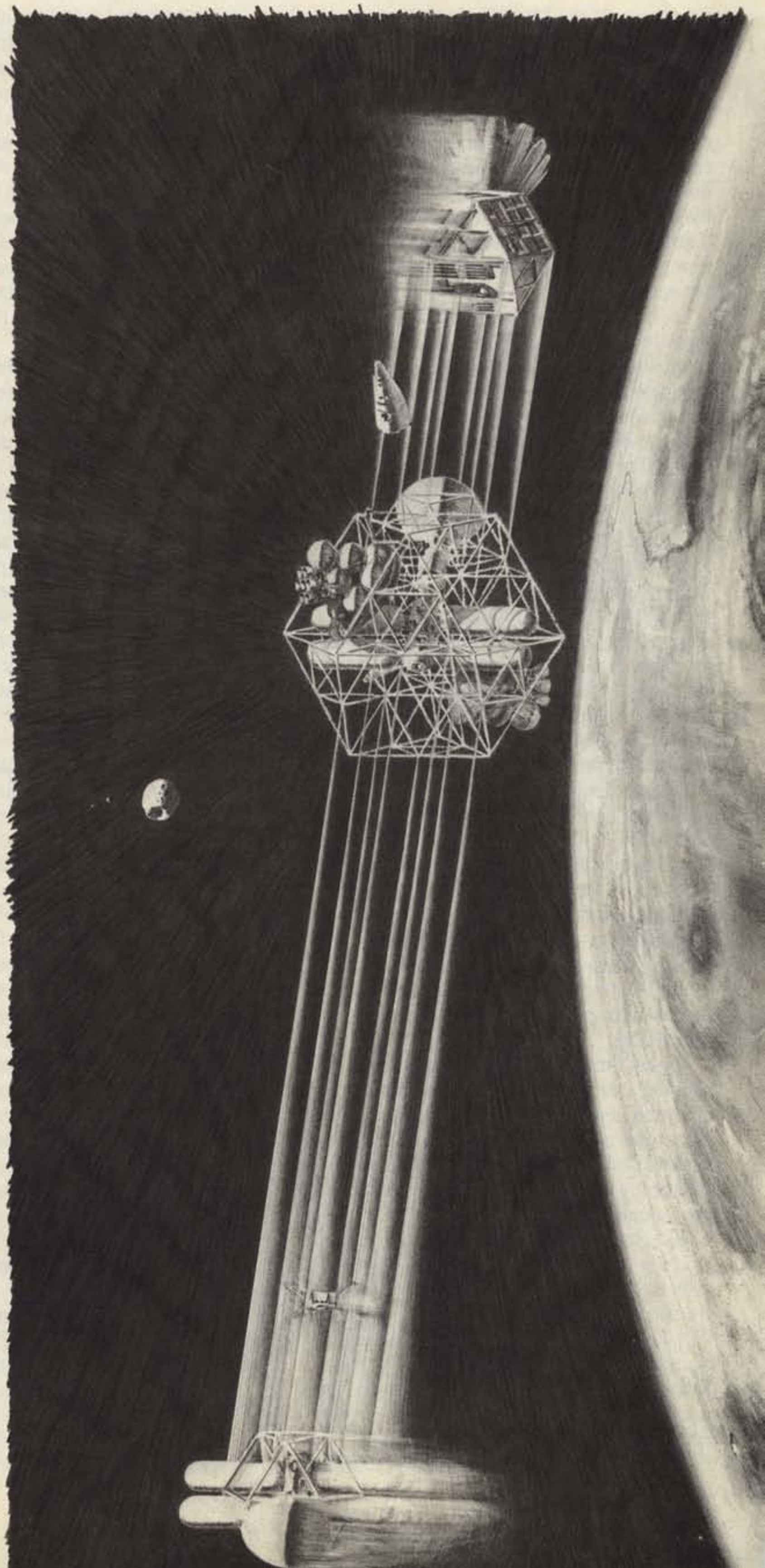
The Cycler would be propelled away from the Starport at L-2 onto its trajectory in a compressed configuration, using a recoverable propulsion stage that would loop back to L-2. The three components would then deploy along their tether bridle and spin up to produce artificial gravity. On this first run, the Cycler would be intercepted after leaving L-2 by a convoy of two crew taxis, a cargo pod, and their three propellant stages. On later missions, crews could depart for the Cycler from either the L-2 or the LEO Starport.

The crew would spend the five-month outward leg putting the Cycler's systems through their paces and verifying that the taxis were ready for deployment to Mars orbit. If serious glitches arose, the crew could simply sit tight and abort, riding the Cycler back to the vicinity of Earth on the 21-month gravity-assisted free return.

This automatic abort-to-Earth capability is one of the Cycler's prime attractions. A propulsion malfunction outbound would not doom the crew. Naturally, the Cycler would have life support provisions to sustain the crew for the full 26 months of the cycle.

Assuming all systems are up and running, about two months after departing Earth the Cycler's Mars crew would dispatch the propulsion stages ahead to the Mars Starport. After verifying the propulsion stages' safe arrival, the crew would then depart the Cycler just before its high-speed encounter with the planet, riding their taxi transfer vehicles to the Martian Starport, where they would take up housekeeping.

