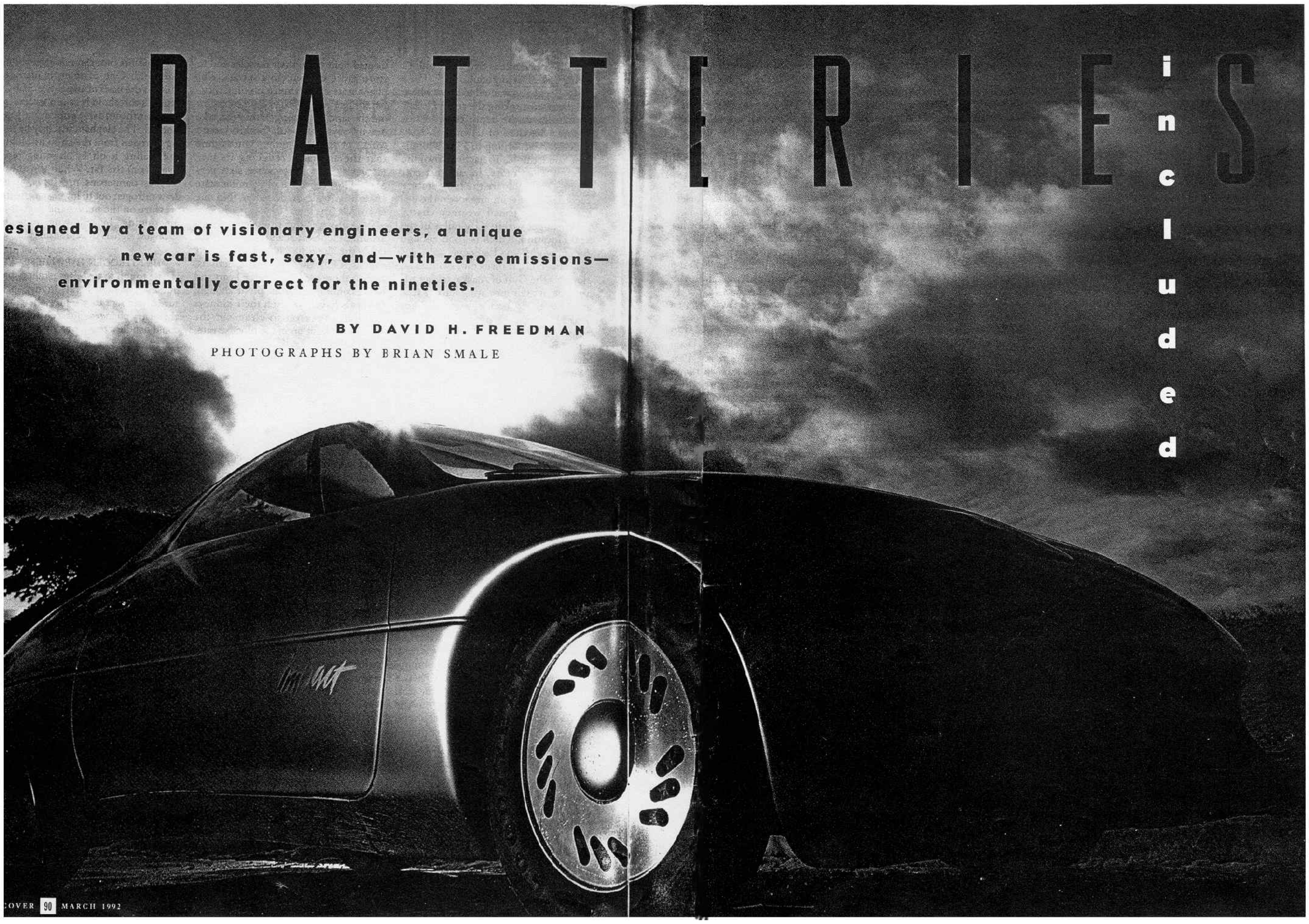
BATTERIES included

esigned by a team of visionary engineers, a unique new car is fast, sexy, and—with zero emissions—environmentally correct for the nineties.

