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EFFICIENCY IN THE WIND: AERODYNAMICS

Reduced coeffient of drag is the light at the end of the tunnel . . .

Ten years ago, there were three people doing aerodynamic work at Chrysler Engineering. The results of their efforts were probably the slipperiest cars ever to roll over an American highway at the time, but those automobiles didn't deliver very good fuel economy. They were the awesome, high-winged Plymouth Superbird and Dodge Daytona, designed primarily for flat-out racing at Daytona and other superspeedways.

"After that died," says Gary Romberg, Chrysler's manager of packaging and aerodynamics, "the nucleus of the group began to look at applying the science to street cars. Fuel economy was not very important in those days, of course, but wind noise, crosswind stability and some other factors were." Aerodynamics, however, remained a fairly low-priority item until shortly after the fuel crisis of 1974.

Then the government came along with its corporate average fuel economy (CAFE) law, and the industry began to take another look at aerodynamics. There are three basic things an automaker can do to improve a vehicle's fuel economy: reduce its weight, change its powertrain components, or lower its body's aerodynamic drag as it moves through the air.

"Aero turned out to be the most cost-efficient way," says Romberg. "It seemed we had a very fertile field to plow." Obviously, the job can't be done with aerodynamics alone as the CAFE requirement climbs from 18 mpg in 1978 to a technically frightening 27.5 mpg for 1985, but there is no question that aerodynamics will play a major role in meeting those difficult standards in the years to come.

Suddenly Detroit has become very serious about aerodynamics. Manufacturers have hired a lot of experts in the field, many from the aircraft industry, and have booked an increasing amount of time at the few available wind tunnels in North America. Both GM and Chrysler have adapted small tunnels of their own, previously used for engine cooling studies, interior ventilation work and the like, to handle car and truck scale model testing. And GM, in the fall of 1977, resumed construction of a huge, new wind tunnel adjacent to its Design Center at the GM Technical Center in Warren, Michigan, which had been started in January, 1974, but then delayed for financial reasons during the slow car sales years of '74-76.

"Until a few years ago," says Ford Motor Company's vehicle aerodynamics chief engineer Jim Chabot, "there really was no quantitative data as to how much aero contributed to fuel economy. So we conducted some tests with easily installed and removable aerodynamic devices, and we found that there were definite effects as low as 30 mph, distinct gains at 40 mph and substantial improvements at 50 mph. In fact, at a 50 mph steady cruise, a 20 percent reduction in wind drag gave a 10 percent improvement in fuel economy." Because most driving isn't done at steady-state highway speeds, it turns out that a 10 percent drag reduction results in a 2 percent gain in EPA composite (city/highway) economy.

Wind drag is primarily a function of how freely air can flow over a given surface. Where there are blunt edges or obstructions on the surface, the airstream breaks away and curls back upon itself, creating drag-producing turbulence. There is also a high degree of turbulence where air flows off the rear end of a body moving through it and has to fill in the "dead" space behind. Therefore, purely from the standpoint of drag, the ideal aerodynamic shape is a smooth tear-drop tapering to a point on its trailing edge.

On the other hand, the ideal shape

U.S.A

By Gary Witzenberg

for packaging people and cargo inside a body with the minimum exterior size is the so-called "three-box design" . . . one box up front for the mechanicals, another in the rear for luggage, and a third, larger box between them for the people. Boxes, however, aside from being unattractive, also offer imperfect aerodynamic characteristics. The trick is to discover an acceptable compromise between pleasing appearance on one hand and efficient interior packaging on the other, and then modify its shape with minor changes to achieve the best possible aerodynamics within those dual constraints.

Total drag on any given vehicle is a combination of air density, speed, the body's total frontal area, and the aerodynamic efficiency of its shape. Engineers have no control over the first, or the second, and the third factor is pretty much dictated by the vehicle's size, so drag reductions are achieved primarily by subtle shape and contour alterations arrived at through many tedious hours of wind-tunnel work.

