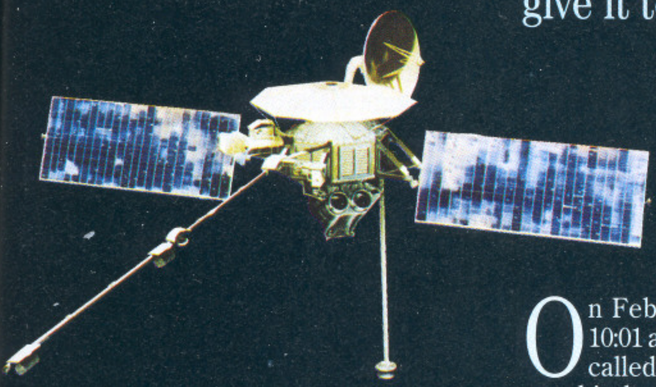
Gravity's Overdrive

Michael Minovitch wants the credit for finding a key that helped open up the solar system. Not everyone is willing to give it to him.



by Tony Reichhardt

Mariner 10 traveled to Mercury by using Venus' gravity to bend its course in toward the sun, a correction that would have otherwise required vast amounts of rocket fuel. The only spacecraft to visit our solar system's innermost planet, the tiny probe transmitted many detailed photographs of Mercury's cratered surface.

On February 5, 1974, at exactly 10:01 a.m. Pacific time, a tiny probe called Mariner 10 introduced a new kind of magic to the space program. The last in NASA's original line of planetary robots, it zipped past Venus with the speed of a bullet, then used the planet's gravity to swing itself around on a new course toward Mercury. For the first time, a spacecraft bound for another world changed course not with rocket fuel but by using a planet's gravitational field.

That simple, elegant maneuver stands, along with the development of the rocket engine, as one of the keys that opened the solar system to exploration. The Pioneer, Voyager, and Galileo missions all used gravity assists, and in fact would not have been possible otherwise. Without a boost from Jupiter, the Voyagers would have needed more than three million pounds of fuel to continue on to Saturn. As it was, they used about 11 pounds. Gravity assist is the most efficient form of space propulsion known.

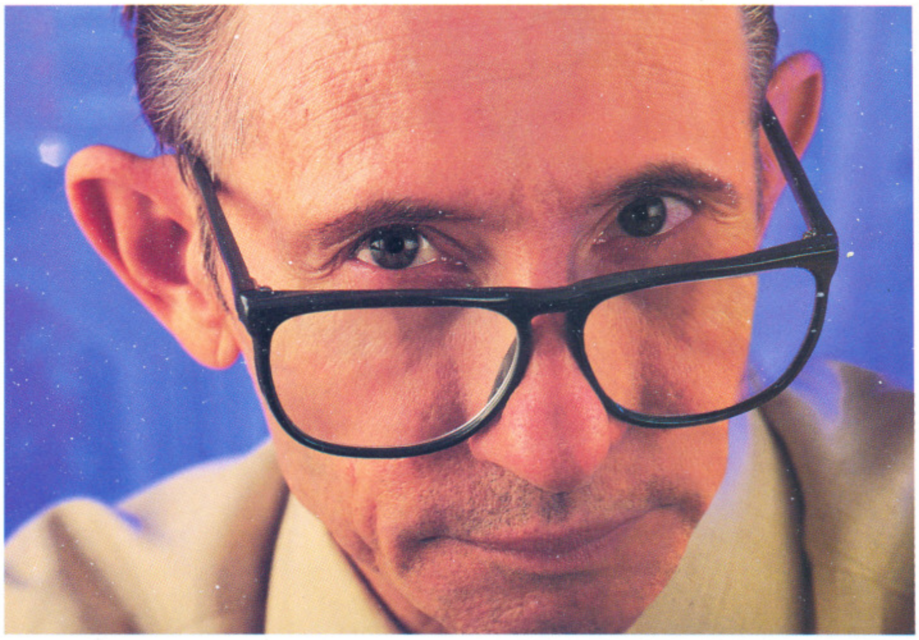
The man whom many agree deserves the most credit for pointing this out did not share in the celebration at NASA's Jet Propulsion Laboratory in Pasadena, California, when Mariner 10 flew past Venus. He was embroiled in a bitter dispute with the lab over who should get credit for inventing the gravity assist technique.

The arguments aren't over yet.

