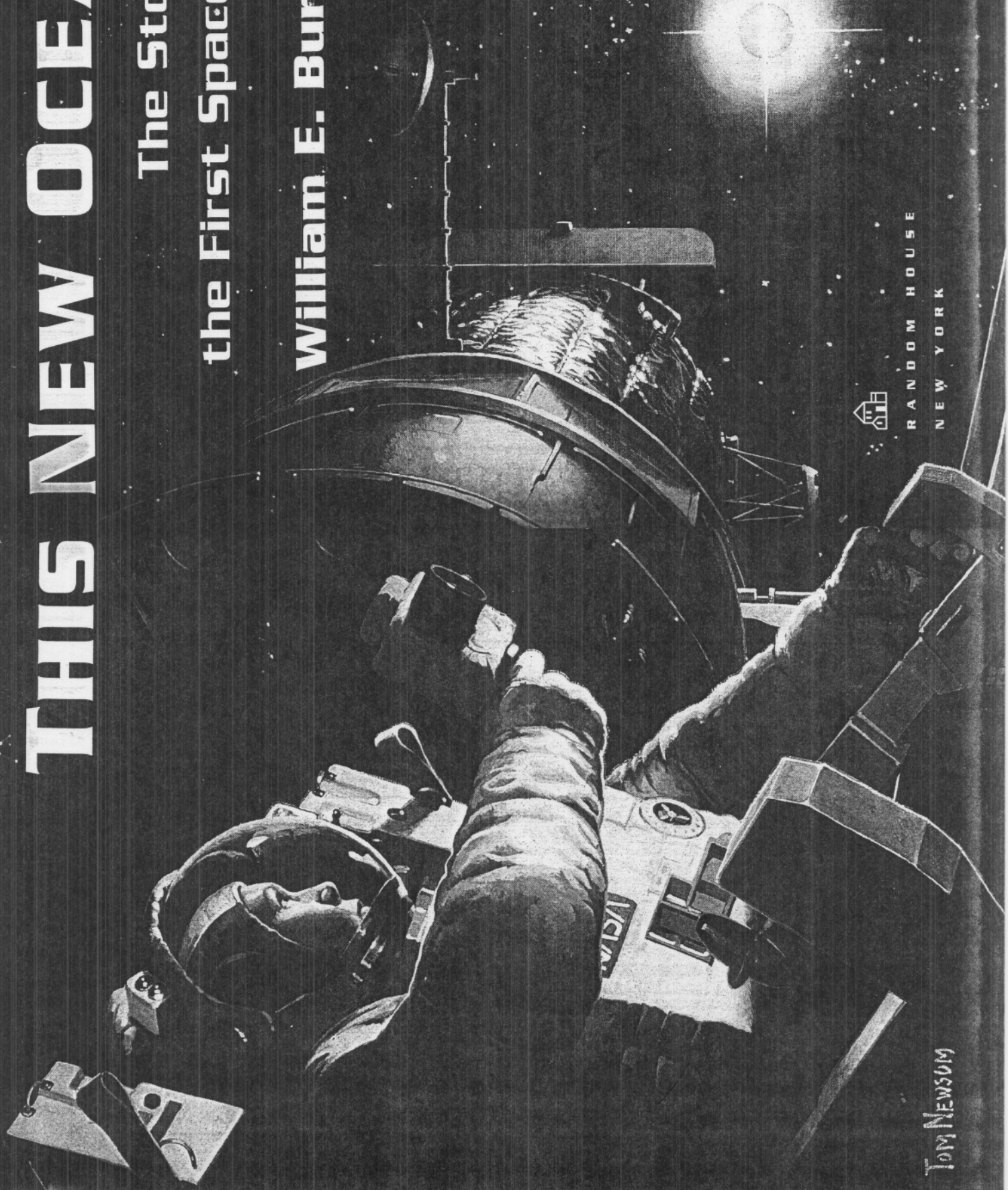


THIS NEW OCEAN

The Story of
the First Space Age

William E. Burrows



RANDOM HOUSE
NEW YORK

TOM NEWSON

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On Reporting the News

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THIS NEW OCEAN

Sun would be a house in Harvard Square, several blocks away. And, he added, the nearest stars—the triple star system called Centuri—would be houses on the real Moon. At some point the imagination that tried to leap such distances fell so far short that it had no choice but to shut down.

As both superpowers were finding out, reaching Venus and Mars, the nearest basketballs, was challenging enough for flights in which any number of otherwise minor glitches could ruin a mission. But at least the two planets themselves could be approached without a forbidding amount of velocity. Visiting the worlds beyond them, however, was an entirely different matter.

The Limits of Self-Propulsion

Conventional wisdom up to 1961, when the exploration race had begun to gather real momentum, said that the distance problem could be overcome only by increasing the sheer velocity of the rocket and using the old Hohmann Trajectory, or Hohmann Transfer.