BY DAVID H. FREEDMAN

PHOTOGRAPHS BY BRIAN SMALE



"EVERYONE IS LOOKING FOR THE GIMMICK, THE GADGET, THE SPECIAL

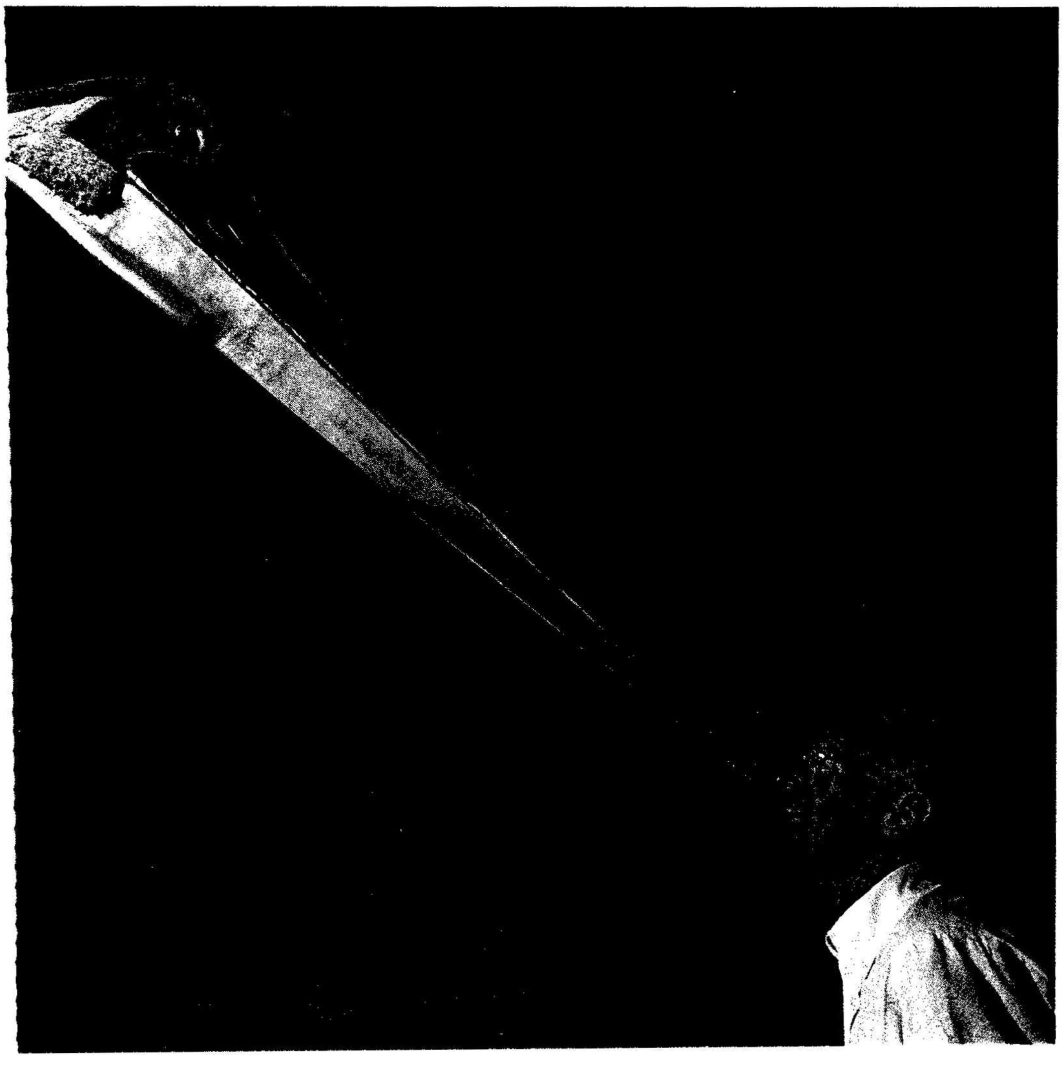
SITTING IN HIS SPACIOUS OFFICE, UNDER the watchful stare of a giant pterodactyl head mounted on the wall behind his desk, Paul MacCready is recounting the virtues of his 1988 Buick LeSabre. "It's reliable, it has good acceleration, and it's reasonably comfortable," he says in his rumbly monotone. "It gets me from point A to point B."

To those who know him, such a glowingly practical assessment of what is—let's face it—a pretty ordinary car would hardly be surprising. MacCready is, after all, a Caltech-trained engineer with zero tolerance for useless frills. He is also a straight-arrow businessman who founded two modestly successful technical companies, as well as a guy who enjoys stopping at the Caltech faculty club on the way to his corporate digs at seven in the morning (after having already put in two hours of work at home) for a bowl of All-Bran.

But how to explain the whimsy of his prehistoric officemate, the pterodactyl? No problem. That's the handiwork of another MacCready who happens to inhabit the same body: the sky's-the-limit inventor who parlayed a preternatural talent with model planes into Da Vinci-like human- and solar-powered vehicles that shattered the world's notion of the limitations of such machines, the passionate naturalist who gets teary-eyed talking about the monarch butterfly and the sooty tern, the easygoing fellow who accessorizes his blazer, tie, and gray slacks outfit with black sneakers.

This 65-year-old walking study in contrasts has now pulled off the biggest contradiction of all. Tapping the sponsorship of none other than lumbering, financially troubled General Motors and blending it with the skills of some of the most innovative, daring engineers in the vehicle business, MacCready has driven his small company to design and build a car that many observers think will make the biggest splash since the '65 Mustang, and maybe even since the Model T. It's fast, it's sexy, and it's being rushed into mass production. Oh, by the way—it's powered by batteries.

Words like *fast* and *sexy* generally aren't issued in the same breath as *electric car*, except perhaps to describe what electric cars aren't. But the unveiling of the GM Impact prototype in 1990 demolished such conventions. This flashy two-seater not only outclasses the Mazda Miata in the curves of its body but on asphalt curves as well, accelerating from 0 to 60 in 7.9 seconds, with a top speed of 110 mph. And it goes 120 miles on an eight-hour charge that costs a little more than a gallon of gas—double the range of most electric-powered competitors, and eminently suitable for the Impact's intended use as an urban-suburban commuting vehicle.



Paul MacCready stares down his most whimsical machine—a flying robotic pterodactyl.

The big automakers have been trying to build a winsome electric car for decades without success. Where did MacCready's engineers work their magic? It wasn't with batteries; the Impact runs on lead-acid units much like the ones in ordinary cars (albeit 32 of them). They eschewed exotic, ultralight body materials for plain old fiberglass. And they allowed no tradeoffs in creature comforts: the Impact has plenty of room for its two occupants and it sports all the trimmings, including a stereo system and air-conditioning.

MacCready sighs when asked about the secret to the Impact's astounding specs. "Everyone is looking for the gimmick, the gadget, the special ingredient that makes the Impact succeed," he drones. "There isn't any. This worked because of something that isn't easy to describe or glamorous. It worked because of systems engineering."