In June 1961, only a month after Alan Shepard became the first American in space, a shy, intense 26-year-old graduate student named Michael Minovitch showed up to work as a summer employee at JPL. Growing up in Los Angeles in the 1950s, Minovitch had been the kind of kid who literally slept with his math books. "I wasn't a Romeo, I wasn't a car buff," he recalls today. "I tried to run my life as a person truly devoted to science." Minovitch was finishing his third year of graduate math and physics studies at the University of California at Los Angeles, working toward a Ph.D. He had spent the previous summer at Linus Pauling's lab at the California Institute of Technology, working on X-ray diffraction of crystals, but when he learned about jobs at JPL, he turned down a second summer at Pauling's lab to go to the place where the U.S. planetary program was being born.

The first successful U.S. planetary

MERCURY COURTESY NASA/JPL : MARINER 10 COURTESY JPL



CHAD SLATTERY (2)

Michael Minovitch (right) first began looking into gravity-assisted trajectories as a summer intern at JPL in 1961. He says Victor Clarke (below), then his boss, was initially skeptical of the idea. "Hogwash," responds Clarke.

mission, Mariner 2, was still a year away from its launch to Venus. At the time, there had been a few papers delivered at aerospace conferences about "multi-planet transfers" that could reach more than one planet with a single launch, but no one was spending much time worrying about *that*. "In the spring of 1961 the space program was challenged by just getting a goddamn spacecraft to last three months to get to another planet," remembers Roger Bourke, who later became Minovitch's boss at JPL.

If few people were thinking about multi-planet flybys, no one was pushing the idea that gravity could be used as a form of free propulsion. However, the principle was nothing new. Astronomers had known for centuries that comets can gain or lose energy when they pass near a massive body like Jupiter—energy exchanged with the planet's own orbital energy as it circles the sun. In the 1920s, the Russian theoretician Fridrikh Tsander pointed out that a spacecraft's course would be altered in exactly the same way. More than one science fiction writer of the 1930s toyed with the idea, as in Lester del Rey's 1939 story "Habit," in which a rocket jockey wins a race by stealing a gravity boost from Jupiter. "I grazed around the side, was caught in [Jupiter's] gravity, and began to swing in an orbit," the narrator says. "That's what I'd been looking for, something to catch hold of out in space to swing me around without loss of momentum, and that's what I'd found; Jupiter's gravity pulled me around like a lead weight on a swung rope."

By the mid-1950s, with the Space Age fast approaching, a few scattered academics, including the members of the British Interplanetary Society, were discussing the concept in a serious, if rather general, way. In 1954 mathematician Derek Lawden wrote in the society's journal, "A number of writers have suggested that the fuel requirements of a journey between the Earth and the other planets might be reduced by taking advantage of the attractions of various bodies of the solar system." Lawden went on to admit, however, that "the method of calculating such perturbing effects and the economies to be expected do not appear to be widely known."

That was still pretty much the case in the summer of 1961. Although scientists at MIT, the Rand Corporation, and elsewhere had discovered cases in which a gravity maneuver could be beneficial (the Russians had already used the moon's gravity to shape the trajectory of their 1959 Luna 3 mission), no one at JPL was applying the principle in any systematic way to planetary mission design. In fact, says Minovitch, "Celestial mechanics was not looked at as a real serious problem. The real problem, and the underlying technical philosophy of space travel, was hardware development." Most space visionaries of the 1950s had been of the mindset that the way to reach farther into space was simply to launch ever more exotic rockets—which, of course, had yet to be developed.

When he arrived at JPL, Minovitch was assigned to a trajectory group headed by Victor Clarke, a laid-back engineer who'd been at the lab for five years. Clarke's group was working with a computer program to calculate one-way interplanetary trajectories and had plans for another program that would yield round-trip trajectories for Earth-Mars-Earth and Earth-Venus-Earth missions. The round-trip program required factoring in the effects of gravity at the target planet.

Minovitch contends to this day that Clarke assigned him to work only on the straightforward one-way trajectories, not the round trips. Clarke remembers it differently. Either way, Minovitch, who had no background in celestial mechanics, began playing around with vector analysis of spacecraft trajectories, which led him to a realization. Years later he wrote: "When I studied the relatively simple equations on my paper, these things just leaped out at me!"