Exploratory excursions to the Red Planet's surface—via landers that would arrive at the Starport on separate cargo flights following the crew's arrival—could evolve in a conservative, progressive manner, executed by successive teams of crews safely based in their Mars Starport. One fundamental difference between this approach and conventional missions is the security of the permanent Mars Starport, an outpost from which rescue craft could be dispatched if



Like the Cycler vehicle itself, the three-component Mars Starport (left) would spin around its central space hangar hub on long cable tethers, creating artificial gravity in the two end units.

needed by surface explorers. This Starport also provides an excellent vantage point above the planet from which scientists can control a variety of unmanned robotic equipment on the surface.

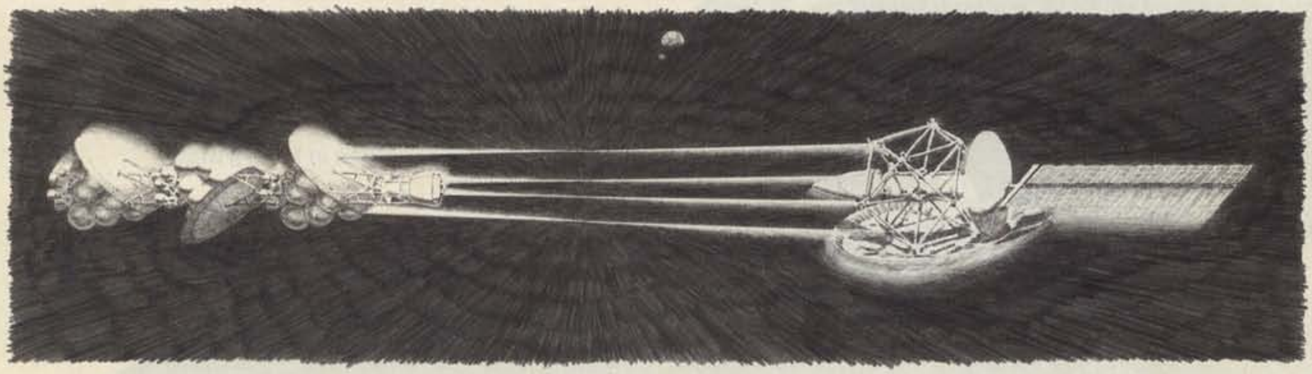
For their return flight to Earth, a Mars crew would leave the Starport in a modular vehicle I call the "Semi-Cycler,"consisting of a habitat module (dispatched, like the Mars landers, on a separate cargo flight) plus the transfer taxis and multiple propulsion stages.

The Semi-Cycler is necessary because the Cycler intercepts Mars at high velocity and quickly continues onward. The Semi-Cycler, so called because it would not cycle continuously between planets like the Cycler, would interrupt its cycle with a four-month aerobraked pause at Mars. The increased flexibility of departure times, coupled with the

five months and the return taking eight. Minor course corrections would be required, and propulsive energy would have to be periodically added to the composite vehicle to maintain its precise orbit. Fuel tanks for these maneuvers would join the Cycler as it passes the Earth.

As the Cycler and Starports mature, they would develop a closed-ecology artificial biosphere in order to remain independent from Earth for years. Like an oceanliner on a regular trade route, the Cycler would glide perpetually along its beautifully predictable orbit, arriving and departing with clock-like regularity. By plying the solar system's gravitational "trade winds" it will carry mankind on the next great age of exploration.

If we follow this evolutionary development track, instead of wasteful sprint approaches



With a transfer taxi and three propulsion stages on one end and a habitat module and taxi on the other, the Semi-Cycler would return crews from the Mars Starport to one near Earth.

spacecraft's low velocity, makes the Semi-Cycler a more forgiving vehicle for the manned inbound trip.

When the Semi-Cycler neared Earth after an eight-month journey, the crew would depart for the LEO Starport aboard the taxis, along with their three propulsion stages. The vacated return vehicle would then use a gravity assist from Earth to accelerate back out toward Mars, a 14-month voyage. (If the module had problems, however, it could easily abort into the Earth-moon system along with the taxis.) This unmanned Semi-Cycler would aerobrake back into Mars orbit to pick up another returning crew.

Compared with conventional vehicles, which need to accelerate out of Earth's deep gravity well, repeatedly abandoning valuable engine stages, the Semi-Cycler is much more efficient in terms of propellant expended and reusable hardware.

Once this outbound/inbound Cycler system was established, crews could commute relatively quickly between the Earth-moon system and Mars, with the outbound leg taking

using either nuclear-propelled or massive conventional spacecraft, the United States and its international partners will easily be able to afford this system of Cyclers and Starports. For roughly the same cost as getting humans safely to Mars via conventional *expendable* rocketry (because the problems to be solved would be largely the same), the Cycler system would provide a *reusable* infrastructure for travel between the Earth and Mars far into the future. As the National Academy of Sciences' National Research Council notes, the exact cost of manned solar system exploration is almost impossible to predict. But the council also calculates that an evolutionary approach—such as the Cycler system—can be undertaken for a few tenths of a percent of our gross national product. Of course, such public expenditures must be justifiable. My Cycler system offers mankind a permanent bridge between the planets, to be expanded and exploited by future generations, just as our predecessors exploited the trade wind routes blazed by Vasco da Gama and Christopher Columbus.