REDIENT THAT MAKES THE IMPACT SUCCEED. THERE ISN'T ANY."

It's enough to make one suspect that MacCready takes masochistic pleasure out of appearing boring. The Impact *is* a product of superb systems engineering—that is, the precise orchestration of a range of technical disciplines. But it's more than that. The Impact is the ultimate beneficiary of MacCready's secret passion, a passion that colors every element of the car from its eccentric profile to the last of its ball bearings. The passion is for efficiency—the ability to move a vehicle between two points with the least possible expenditure of energy.

MacCready's pursuit of efficient motion dates back to his childhood in New Haven, much of which was spent building model planes out of balsa wood from his own designs. Later he turned to piloting sailplanes—fragile, engineless aircraft so aerodynamically efficient that they can keep several hundred pounds of plane and pilot aloft on less than one and a half horsepower's worth of lift. Never one to follow through on anything halfway, MacCready became world soaring champion in 1956.

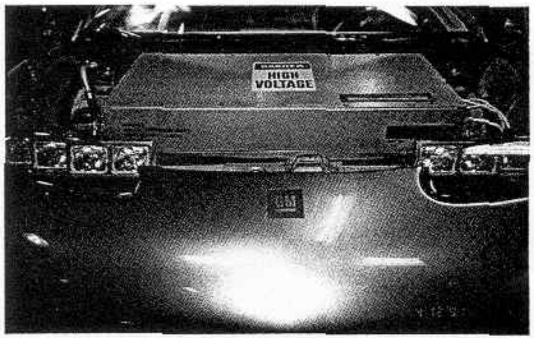
By that time he had a Ph.D. in aeronautical engineering from Caltech and had decided, reluctantly, to go into business for himself. "I would have liked to work for a larger company," he says, "but I couldn't find one that was interested in the same things I was."

His first company, Meteorology Research, focused on meteorology and cloud seeding and gradually grew to 120 employees before he sold it in 1965. In 1971 he founded a new company called AeroVironment, intending to combine his old love of aerodynamics with a growing interest in the environment. Specifically, MacCready helped corporate clients devise creative solutions to hazardous-waste problems ("Sludge can be as exciting as anything else," he declares) and for other clients came up with various vehicle designs intended to move efficiently through the air—or, in the case of a one-man scuba propulsion unit, the water.

Tucked away in suburban Monrovia, a short freeway hop east of Los Angeles, AeroVironment grew from a three-person operation to a company that now employs 200, including several dozen engineers. They come from an odd assortment of disciplines and have turned out designs for an even odder assortment of objects: custom-made blimps, remote-controlled surveillance planes, propellers for the windmills on California's "wind farms," and drag-reducing fairings for trucks. But even after starting his new company, MacCready was still restless. He realized what was missing in 1976 when he read about the Kremer Prize.

In 1959 British magnate Henry Kremer had offered £50,000 to the first team to achieve human-powered flight on a figure-eight course around two poles half a mile apart. A number of groups had built pedal-powered planes for that purpose, but none had come close to grabbing the prize. No matter how sleek and streamlined the aircraft, the human pilot couldn't put out enough power. Only a superhuman, it seemed, could keep a plane moving fast enough to generate the lift needed for sustained flight. MacCready struggled with the problem awhile, then followed his favorite technique when stumped: he promptly put it out of mind.

Weeks later, while he was watching a bird soaring and banking, he began wondering how it made its turns; obviously it was staying aloft at low speed using very little power. MacCready started doing calculations, and then it occurred to him that the bird had shown him the key to winning the prize. "I recognized that a giant wingspan combined with a negligible total weight would work much better than elegant aerodynamics," he recalls. "It's an awfully simple formula in hindsight, but if I had been with a large aircraft company I never would have figured it out. It was my lack of experience combined with a breadth of knowledge from having done things on my own that enabled me to see it."



Under the hood there's no transmission, no engine. The box is a power inverter that weighs only 60 pounds.

The result of this insight was *Gossamer Condor,* a flimsy, ungainly contraption fashioned out of aluminum tubing, balsa wood, piano wire, and high-tech plastic wrap. It had a whopping 96-foot wingspan and weighed all of 70 pounds. In 1977, skimming the floor of California's San Joaquin Valley under the power of pedaling pilot Bryan Allen, *Gossamer Condor* earned MacCready the Kremer Prize.

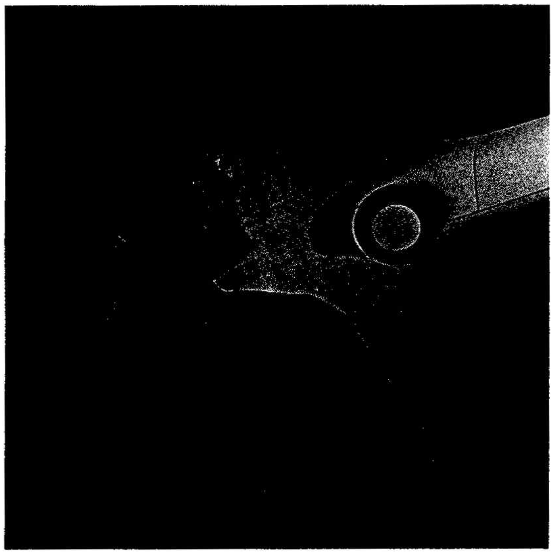
He was just getting warmed up. In 1979 a second plane called *Gossamer Albatross* copped a different Kremer Prize for being the first human-powered plane to cross the English Channel. Another Kremer prize for speed fell to MacCready's *Bionic Bat*, which was pedaled to a blistering 26 mph. In 1981 the sun-powered *Solar Challenger* flew 163 miles from Paris to the English coast. MacCready even constructed a flying, remote-controlled, half-scale model of a pterodactyl that flapped its wings under the power of 13 electric motors. (The head in his office came off a mock-up of the flying version.) He had been amazed by a fossil he had seen in a museum and, being an incurable model builder, had talked the producers of a movie being made about natural and artificial flight into funding his robotic pterodactyl.