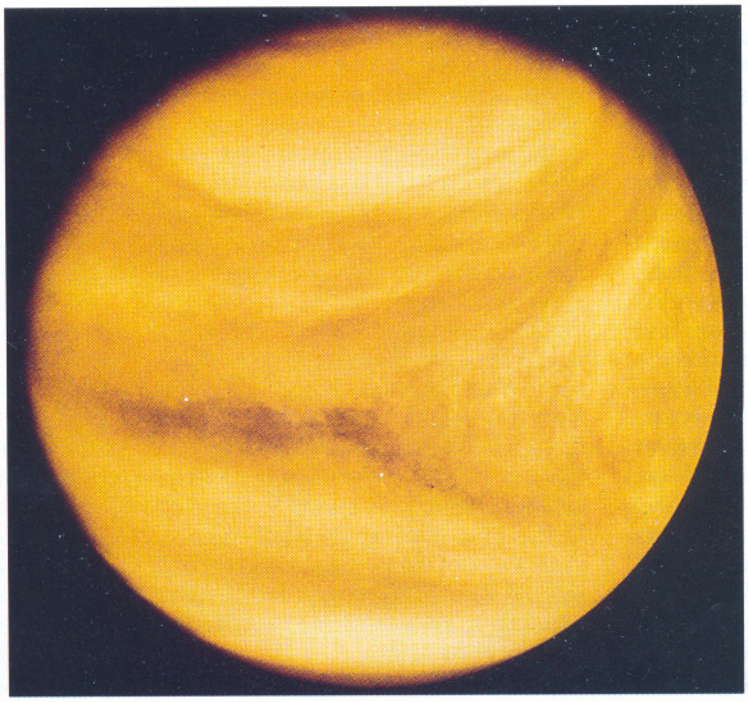
Most mission designers of the day, concerned as they were with producing nice, clean, elliptical trajectories, thought of gravity "perturbations" as annoyances to be canceled out with rocket burns. Minovitch's insight was exactly the opposite. Gravity swing-bys could be used to *replace* rocket burns. In fact, the most efficient way to reach any planet (except Venus, the planet closest to Earth) was to go somewhere else first, then use the intermediate planet's gravity for a free boost. It meant that any place in the solar system—the giant outer planets, even the sun itself—was accessible with relatively small launchers. You didn't need big nuclear rockets, as the textbooks said. All you had to do was get to Venus first, then let nature's own energy take over.

In August, before returning to UCLA, Minovitch wrote up his ideas in a JPL technical document. But he knew that his quick slide rule calculations weren't enough to prove the concept. He needed a powerful computer to perform the long and tedious calculations that could identify real trajectories.

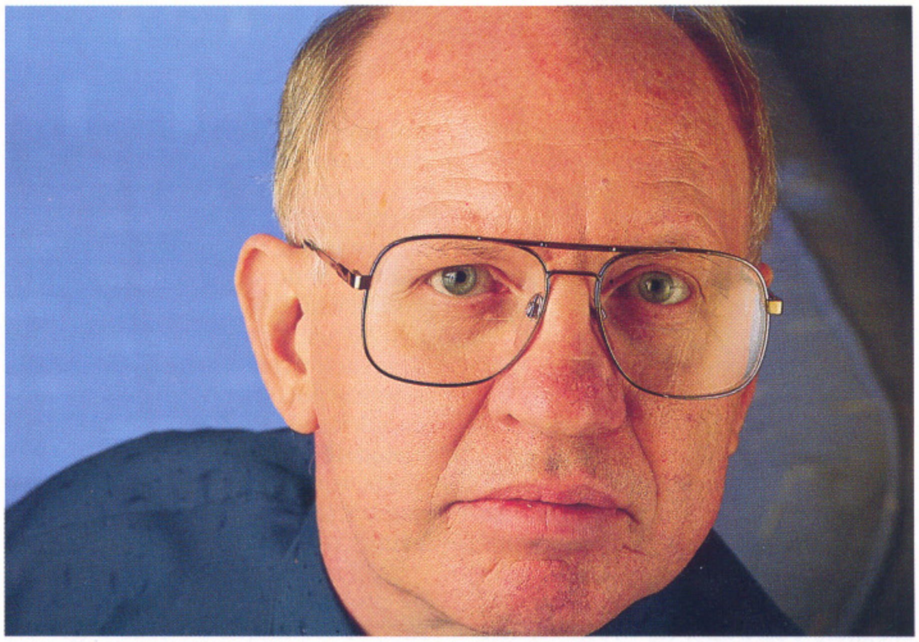
Back at UCLA, Minovitch dove into the project independently, convinced that the technique he called "gravity propulsion" could change the course of space exploration. He took courses in FORTRAN programming and convinced his professors to give him access to what was then one of the most powerful computers of the day, an IBM 7090. He used a smaller JPL computer over Christmas break, and when he returned to work there the following summer he was allowed access to the lab's own IBM 7090s.