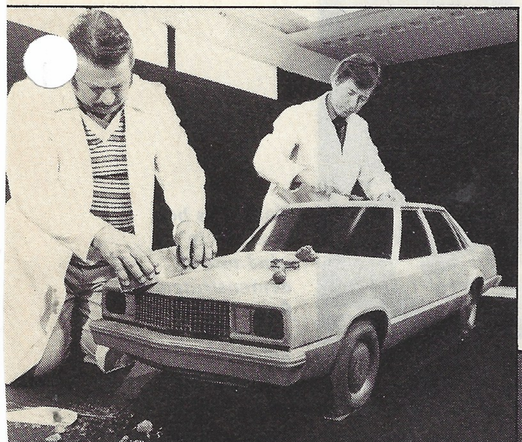
In the early stages of design, once overall size and basic appearance of a particular vehicle have been determined, scale models molded of clay are taken to the tunnel and fastened at the wheels to sensitive balance pads that measure forces in every direction as air is forced past the body at high speed by huge fans. In a very large facility such as Lockheed's tunnel in Marietta, Georgia, these fans are turbine-powered, while Chrysler's tunnel at its Chelsea, Michigan, Proving Ground, for example, has a 12.5-foot, 16-bladed fan powered by a 600-hp electric motor. This system is capable of moving 670,000 cu. ft. of air per minute and can simulate wind velocities of up to 120 mph for full-sized vehicles, and 150 mph for 3/8-scale models. GM's multi-million-dollar tunnel, which should be operational by mid-1980, will have a test area 70 feet in length and a cross-section more than 25 times the average car's frontal area to allow simultaneous testing of several vehicles in conditions closely approximating a real-life highway environment.

In simplified terms, a vehicle's drag coefficient (Cd) is the ratio of its resistance to airflow to that of a flat plate of the same frontal area. Thus a Cd of 0.5 represents a shape with approximately half the wind drag of the theoretical flat plate, and the measurement is independent of vehicle size. Both a large van and a small, subcompact car, for instance, could have a coefficient of 0.5, but the total drag of each would be its coefficient times its total frontal area. "Cd is a dimensionless number that allows you to compare an elephant to a mosquito," explains Kent Kelly, staff engineer in charge of aerodynamics at GM's engineering staff.

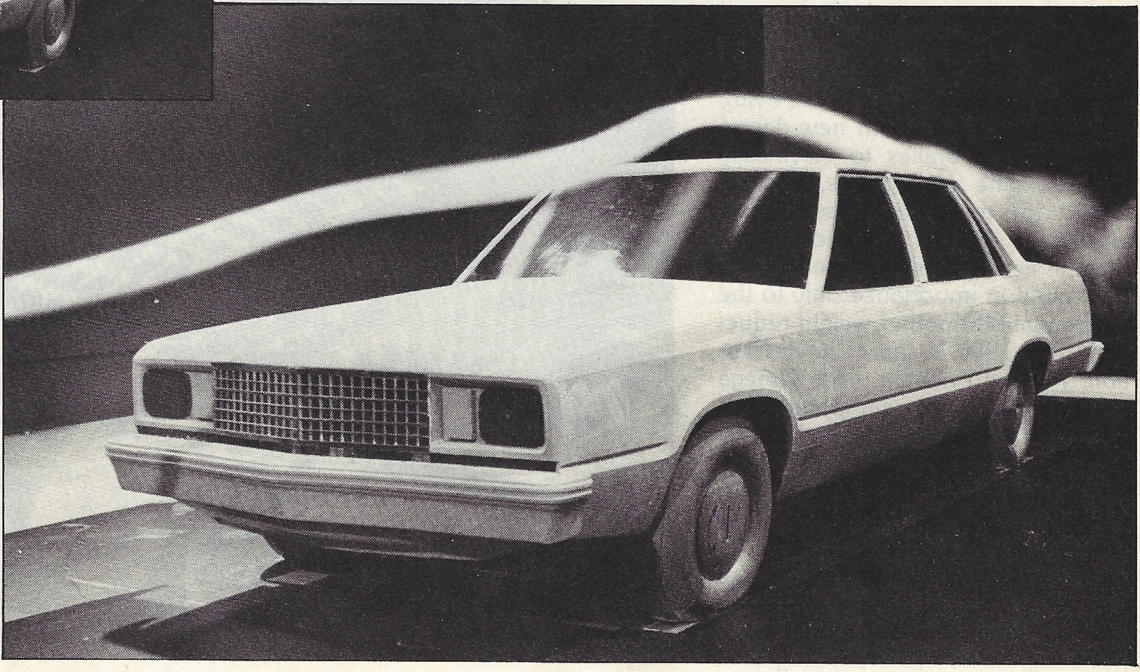
A few years ago, the average U.S. car was in the 0.6 Cd range—not too swift as compared with the average European car of the day—but now cars are down around 0.5 and getting better all the time. Unfortunately, Cd numbers are not directly comparable between manufacturers, because there are large differences in tunnel facilities, test procedures and the application of mathematical correction factors to the test data.