The people who pondered solar system exploration going back to the pioneers thought that it depended squarely on very high velocities and precise trajectories: on brute power and on knowing exactly where to go and how to get there. Everyone believed that increasing velocity was the key to exploring the solar system, so as the 1960s got under way, mathematicians, physicists, engineers, and others considered ways to squeeze more velocity out of the rockets. Between 1959 and 1962, while the world watched the duel taking place between Gagarin, Titov, Shepard, and Glenn, while generals and their staffs were fantasizing about lunar bases, orbital bombardment systems, space fighters, and real-time reconnaissance, and while the race to the Moon itself was gathering momentum, the scientists and engineers who were thinking about sending spacecraft on really long-distance missions were busily working the problem. Technical papers, journal articles, magazine pieces, and even chapters in anthologies that tried to come to terms with velocity proliferated.

Some considered, and invariably rejected, liquid-propelled chemical rockets of gargantuan proportion as still being inadequate. One, at 660 feet high, the length of a battleship, was named Sea Dragon and would have towered 125 feet above the Washington Monument. It would have weighed 100 million pounds and developed 130 million pounds of thrust. But even that monster would not have been able to carry a serious payload to the outer planets and beyond.

There was also a long-standing flirtation with atomic energy. As early as 1953, two British authors with technical backgrounds wrote a book entitled *Space Travel* in which they stated categorically that “nothing short of an applied form of atomic energy will ever be adequate” to propel men to the

Moon. A few years later, Theodore B. Taylor and Marshall N. Rosenbluth of the General Dynamics Corporation came up with a concept called Orion in which a very large spaceship would be pushed across interplanetary space at high speed by a series of nuclear explosions. Freeman Dyson, the Princeton University physicist who was renowned for his imaginative speculation about the future, also worked on the project. He explained years later that Orion's creators wanted to build a ship that would carry mankind peacefully from one end of the solar system to the other. But the project was funded by the Air Force. As recounted by Dyson, one Air Force captain became fixated by the notion of using fleets of Orion spacecraft as battleships that would stay on constant patrol, "cruising majestically" beyond the Moon, in a Deep Space Bombardment Force that would, as the physicist derisively put it, "stand between the tyrants of the Kremlin and dominion of the world." The captain's superiors thought they had better things to do with their money, however, so Orion soon sank out of sight.

Other plans described in intricate detail at least three kinds of nuclear engines that would "burn" fissionable materials, or use fusion, or decaying isotopes to generate heat from alpha, beta, or gamma particles that would heat hydrogen. And still others suggested three kinds of so-called ion, or electric, engines, one of which would strip electrons off a gas such as xenon and shoot them through an electrical field, which would make them accelerate. Ion propulsion was and remains one of the most feasible and attractive energy sources because the engine weighs only about a hundred pounds and could reach speeds as high as 300,000 miles an hour. The problem was that it would have to be carried to orbit, initial velocity would be measured not in pounds but in millipounds, and it would take ten years for the little beast to work its way up to top speed. Even solar sails, which would coast on the solar wind—Kepler's "heavenly breezes"—were considered.

It was widely accepted that only the spacecraft itself could increase its velocity and that the most efficient way to get from one planet to another was through the classic "minimum-energy" Hohmann Transfer or Trajectory, first articulated in 1925 by architect and VfR member Walter Hohmann. This involved a spacecraft leaving Earth and catching up with another planet by flying a long, flat ellipse until it and the target planet converged. Three Grumman engineers maintained in 1960 that the Hohmann Trajectory was absolutely the "optimal . . . least fuel path" for getting around the solar system. No one disagreed. Yet the farther out a planet was, the longer the ellipse, until it translated into more than thirty years for a flight to Neptune. During that time some of the mission scientists (not to mention their journal editors, publishers, and colleagues on promotion and tenure committees) would inevitably also leave this world, though not for Neptune. Indeed, it would take Rip Van Winkles to run such missions.

And if the object of Hohmann's nice clean elliptical flight path was a smooth, graceful, and efficient voyage, then planetary "perturbations"—the tugging and pulling of the heavenly orbs—amounted to an annoying hindrance that had to be canceled out by using the spacecraft's own engine.

Free Lunch

All of that was turned upside down in 1961 by a precocious twenty-five-year-old doctoral candidate named Michael A. Minovitch, who was studying mathematics and physics at UCLA and whose idea of fun was doing vector analysis. New to celestial mechanics, vector analysis had to do with developing equations to calculate orbits in three dimensions under all sorts of conditions. What Minovitch had done for fun as a youngster, besides read and study science voraciously, was watch *Destination Moon* and build model airplanes. Now it was all leading somewhere.