For the next two years Minovitch juggled a full load of graduate courses with his work on gravity propulsion. He was a man on fire. "For months, he wanted to talk about little else over dinner," recalls his college friend Lowell Wood, later a guiding spirit of the SDI missile defense concept. Minovitch would run his trajectories on the giant room-size computers late at night, when they weren't in demand. Less than an hour after Mariner 1—JPL's first attempt to reach Venus—exploded on the launch range, Minovitch parked himself in front of a 7090, taking advantage of the unexpected down-time. Working in the pre-dawn hours, often by himself, he tried different combinations of launch dates and target planets. He had punched in the entire planetary ephemeris (a table showing the precise positions of the planets over time) himself. It took two weeks. He didn't care. Each time he heard the buzzing of the computer tape as it filled with data, he knew he had another "hit," another viable gravity-assist trajectory. The work was Herculean, mind-boggling. "He had this fixation on understanding everything that could possibly be done, every launch date, every planetary combination, everything," says Wood.

The folks at JPL didn't quite know what to make of this brilliant, obsessive grad student who only came out at night, loading computer paper into his beat-up car to haul back to UCLA for more number crunching. They got a big laugh the time he forgot his badge during one


JPL

Minovitch determined that it would be quicker to send probes to other planets by having them swing by Venus first. Mariner 10 also used its Venusian flyby for science, returning ultraviolet images of Venus' upper cloud layers that revealed how quickly the atmosphere circulates around the planet.



CHAD SLATTERY (2)

Fran Sturms (right) and Joe Cutting (opposite) grasped the importance of the gravity assist concept. While investigating possible trajectories at JPL, they dubbed their group the "Cheap Missions Office."

of his midnight runs, tried to climb the fence, and got caught by the guard.

Not surprisingly, he didn't fit in well with the more practical-minded engineers and scientists at the lab. Although many of them could also be hard-charging, even a bit eccentric, they were more collegial, dropping into one another's offices to shoot the breeze, working out problems on blackboards together. Minovitch kept to himself. Norm Haynes, who later managed the Voyager project during the Neptune flyby, joined the trajectory group in 1962, and, though his office was next door to Minovitch's, Haynes never saw him. "I didn't even know who he was," Haynes says. "We just knew he was there because he'd leave these giant stacks of computer printouts, and the stacks just kept getting bigger and bigger."

At the same time, Minovitch was becoming increasingly frustrated with the atmosphere at JPL. "When I came to the lab," he recalls, "my feeling was it was going to be an academic institute, or like a subset of Caltech, where elite theoreticians were working. And that was not the case." He was more at home with academics and thought of engineering as, well, the equivalent of manual labor. This was the nation's premier space laboratory? They didn't even seem to realize the importance of his idea! Remembers Wood, "[Minovitch] was constantly complaining that he couldn't get the people at JPL interested."

There were, of course, plenty of people at the lab who understood Minovitch's concept. They just weren't as excited about it as he was—or didn't act like it, anyway. Minovitch was especially frustrated by the reaction of his own boss. Perpetually up to his eyebrows in memos, meetings, and project-related deadlines, Vic Clarke didn't have much time to discuss his summer employee's research. At first, some recall, he had even been among those who argued that the physics of the idea were all wrong and that there was no such thing as a free ride. According to Minovitch, Clarke "truly believed that the underlying theoretical concept violated the laws of conservation of energy." Yet the energy wasn't created from nothing. It was stolen from the planet's own enormous orbital energy.

To understand how a gravity assist works, think of a rapidly spinning carousel with a rider standing on its edge. A passerby running up to the carousel could briefly grab hold of the rider's hand and get a boost from the carousel until he releases his grasp and is sent running off more rapidly in a different direction. The carousel, for its part, would have slowed slightly. (JPL engineers later calculated that when Voyager picked up some 35,700 miles per hour of velocity from Jupiter's gravity, the planet's orbit slowed down by one foot per trillion years.) Gravity assists can also be used to slow a spacecraft. In the case of Mariner 10, the spacecraft was slowed by Venus as it turned inward toward Mercury. During the maneuver, Venus speeded up ever so slightly in its orbit.