Both European and Japanese Cd numbers tend to run lower than those produced in the U.S. Porsche, for example, claims an excellent 0.35 for its sleek 924 Turbo sports car, while Mazda reports its RX-7 sports car, 626 coupe and 626 sedan at Cd numbers of 0.36, 0.39 and 0.42, respectively. On the other hand, Ford spent some 136 hours in the wind tunnel honing the 1979 Mustang's shape to a Cd of 0.44, but Jim Chabot says the identical car came in at 0.38 in tests conducted in England.

Each carmaker has its own specific organization for carrying out aerodynamic work on its products. With the most vehicles to deal with and the most money to spend, GM has the largest number of people involved,



Above, Ford design sculptors prepare 3/8ths scale model of a Fairmont. Right, the model is wind tunnel tested. Smoke shows airflow and turbulence.



from Kent Kelly's aero group at the engineering staff to individual product chief designers and design assistants at Design Staff (formerly Styling) to a variety of product planners and engineers at the five car divisions and Fisher Body Division. Along with clay modelers, technicians and other specialists, these people work together to aero-tune a given design, using first 1/4-scale models, later full-sized clay and fiberglass models, and eventually complete prototype vehicles. GM is currently spending more than 2000 hours per year on wind tunnel work, about half of which is full-scale testing in the Marietta, Georgia, Lockheed facility—at more than $900 per hour.

"There are now aero objectives set for each product the same as there are weight and interior packaging objectives," says Kelly. "It's relatively easy to streamline a car," he adds, "but the challenge is to integrate all the other requirements, such as divisional identity, packaging and pleasing appearance in the process. The lowest-drag vehicle, if it's not appealing to the public, is not going to do anyone any good sitting unsold in the showroom."