He landed a job that summer with JPL's Trajectory Group, which was trying to provide Mariner mission planners with one-way routes to Venus and Mars. They were doing that with their pride and joy, a new IBM 7090 main-frame computer that churned out pounds of calculations, and with their knowledge of the Hohmann Trajectory. The work was immensely complicated and tedious and involved using complex numbers to integrate the launch location (Cape Canaveral) with every phase of the flight. This would enable the navigators to set up simulated missions that told them where thrust vectors had to be pointed in order to get the rocket into a so-called parking orbit around Earth and then off to intercept Venus or Mars. Spacecraft were parked in parking orbits until the perfect moment came for them to strike out in a new direction.

"It's a killer," Minovitch would explain later. "I mean, talking about numerical headaches. It's like a labyrinth . . . very detailed number crunching. . . . But it's the type of work that has to be done to translate Oberth's and Tsiolkovsky's theoretical ideas of space travel into engineering realities. This was the nuts and bolts of preparing for rocket flight," he said, and it was happening under the pressure of beating the Soviet Union to the planets. "The federal government was throwing millions and millions of dollars at JPL like there was no end to the water spigot," Minovitch would recall. "It was like a miniature Manhattan Project," he added, still savoring the government's largess.

What Minovitch wanted to do was solve the endlessly frustrating Problem of Three Bodies. He therefore avoided Hohmann's elliptical approach to calculating trajectories. Instead, he applied his beloved vector analysis to three-body trajectories—Earth, spacecraft, and Planet X—and specifically to differential corrections. "Differential corrections" is jargon for using a com-

puter to pick the best possible trajectory for a spacecraft and then gradually refine the model, making small corrections, until the combined effect of all three bodies on each other is precisely established.

Minovitch, feverishly working alone through the night at JPL's computer or at home, was trying to use vector analysis to get a spacecraft to a given destination by knowing where it, the planet it came from, and the target planet were at all times. The secret was to start with the best possible trajectory and then keep refining it: by using a high-speed computer to reduce the three-body picture into a series of Problems of Two Bodies and then combine all of them.

And that was not all. The young physicist-mathematician had taken the Problem of Three Bodies out of mathematics and put it into physics. It was then, while working on the problem from a physical perspective, that he came to see that the amount of energy, expressed as gravitational pull—the hated perturbation effect—could actually be used to fling a spacecraft toward another planet or a moon without using the spacecraft's own engine. It dawned on the driven young scientist that a spacecraft swinging around a planet would pick up some of the huge body's own energy as gravity pulled it toward the planet. It would then leave the encounter flying much faster relative to the Sun than it had been when it arrived.

This meant that once a spacecraft reached Venus, for example, with minimal velocity from its own rocket, the planet itself would fling it in any direction its navigators on Earth chose, provided it skimmed past the planet at just the right distance. If it was too far away to be fully affected by the planet's gravity, it would race out to infinity; too close, and it would be pulled in by an embrace that ended in a crash. Since the planet itself would be speeding along when the spacecraft caught up to it, the machine from Earth would gain speed, perhaps doubling it, as it was hurled out in a new direction.

But, he realized, it got still better. If this worked once, it would work repeatedly. In fact, it would work infinitely. Every time a gravity-propelled spacecraft reached a new planet and was steered into the same maneuver, it would get another massive shove through no effort of its own. Theoretically, then, a robotic explorer could fly around the solar system indefinitely like a billiard ball bouncing off the cosmic cushion with absolutely no further assistance from the engine that got it off Earth in the first place. Gravity would provide an infinite free lunch.

Minovitch was not the first to think about using planetary perturbations to help propel spacecraft. Tsander had done so, as had New Zealand's Derek F. Lawden, one of the century's outstanding astrodynamists, and both UCLA's Samuel Herrick and Krafft Ehricke at General Dynamics. All of them except Lawden, however, either disregarded gravity propulsion or wanted to use it with the Hohmann Trajectory. But using Hohmann's Trajectory necessarily also meant using the spacecraft's own engine the way a swimmer pushes off

from a boat or the wall of a pool. Lawden had briefly mentioned using a large moving body to increase velocity “without expenditure of fuel” in an article in the *Journal of the British Interplanetary Society* in 1954, but it had gotten lost in the literature and been all but forgotten.

Minovitch turned his research into a forty-seven-page paper, loaded with equations and charts, called “A Method for Determining Interplanetary Free-Fall Reconnaissance Trajectories.” The document, dated August 23, 1961, would shrink the distance separating Earth from the outer planets and in the process create a revolution in solar system exploration. It would come to be called “gravity propulsion” or “gravity assist,” and the credit for discovering it would be controversial for years.*

The Soviet Union, which probably had the best mathematicians in the world, was nowhere near nailing down gravity propulsion despite the head start bequeathed by Tsander. This is undoubtedly because it trailed the United States in computer development. The Russians only sent probes to Venus and Mars, which did not require gravity-assisted trajectories. But there was ample evidence, certainly in the papers they presented at international meetings, that they considered all planetary missions to be straight, direct transfer shots without intermediate detours. Two prestigious Soviet scientists, G. N. Duboshin and Dmitriy Y. Okhotsimsky, made that point in a paper they presented at the Fourteenth International Astronautical Congress in Paris in 1963.