Gary Flandro, then a Caltech graduate student and later the discoverer of the Voyager planetary "grand tour" opportunity, remembers the arguments. At first, "Clarke did not understand that you could get an energy gain when you did a planetary flyby," says Flandro. "He and Mike had many, many verbal battles over that one." (Today Clarke dismisses the assertion that he didn't understand the concept as "hogwash.") Clarke eventually did allow Minovitch to use JPL's computers to explore the concept more fully but he never placed it very high on his priority list. JPL had its hands full with simple trips to Venus and Mars. Multi-planet missions and the outer solar system were still off in the future. Why worry about them now?

Minovitch kept beavering away nonetheless, running every conceivable combination of planetary encounters on the UCLA and JPL computers. He had Mars missions. He had Mercury missions. He even had missions to Neptune and Pluto. But he was working in virtual isolation. "He was very closed in what he wanted to reveal about his work," remembers Roger Bourke. "He considered it such a secret." Which, along with the lack of any project-related urgency, helps to explain why, three years after Minovitch published his first paper on gravity assist in 1961, the concept was still outside the mainstream of thinking at JPL.

In 1964 Clarke left the trajectory group, and Elliot "Joe" Cutting, one of the analysts in the section, took over. It wasn't long before Cutting turned his attention to gravity assist. "I was quite interested in what Mike had done," Cutting says. "I'd read his stuff, and I said 'Gee, this looks kind of interesting. Is it practical?' " Cutting assigned Fran Sturms, who had recently arrived at JPL, to help him find out. They picked a test case—a 1970 trip to Mercury, using a gravity maneuver around Venus—for a detailed feasibility study. One major concern—some naysayers even thought it would be a showstopper—was navigation, a problem Minovitch had never addressed in any detail. If a spacecraft missed its target point at the first planet even slightly, it could be hurled off in the wrong direction. (When Mariner 10 used the technique, each mile of error at Venus would have translated to a thousand-mile miss at Mercury.) The key was being able to hit your aim point exactly. Cutting and Sturms not only showed that the navigation requirements were well within the state of the art, they produced a whole mission profile, complete with launch dates and energies, flight times, and aim points. True to Minovitch's premise, they found that the gravity assist at Venus reduced fuel requirements—by a whopping 70 percent. Instead of needing a big, expensive rocket to reach Mercury, as conventional wisdom argued, you could get there with a modest Atlas-Centaur and some help from Venus.

Cutting's group started calling itself the Cheap Missions Office. Bourke, who later headed JPL's advanced studies group, sees Cutting and Sturms' work as a watershed in the development of gravity assist. Before their report, he says, "the whole multi-planet trajectory business was thought of as kind of a curiosity but not a practicality." With an actual mission profile on the shelf, people began to think, *My God, maybe we could actually do this.*

Minovitch was still working summers at JPL, but not on the Venus-Mercury mission study. Although Cutting had included his name on a list of team members, Minovitch was more interested in extending his already massive compendium of gravity assist possibilities. He came up with gravity-boosted manned missions to Mars and outer solar system missions, including the Voyager opportunity later found independently by Flandro. The list just kept getting longer.

Ironically, after all those hundreds of hours Minovitch spent learning FORTRAN and punching in planetary position data and hauling printout paper around in the back of his car, his custom-built program got little use at JPL. The lab's programmers tried but found it too idiosyncratic. The programs they developed were faster and more efficient and produced perfectly useful trajectories.