MacCready now brought his growing mastery of vehicle efficiency back to Earth. During the 1980s he helped organize new competitions for human-powered vehicles—one notable bicycle built for two, called Vector, cruised a 40-mile stretch of freeway at nearly the speed limit, averaging better than 50 mph. Then in 1987 MacCready got a

"NO ONE HAD EVER TRIED TO BUILD A SUPEREFFICIENT CAR

call from an old Caltech classmate at Hughes Aircraft. Would AeroVironment, which by then had nearly 100 employees, be interested in helping Hughes and parent company General Motors compete in a 1,950-mile solar-powered car race across Australia? MacCready called the Hughes vice president in charge of the project, Howard Wilson, and agreed to help. As it turned out, one of MacCready's young engineers—Alec Brooks, a fanatic about human-powered vehicles—had already sketched plans for a car that could compete in Australia before shelving them for lack of resources to build it. Suddenly Brooks found himself in charge of the project, sponsored by GM.

With only seven months until race time, Brooks, MacCready, and Wilson went all out. The result was a 365-pound car that looked something like a flounder on bicycle wheels but was capable of moving at 50 mph on less than two horsepower, thanks to a near-complete absence of mechanical friction and a minimum of air friction. "When you've been working with vehicles that you power with your own legs, you learn to develop a real sensitivity for how well that power gets used," explains MacCready. Sunraycer, as the car was called, won the race, beating the nearest competitor by two and a half days. As one measure of its satisfaction with AeroVironment's efforts, GM bought 15 percent of the company. "GM couldn't care less whether that investment increases by a factor of ten or drops to zero—they spend a million dollars a minute," says MacCready. "The point of the investment was to establish a cultural connection."



Alec Brooks headed the team that got sports car performance out of little more than golf cart technology.

Buoyed by the success of Sunraycer, Brooks began to wonder in early 1988 if there wasn't some way to convince GM to apply a tiny fraction of its vast resources toward a far more ambitious project than anything AeroVironment had ever tackled: a production electric car. Brooks was enamored of the technical challenge, Wilson knew the people to talk to at GM, and MacCready encouraged the idea. After a long string of slightly kooky projects, he felt that AeroVironment was finally in a position to make a real impact on everyday transportation. "The fuel savings from an efficient car would be enough to power all the world's airplane fleets," says MacCready. "Buckminster Fuller called it the 'trim tab' effect: it's the idea that you can apply an itty-bitty force at the helm and end up moving an ocean liner."

The three knew they wouldn't be able to talk GM into backing an electric car without providing a convincing reason why they could succeed where so many others—including GM itself—had failed. After all, the AeroVironment engineers would face the same obstacle that had short-circuited the other efforts: the sad state of battery technology. Though carmakers and others had poured tens of millions of dollars into battery research, even the most costly power cells have trouble putting out enough power to briskly accelerate a typical car. Ford's premier electric vehicle, for example, a minivan loaded with high-output sodium-sulfur batteries, takes a painful 14 seconds to climb to 50 mph. "Batteries provide one percent as much power per weight as does gasoline," says MacCready. "From that point of view they're a terrible power source."

But just as with *Gossamer Condor*, MacCready and company would be looking at the problem in a different way. Instead of trying to find better batteries to put in a standard car, their approach would be to put more or less standard batteries in a better car—that is, a car that would get more performance out of the limited power. "No one had ever tried to build a superefficient car from scratch," MacCready says. That's because no one had ever needed to. Energy has always been cheap and pollution controls are relatively recent, so automakers have never needed to pay fanatical attention to efficiency. "This was going to be a real culture shock for GM," says MacCready. As it turned out, it would be a culture shock for AeroVironment too. "We didn't realize how big a job it was to engineer a real car," says Brooks.

To verify their off-the-cuff thinking, MacCready, Brooks, and crew took a closer look at the efficiency of a typical car. What they found was a blast furnace on wheels. By the time the energy in gasoline has been converted into useful work, the average car has thrown away fully 85 percent of it in the form of heat. First of all, the heat of combustion escapes with the exhaust or is pumped out through the radiator. More energy is wasted as friction heats up the engine and transmission. The soft, fat tires of a typical car get hot as they squish against pavement. Then there's air resistance; a car actually heats the air as it fights its way through. Finally the brakes get hot: in a typical mix of urban and highway driving, half the energy that makes it into forward momentum is ultimately squandered through braking. "Most of the gasoline we use goes to stirring up air and making brakes hot," intones MacCready.

Brooks, MacCready, and company were convinced they could build an electric vehicle that would zealously guard enough of this ordinarily misspent horsepower to the point where batteries could provide the necessary

ROM SCRATCH. THAT'S BECAUSE NO ONE HAD EVER NEEDED TO."

juice. First of all, they knew an electric car doesn't waste heat through combustion. The local electric company performs that service far more efficiently when it burns fossil fuels in its big generators; the car stores only the residual electrical energy in its rechargeable batteries. The main concern would be frictional losses through the powertrain and wheels, as well as the energy lost fighting air resistance. As for braking, the engineers felt it was mostly unnecessary—they had a less wasteful plan for slowing the car.