Meanwhile, Minovitch continued to work on gravity propulsion and related areas sporadically at JPL, but mostly back at UCLA, during the next few years. He soon coaxed the computers to lay out the basis for a long gravity-assisted deep-space mission. Given the fact that Jupiter was by far the most

* There was a persistent unwillingness at JPL to credit Minovitch, possibly because of an institutional unwillingness to admit that a twenty-five-year-old summer employee, and a newcomer to the subject at that, could accomplish what the best minds in trajectory analysis there and throughout NASA and beyond were not able to do. Minovitch's boss that summer, Victor C. Clarke Jr., was credited with the discovery nine years later. Clarke was cited in a NASA press release for a prize-winning essay on applying gravity assist to space flight, for example. The release stated that “he first demonstrated in 1961 the possibility of bouncing a spacecraft from planet to planet.” The use of a planet's gravitational field to change spacecraft speed and direction “can significantly shorten flight time,” it added. Minovitch was given credit at the end for helping. (“Mariner-Venus '73 Flight Genesis,” release No. 70-112, July 5, 1970.) Nineteen years later, Minovitch's discovering gravity assist was acknowledged by JPL in its *Voyager Neptune Travel Guide* (pp. 104–5). In his own fine work, *Mapping the Next Millennium*, Stephen S. Hall gave credit to Gary A. Flandro, another JPL scientist, though he acknowledged a “rivalry for credit” between the two. Hall cited a “key” 1966 paper by Flandro, which appeared five years after Minovitch's. (Hall, *Mapping the Next Millennium*, pp. 40 and 406.) And in 1994, a writer in *Air & Space* advanced the sophistic argument that, in any case, “it was just a matter of time” before someone else solved the problem because gravity assist was an evolutionary development. (Reichhardt, “Gravity's Overdrive,” p. 78.) That discounts the inventive process. By such reasoning, it was just a matter of time before someone else invented the telephone, penicillin, and cubism, so Bell, Fleming, and Picasso should receive no special credit for doing so first.

massive of the planets—the solar system’s most powerful sphere of influence after the Sun—it was a logical candidate to get probes to the other outer planets off to the fastest possible start. In August 1964, three years after the birth of gravity propulsion, Minovitch got a computer to tell him that there would be a perfect window to Jupiter in 1977 that would allow a spacecraft to skip like a rock on water from it to Saturn, Uranus, and Neptune, all three of which would be strung out in the right positions for successive encounters. That same year, 1964, Minovitch’s gravity propulsion work was included in a JPL mission design paper. The following year, Gary A. Flandro designed his own set of outer-planet missions based on gravity propulsion.

The Great Leap Outward

Mission planners in the Soviet Union began thinking seriously about sending spacecraft to Venus and Mars almost as soon as Sputnik’s flight was a reality, and their American counterparts were close behind. The drive to reach Earth’s closest planetary neighbors was a complex brew of scientific curiosity and nationalism that was not easily untangled, though there is no doubt that the former far outweighed the latter as far as the scientists and the engineers who were supposed to get the spacecraft to the planets were concerned. The problem was that science, as always, was captive to politics. “There was always a sense of competition,” Soviet physicist Roald Sagdeev explained about the exploration of Venus. “The Soviet government always was supportive of such missions from the point of view of propaganda and flexing muscles. Venus was considered by them as one of the battlegrounds of the cold war.” For both Soviet and American scientists, it was a battleground where the flower of knowledge blossomed. But as usual, the politicians cared more for prestige, and they were the ones who provided the funding. So Korolyov, supported by Keldysh, needed to protect his lead against the United States by being first to reach Earth’s nearest neighbors.

But steady, relentless progress in the Gemini and Apollo programs in the early and mid-1960s and the faltering Soviet manned Moon program was eroding the lead. And as it slipped away, desperation set in. Pressure on Korolyov and his colleagues to leapfrog the American manned program by going to the planets became intense. The record of Soviet shots at Venus and Mars between October 1960, when the first was attempted, and October 1967, when an “Automatic Interplanetary Station” named Venera 4 actually returned data from the Venusian atmosphere, indicates sheer frenzy. And the results, at least to begin with, were appalling.

There were at least twenty consecutive failures, several of which were neither named nor announced, in which the spacecraft either blew up on the pad, failed to make it out of Earth orbit, or had a catastrophic communication prob-