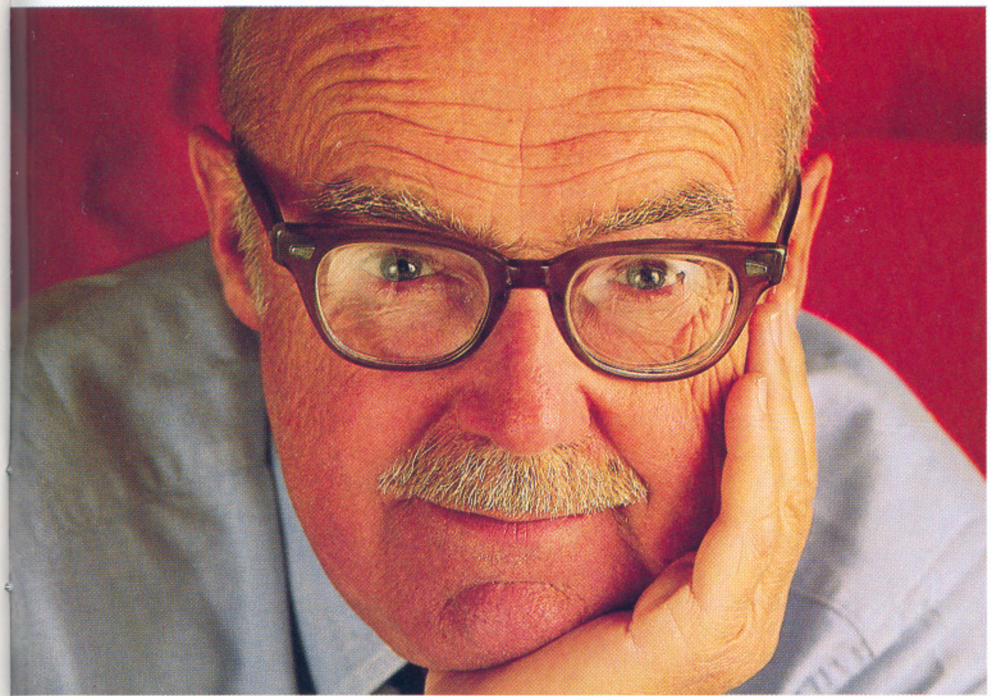
When Cutting and Sturms published their findings in 1964, the idea of gravity assist was still a novelty. (At a professional society meeting the following year, they had to attach a disclaimer saying that neither JPL nor NASA had endorsed the mission.) But by decade's end the concept was established enough to be included in a real project. In 1969, NASA approved a Venus-Mercury mission with a cut-rate price of $98 million. The launch was set for November 1973. By the time Mariner 10 radioed back its last burst of data in March 1975, it had visited Venus once and Mercury three times, giving NASA more bang for the buck than any planetary project up to that time. By then practically every mission on NASA's drawing board—the Pioneers, the Voyagers, and later the Galileo exploration of Jupiter and its moons—relied heavily on gravity assist to reach its destination.

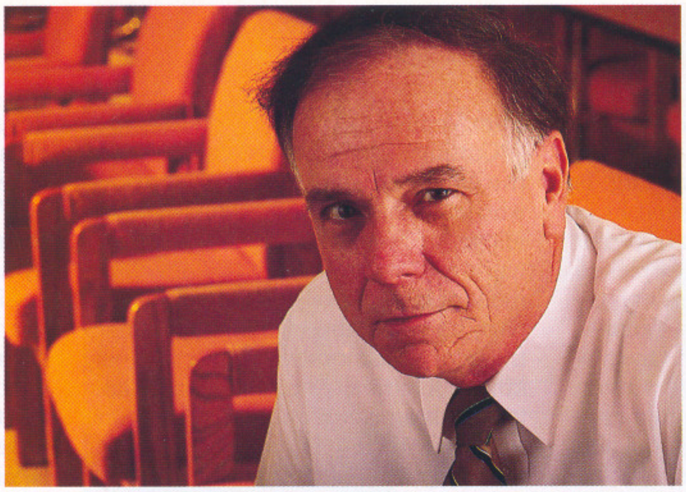
After Minovitch earned his Ph.D. from the University of California at Berkeley in 1970, he returned periodically to JPL to work on various assignments. In 1972 he was awarded the NASA Exceptional Service Award for his contribution to the development of the gravity assist concept.

And that's around when the trouble started.

Minovitch felt slighted at having been passed over for a more prestigious citation (he was later angered when Clarke applied for a joint monetary award). What's more, he became increasingly concerned about what he saw as a deliberate attempt to downplay his role in discovering gravity-assist propulsion.

In 1974, the year Mariner 10 reached Mercury, he threatened to sue JPL over statements made by Clarke and others to University of Kansas historian Norriss Hetherington, who planned to publish a paper in a professional journal on the origins of gravity assist. Minovitch challenged statements in the paper suggesting that it was a natural result of ongoing work at JPL, not a unique idea. The episode touched off an internal inquiry at JPL, caused a blizzard of memos and letters between Hetherington and Minovitch, between Clarke and his bosses at JPL, between everyone and