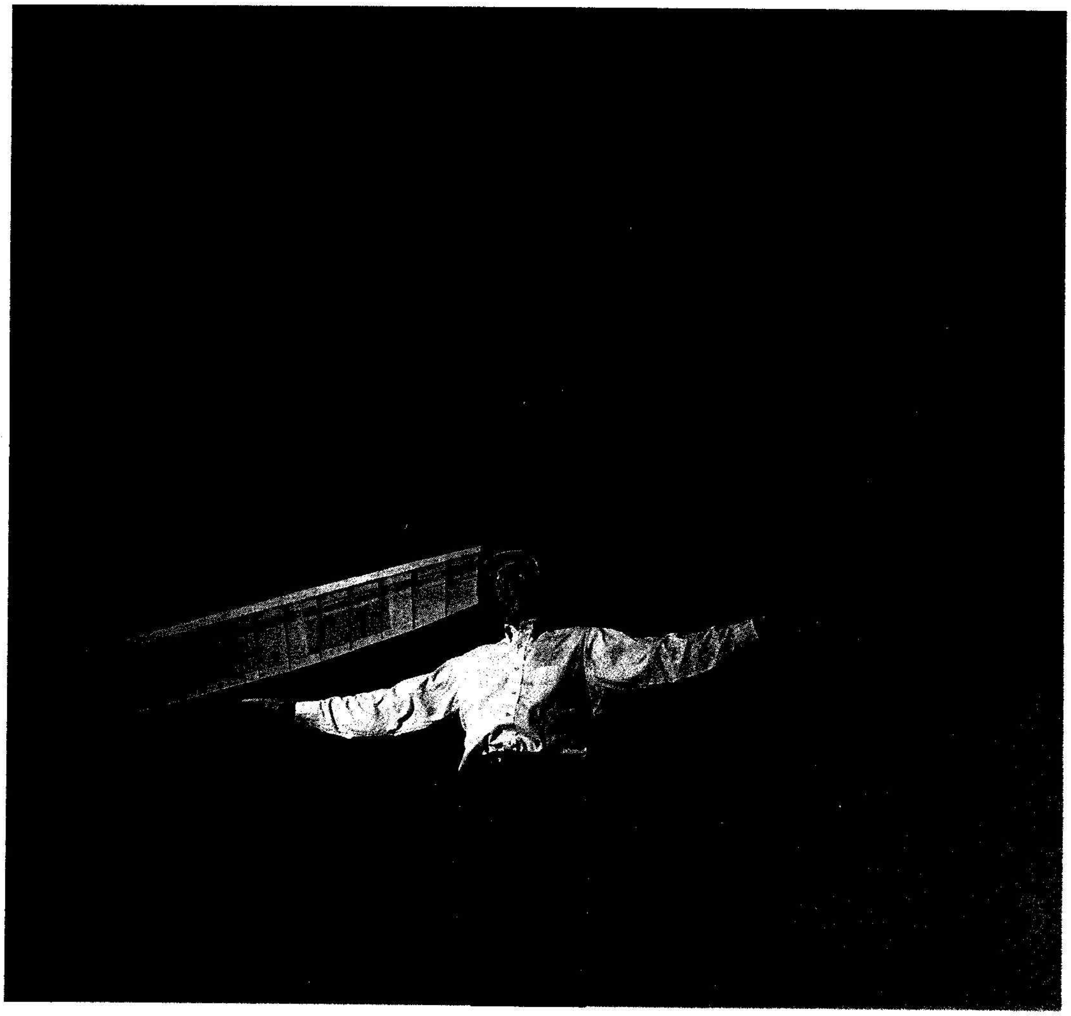
As with AeroVironment's previous wonder machines, weight reduction would be a key element; the less stuff there was to move, the less energy it would take to bring it up to speed. It's not that other cars are obscenely heavy; a typical subcompact weighs in at an electrically movable 2,500 pounds or so. But when you add 1,000 pounds of batteries, you've got a problem.

The team set a goal of 2,050 pounds, complete with batteries. That kind of weight had been achieved in experimental electric vehicles with tubular frames and paper-thin bodies, but MacCready wanted "a real car that does real things." In other words, a car that could be made of standard materials and put into mass production. "All the marvelous techniques people have come up with for making electric cars work don't do any good because they can't be made cheaply in large quantities," he says. "The only way to have an effect on this country is to get at least a hundred thousand cars produced."

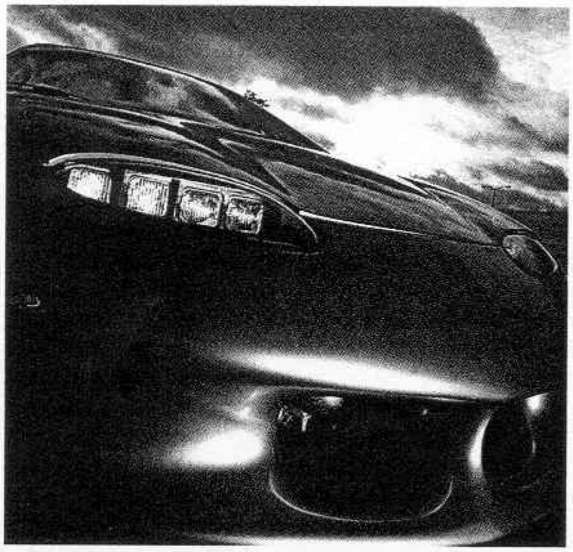
Aerodynamic slipperiness would be another key factor. Here the team set a goal of a .19 drag coefficient, a number that indicates how much wind pressure a given shape must overcome when it's moving. In theory a perfectly flat, unstreamlined object—say, a square plate—has a drag coefficient of 1.00. By combining a low drag coefficient with a small cross-sectional area, AeroVironment engineers hoped to give the Impact 80 percent less drag than a 1930s car and 50 percent less than one from the 1990s.