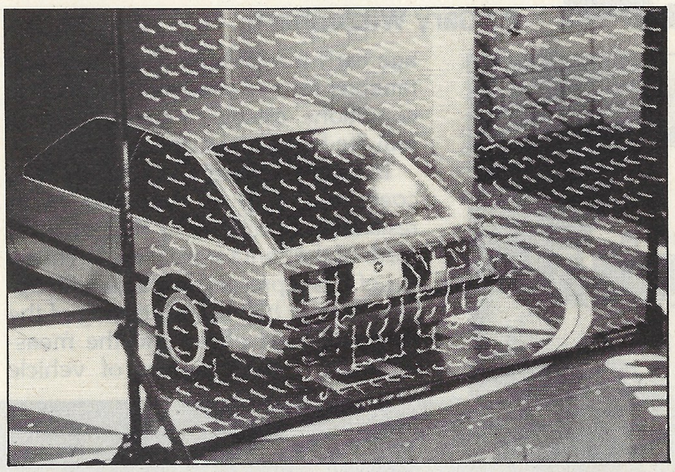
GM's first new-product program involving aerodynamics as a major consideration from the earliest design stages was the front-drive compact "X-car" development effort, and the result was a total drag improvement (Cd times frontal area) of some 24 percent, as compared to the larger, rear-drive compacts the X-cars replaced. Their lowered drag coefficients alone (not counting the smaller sizes and more efficient powertrains) are credited with a 1.2-mpg improvement in EPA composite ratings and an impressive 3.6-mpg boost in real-life expressway mileage. While every X-car component, from new-design low-drag disc brakes to electrically driven engine cooling fans, was designed for maximum possible fuel efficiency, the contribution from "clean" aerodynamics turned out to be second in importance only to the substantial 800-pound weight reduction. The 1980 X-cars (Chevy Citation, Pontiac Phoenix, Olds Omega and Buick Skylark) as a group spent some 600 hours in the wind tunnel and have Cd numbers ranging from 0.417 to 0.466, depending on individual styling and body type. These compare to a range of from 0.459 to 0.578 for other family-type cars that GM has tested.

The largest GM family cars, while not designed for minimum drag from the beginning, recently have undergone a subtle facelifting to improve their aerodynamics from 8 percent (Oldsmobile 88 and 98) to 14 percent (Buick LeSabre). Lower hoodlines with "softer" leading edges, higher rear decks with upraised, spoiler-like trailing edges, more squared-off rooflines, more rounded fender shapes and flatter wheel covers, all contribute to the improvement—which translates to about one mile per gallon improvement in highway economy. In coast-down tests, used to measure actual "road-load" horsepower required to move a vehicle, 1980 full-sized Chevrolets coast 30 percent farther than their 1979 counterparts—partly due to new high-pressure, low-rolling-resistance radial-ply tires, but largely as a result of a reduction in drag coefficient from 0.50 to 0.45.

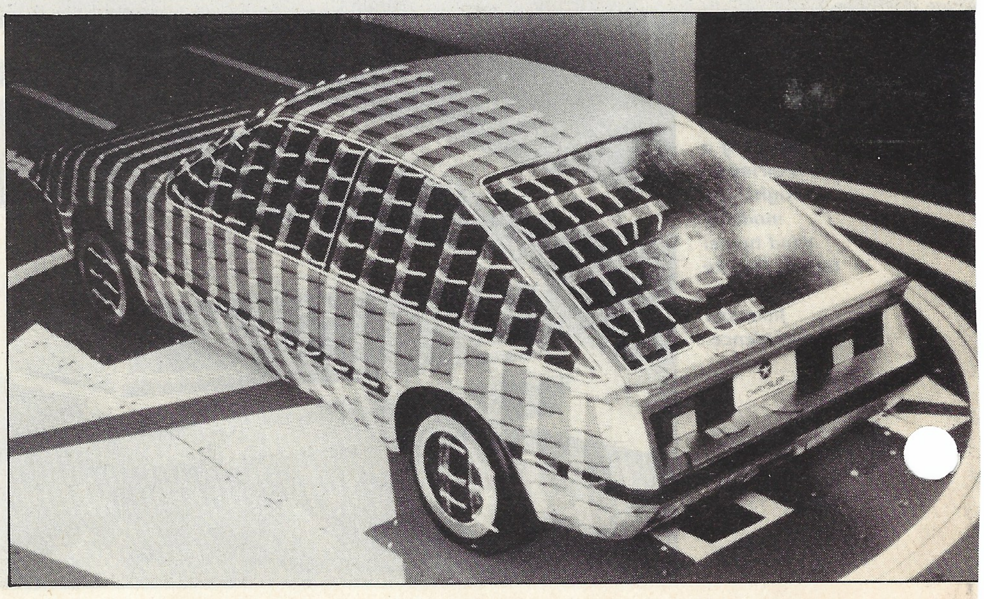
Ford Motor Company currently has more than 50 people in the aerodynamics department at its Design Center, headed by a group of aero engineers (some with masters' degrees) under Jim Chabot. Scale model work is done mainly at a University of Maryland tunnel, while full-sized testing takes place at Lockheed's Georgia facility. Chabot prefers not to discuss dollar figures, but he does say that Ford's aero work expenditures have increased tenfold between 1973 and 1977, and another 2.5 times since then—to the point at which constructing a company tunnel has suddenly begun to appear as a smart investment, even at a cost to Ford of $20 million or more.