RICH MAYS

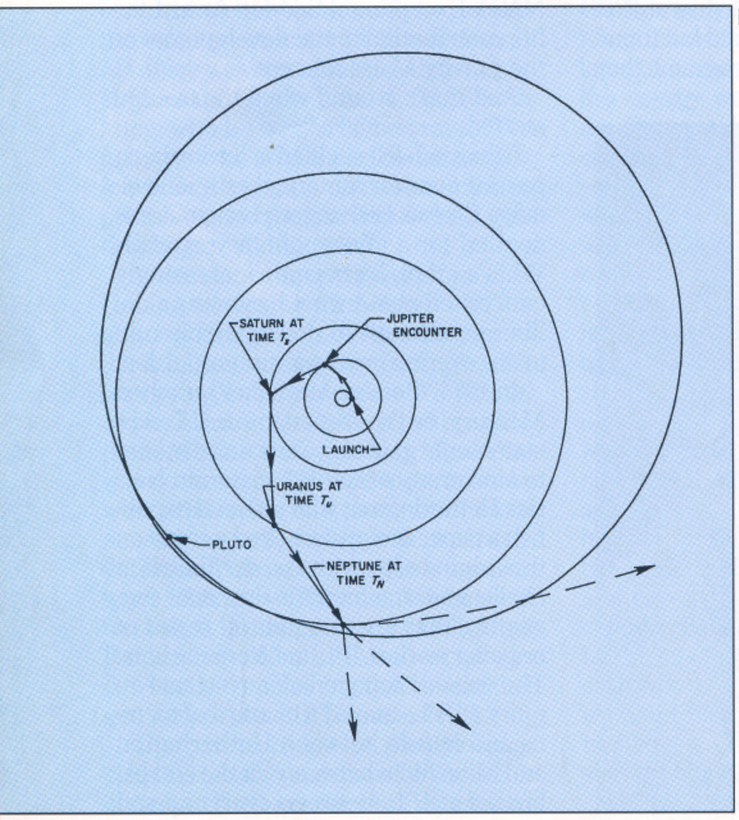
One trajectory Minovitch discovered was a gravity-assisted tour of the outermost planets. Later known as the Grand Tour (below), the trajectory was discovered independently by JPL's Gary Flandro (left) and used by the Voyager spacecraft.

everybody. Hetherington and the journal backed off, not wanting to get involved in a lawsuit.

So who *did* invent gravity assist? John Niehoff of Science Applications International Corporation, who started working on trajectory design in the early 1960s, states flatly, "Mike was the first person in the Space Age to recognize and demonstrate the utility of planetary gravity fields in spaceflight." But, he adds quickly, "The problem I have with Mike is that he has consistently been unwilling to acknowledge the contributions of anyone but himself."

Certainly there were others before Minovitch who had been aware of the concept, who had even started thinking about its application to spaceflight. Ask the people who were working in the field of astrodynamics in 1961, and they'll tell you it was just a matter of time before someone looked into the problem as deeply as Minovitch did, that gravity assist was an evolutionary development, not a single person's invention. Fran Sturms, who thinks Minovitch's contribution was critical, says nonetheless, "He seemed to think that his early idea was so fundamental that it was something world-class. I have a little trouble with that. It's the kind of thing that happens around here all the time. There are a lot of smart people who work here, and people are always coming up with new concepts and ways to do things."

Minovitch's cantankerousness probably makes it harder for others to give him the sole credit he wants. William Kosmann, a former JPL mission planner who collaborated with Minovitch on two papers delivered to the International Astronautical Federation in 1990 and 1991 that told his version of the story in exhaustive detail, admits that Minovitch's personality can put people off. When Kosmann, a much younger man, was working on the Voyager mission in the late 1980s, he decided to find out who had invented the ingenious technique that made it all possible. Kosmann determined to his own satisfaction that Minovitch should get most of the credit, and wrote a chapter in the JPL-produced *Voyager Neptune Travel Guide* saying as much. He also arranged to get Minovitch invited to JPL for the 1989 Neptune encounter, the first time anyone had thought to ask him to one of the flybys. After a meeting with Voyager project officials and a photo session, Minovitch says, "I had tears in my eyes for two months."



JPL

Minovitch, who left JPL for the last time in 1972, started a business in Los Angeles called Phaser Telepropulsion, Inc., published a couple of papers on laser-powered rocket propulsion, and eventually got into a minor dispute over who should get credit for *that* concept—Minovitch or Arthur Kantrowitz of Avco Corporation. But the last few years have been kinder. There was the Neptune invitation and the two IAF papers, and then, in 1992, a segment on the PBS television series "Space Age," including footage of his boyhood, that extolled Minovitch as the man who opened up the solar system. Now he says he wants to leave all the rancor behind him.