And MacCready's crew was confident they could do it. For one thing, they knew that carmakers had never been forced, like airplane designers, to completely subjugate styling to aerodynamics. "Who cares if an automobile has lots of drag? Gas is cheaper than bottled water," MacCready points out. Besides, carmakers worry that buyers will reject any design that seems eccentric. So Detroit and its international competitors build cars that look aerodynamic but that to a large extent pander to the public's misconceptions. "People think rocket-ship shapes are efficient, so the car companies add long, sloping hoods with sharp corners that create turbulence," says MacCready. How did the AeroVironment engineers plan to get GM's stylists to go along with a daring departure from popular designs? "Our trump card," MacCready says, "would be one that no automobile designer ever had: an absolute need for aerodynamic efficiency."

The AeroVironment team tacked on one more key goal: the acceleration of a sports car. That wasn't important from a practical point of view, but MacCready knew that a healthy dose of old-fashioned muscle would be a marketing coup for a product that would be fighting the perception that electric cars are wimpmobiles. "Instead of having to make apologies for its performance, we wanted to have something to brag about," says MacCready. Calculations revealed that given the vehicle's target weight, achieving a modestly spine-pressing acceleration of 0 to 60 in 8 seconds would require a power plant that



A featherweight propeller got MacCready's solar-powered plane from Paris to the English coast.



could put out 110 horsepower—nearly twice as much as Chrysler packs into its experimental electric minivan. They definitely weren't talking golf cart.

AeroVironment showed GM a formal proposal in the summer of 1988. "If someone else had submitted the same idea, they probably wouldn't have gotten very far," says MacCready. "But we had already hit a home run for them with the Sunraycer, so we had that credibility. We also had learned how to talk to them." Apparently so. The proposal quickly got a green light from then chairman Roger Smith.

"MOST OF THE GASOLINE WE USE GOES TO STIRRING UP AIR AND MAKING BRAKES HOT."

Wasting no time, the AeroVironment group split into teams, each one working closely with GM's experts, and with Alec Brooks as coordinator. The first group to get to work was the outer-body team, which combined MacCready's top aerodynamicists with stylists from GM's famed Advanced Concepts Center in Newbury Park, California. Not surprisingly, AeroVironment's efficiency-obsessed engineers quickly found themselves butting heads with GM's sales-minded designers.

The AeroVironment crew knew that ultralow drag has little to do with a narrow-at-the-front, rocket-ship look. "What really slips is a dolphin shape," explains MacCready. In other words, you don't want to knife through the air; you need to part it with a bulbous front end—"it doesn't matter how wide it is"—and then ease the air ever so gradually back together again, letting it hug a long, tapering tail until it reaches a knifelike *rear* end. It's a shape that's almost the opposite of the paradigm revered by car designers and the public. In fact, notes MacCready, some American cars probably have a better drag coefficient when driven backward.

Brooks and his engineers kept rejecting the GM styling team's ideas as too draggy, while the GM group vetoed AeroVironment's offbeat shapes. The GM designers, for example, wanted a long, rakishly slanted windshield that would have added nothing to slipperiness but would have allowed sunlight to flood the interior, increasing air-conditioning requirements. AeroVironment's engineers, meanwhile, tossed around ideas that even they admit looked silly, including one with a long pointed tail. Relations between the two groups grew ugly, and a top GM executive had to fly out from Detroit to knock heads.

After a steady stream of designs that the GM people converted to one-third scale models and lugged into Caltech's wind tunnel, the AeroVironment team finally came up with a shape that narrowed at the back just enough to score the sought-after .19 drag coefficient while managing to retain the serious sex appeal the stylists were after. "There was blood on the floor," says MacCready, "but in the end we had something everybody was happy with." One trick that helped was a gently curving underbody instead of the tailpipe, transmission, and fluid pans normally found under cars. "Car companies don't make the bottom aerodynamic because people don't see it," explains MacCready. "But the air sees the bottom of the car just as much as it sees the top."

Meanwhile, the group working on the chassis and interior were struggling to keep weight down. No component escaped scrutiny. "We brought an airplane-design culture to the process, which is very different from the car-design culture," explains MacCready. "It may seem silly to worry about four extra ounces on a strut, but if you don't, then all those four ounces add up and by the time you're finished you have two hundred thirty-five extra pounds, and your car is slow."

To avoid that fate, the group cut holes in unseen panels and shaved every possible millimeter of thickness off every part, maintaining rigidity through careful design instead of bulk. GM's Delco subsidiary pitched in with an aluminum-encased radio and speakers incorporating ultralight magnets. The team shrugged off GM's request for large, sporty-looking wheels, opting instead for smaller, narrower versions that weighed less and created less air drag and rolling friction. And because smaller wheels spin faster, they required less of a gear reduction to match their rotation to that of the motor, saving on gear weight and friction.

The powertrain team started with a decision to use an AC motor instead of the DC motors found in most electric vehicles. DC motors have heavy electromagnets that are mounted on a shaft and turned by heavy, permanent magnets stationed in a circle around the shaft. AC motors, on the other hand, have a relatively lightweight rotor surrounded by a ring of light electromagnets that change their magnetic poles as the direction of current flow changes, creating a rotating magnetic field.