But it doesn't take much to get him riled up again, to get him talking vaguely of lawsuits and investigations by the National Academy of Sciences if people don't tell the story the way he'd like it told. He wants peace, but on his own terms.

As for the other participants, most of them say they don't care who gets the credit. Clarke, who has left JPL, says he can hardly stand to talk about it anymore. The controversy of 20 years ago left every participant with a sour taste that still lingers.

Some aren't even aware that it's been a matter of controversy. Derek Lawden is the British mathematician who wrote about the practical benefits of planetary gravity back in 1954; asked what he thinks about Minovitch's place in history, Lawden has to rack his brain. "Who?" he asks.

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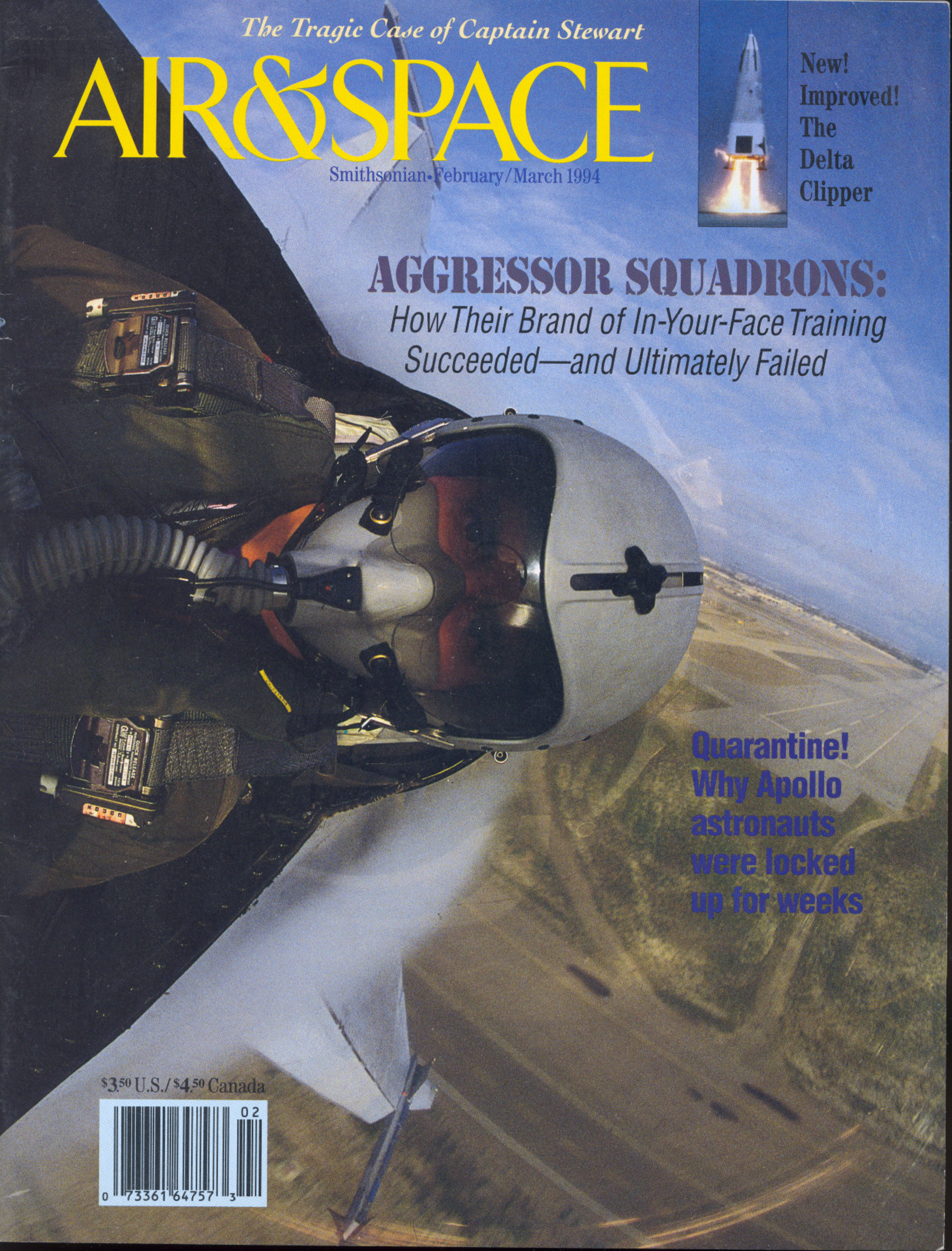

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