The problem is that batteries put out not alternating current but steady, unchanging direct current. A power inverter can make the conversion to AC, but a typical inverter with the required capabilities contains about 300 pounds of material: a computer to change the frequency of alternating current as motor speed changes, massive switches, and cooling equipment to dissipate the heat generated by the heavy current. Desperate to get that weight down, the team called in electronic power wiz

Alan Cocconi, who had worked with Brooks and MacCready on Sunraycer. By replacing the bulky switches with smaller, cooler-running transistors, Cocconi came up with a new, digital-chip-based inverter package that tipped the scales at a mere 60 pounds.

The team found a really good way to reduce frictional losses from the transmission: they did away with one altogether. Instead they coupled a 57-horsepower, 50-pound, bread-box-size motor directly to each of the front wheels, connected only by a single gear that allowed the motor to spin 10.5 times faster than the wheel. At top speeds the motor would be turning at 12,000 rpm, a rate that would threaten to melt down a friction-laden internal combustion engine. At a more typical 6,000 rpm, still much higher than in highway driving with gas-powered engines, AeroVironment's AC motor would be right in the middle of its prime powerband territory.

The group knew that no matter how efficiently the powertrain brought the car up to speed, precious energy would go up in brake-pad smoke every time the car was slowed. To salvage some of that energy, the team added a "regenerative" braking system: when the driver's foot is removed from the accelerator, the electrical connections are reconfigured so that instead of electricity going from the batteries to turn the motor, the motor generates electricity that flows back through the inverter to recharge the batteries. In a sense, the road passing underneath the wheels plays the role of a river for a hydroelectric plant. When the system is engaged, the rotating wheels keep the motor turning, but the rotor now fights against the surrounding magnetic field rather than being turned by it, so the car slows down. The car's momentum, instead of being grabbed by high-friction brake pads and thrown away as useless heat, is mopped up in the form of electricity that replenishes the batteries.

For drivers who find the downshifting-like sensation disconcerting, a knob on the instrument panel allows reducing or even eliminating the regenerative braking. But most drivers come to find it preferable to ordinary braking, claims MacCready. "After a while," he says, "you start to treat the regular brakes like emergency brakes."

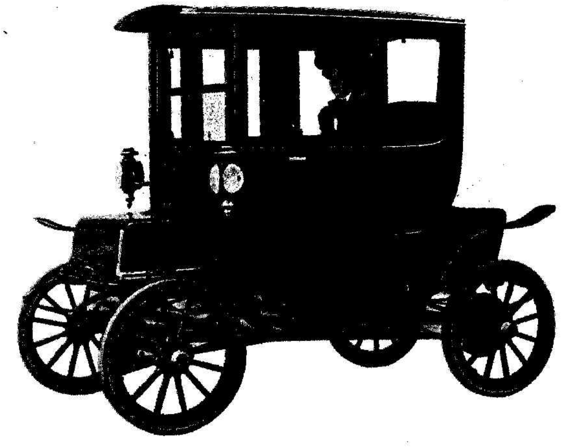
By August of 1989, despite the progress that different teams were mak-

An Intensifying Electric Field

THE GM IMPACT may be the odds-on favorite to become the first electric car to win a mass market, but there's no lack of rivals. In fact, just about everyone seems to have some sort of electric vehicle in the works.

Both Chrysler and Ford, for example, have built electric versions of their minivans. Ford's, which boasts the innovation of a motor built around the rear axle, is slated to go into production in the latter half of the decade. Although these electric vans can't touch the Impact's quickness or range, their roominess and otherwise conventional design may give them an edge with some buyers. These vans, along with the Impact, should eventually benefit from the better batteries expected to emerge from a battery research consortium that Detroit's Big Three recently set up.

Needless to say, it would be a serious mistake to count the Japanese out of the race to build a better electric car. Nissan seems to have the lead there, having already shown off a sluggish but snazzy-looking prototype boasting a nickel-cadmium battery that can be fully recharged in a mere 15 minutes—but only from a special, high-power source. Mitsubishi and Daihatsu have also announced aggressive programs. (But GM is hoping to turn the tables on the Japanese for once, having pointedly mentioned that the Impact will be produced in a right-side steering version—the Japanese, like the English, drive on the left.) Europe too is eyeing the market; electric car contenders there include Volkswagen, BMW, Audi, Fiat, and Peugeot.


THE 1908 KIMBALL ELECTRIC WAS A STYLISH HORSELESS CARRIAGE.

Nor is the field limited to the conventional car manufacturers. Canada's Vehma Corporation produces an electric version of a GM van, while the Eaton Corporation in Troy, Michigan, offers a Chrysler minivan conversion. And Clean Air Transport in Sweden recently won a $7 million subsidy from the City of Los Angeles to start selling its $25,000, 75-mile-per-hour electric sedan next year. In a few years, the budget- and fashion-conscious among us may even have a Swatch Car to consider; SMH, the Swiss manufacturer of the ubiquitous Swatch timepieces, has announced plans to develop an electric car with Volkswagen's help.

Smaller, "boutique" electric car efforts abound. Tiny Solectria in Waltham, Massachusetts, for example, markets an electric version of GM's Geo Metro. And the Vehicle Research Institute at Western Washington University is employing a modest $250,000 grant to implement its provocative design for a solar-powered electric car incorporating a small gasoline or natural-gas burning engine to extend its range. "My belief is that hybrid vehicles will be in much wider use than pure electric cars," says Institute director Michael Seal.

GM isn't sure it disagrees; it has hedged its bets with a hybrid prototype of its own. Indeed, many observers insist that, at least for the next decade or so, the best way to reduce air pollution and cut down on oil consumption is to come up with cleaner-burning gasoline and more efficient gasoline engines. That's already happening. Instead of adding its name to the long list of electric car wannabes, Honda recently unwrapped a prototype for a gas-burning two-seater that gets 100 miles to the gallon. And Arco Oil has developed a gasoline that significantly cuts emissions—though it has no intention of marketing the stuff until pending clean-air laws force consumers to put up with the fuel's higher cost. Don't hold your breath. Or on second thought, maybe you should. *—D.H.F.*

BETTMANN ARCHIVES

ing, Brooks saw that the myriad challenges of turning bright ideas into working machinery had put the project behind schedule. The body team was still making molds, and the chassis and powertrain hadn't yet been assembled and tested. When Brooks reported to GM that there was no way the car would be rolling by the original goal of the end of the year, GM responded that it had already arranged to unveil the Impact in fully functional form on January 3 at the Los Angeles Auto Show, one of the industry's mega-events. "I felt that goal was practically impossible," says Brooks. "But all I could do was assign the teams individual deadlines that were all equally impossible."

"WHO CARES IF AN AUTOMOBILE HAS LOTS OF DRAG? GAS IS CHEAPER THAN BOTTLED WATER."

The groups started working late into the night, and sometimes into dawn, seven days a week. Then in late October the body team delivered the finished shell to the powertrain and chassis teams. For all of November the teams labored together in an enormous shop north of Los Angeles, almost without stop, to fashion the major components into a complete car. Finally on November 28 the crew lined up to cheer as the still-doorless Impact was taken on its maiden voyage around the AeroVironment parking lot. "It drove beautifully," said Brooks. "The only thing we couldn't get to work right was the windows. They were mounted on tracks and everything, but they just didn't roll up and down right."

There was no time to worry about the windows. The car was immediately whisked via truck to GM's proving grounds outside Phoenix for a battery of road tests. There the AeroVironment teams watched in horror as the Impact accelerated well—and then died before going very far. Its range was pathetic. Then one of the engineers realized that the powertrain was swimming in oil, thanks to an overfilled gearbox. After a quick draining the Impact stunned everyone with its performance; not only did it leave a Miata and a Nissan 300ZX in its dust in a head-to-head, standing-start race to 60 mph, but even when cruising at highway speeds it retained enough kick to press a driver into the seat when the accelerator was stomped—a benefit of its high-rpm, gearless powertrain. "By the time an ordinary car going sixty downshifts into the right gear to accelerate," says MacCready, "the Impact is already in the passing lane moving ten miles an hour faster."

There was something decidedly eerie, though, about all these impressive tests: the car's almost total silence as onlookers watched it winding out and tearing up the track. Being electric, it barely whirred.

The Impact stole the show in L.A.; three months later GM announced it would begin manufacturing a production version of the car sometime "in the mid-1990s." GM was being cautious; the company had let out word of similar intentions for a different, far less impressive electric car a few years back but had never followed through. This time, however, it appears to mean business.

Although GM refuses to set a specific target date, some industry watchers are predicting a 1996 introduction for the Impact—long enough to give GM a chance to do the necessary fine-tuning, but soon enough to give the company a running start at meeting tougher vehicle emission laws slated to take effect in 1998. So far things seem to be moving apace; GM has announced that the Impact will be assembled at the Lansing, Michigan, plant that had been the home of the ill-fated Reatta—the sporty Cadillac that was recently discontinued—and has assigned to various GM divisions the jobs of producing the major components.

It helps, of course, that the Impact was specifically designed for mass production. AeroVironment insists on calling it a "demonstrator" rather than a "concept" car, which is just a showpiece to gauge public reception. Yet the car that AeroVironment actually delivered to GM was, after all, only one vehicle, obviously a very labor-intensive one. MacCready cautions that GM will make many compromises to get the design to be as factory-friendly as possible. "Mass production is a whole different ball game, and it's GM's ball game," he says. "We'll probably be advising them along the way, but they'll be deciding what changes to make." It's not a prospect that fills everyone at AeroVironment with joy, but it's necessary, of course, if the car is ever to have the impact that MacCready and crew originally envisioned.

As for what the Impact is likely to cost when it does roll off the assembly line, MacCready professes ignorance there too. "I don't know how they'll calculate pricing," he says, "but I imagine they'll sell it way, way, way below cost." Subsidizing Impact sales would make it easier for GM to meet increasingly stringent pollution and gas mileage requirements on automaker fleets and would help the company develop the market it would need to justify designing and building other, more profitable electric cars.

Actually, MacCready predicts that the big market in the coming decade or two may not be so much for all-electric cars as for hybrid cars designed to run on batteries in pollution-choked cities and on gasoline—or natural gas, or ethanol, or hydrogen, or some other range-extending fuel—on long highway trips (though the way Americans drive now, 90 percent of all car trips fall within Impact's 120-mile range). AeroVironment is rumored to be working now on a hybrid car for GM, but MacCready won't confirm or deny it. The impetus for such cars is building, especially since Los Angeles declared its intention to become a "zero-pollution" car zone, meaning that electric cars will have to make up an increasingly large portion of all new-car purchases in the city beginning with 1999 car models. Nine eastern states and the District of Columbia have already enacted legislation that follows the Los Angeles lead.

Whether or not MacCready is working on a hybrid car for GM, he lets out that whatever it is, the project is relatively "far-out." He claims he has no choice. "Our contract with GM specifically states that we are expected to occasionally fail," he notes. It may be the only clause in the contract he violates. D