Some 400 hours of wind tunnel work went into the 1980 Ford Thunderbird design alone, with similar efforts directed toward smoothing the contours of Lincoln-Mercury's new Cougar XR-7, and Lincoln Continental and Mark VI luxury cars. In the T-Bird's case, the final configuration (at 0.44 Cd) turned out 14 percent more "slippery" than the 1979 model and a whopping 24 percent better than the first 1980 model that was tried in the tunnel.

The big Lincoln's wind drag was



Yarn tufts behind car in wind tunnel demonstrate airflow. Below, yarn strips affixed to body indicate smooth flow.



smoothed 22 percent and the Mark VI's 14 percent from their initial designs.

"There are very important gains to be derived from aerodynamics," says Chabot, "and much of it is free. Just doing a grille header one way instead of another, for example, can make the difference between attached flow and separated flow, and nearly all drag is created by separation, or turbulence, from the vehicle's surface. Design changes made on the cars as a result of wind tunnel testing are usually slight, sometimes only a matter of millimeters in curve or width on the edge of a hood, a grille opening or a pillar. Add-on devices such as a seal between the grille opening panel and the hood, let's say, can have a significant effect for a small added cost—maybe $1 per car. Most items give only a 1 to 3 percent improvement, so a total aero program consists of a lot of these little things adding up to a substantial benefit."

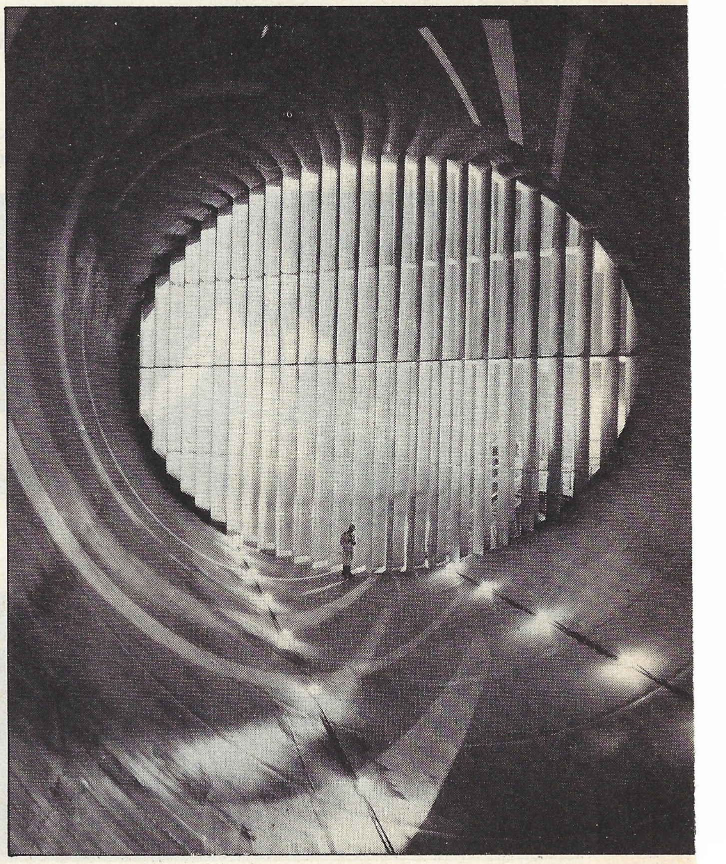
Chrysler, for its part, boasts the most aerodynamically efficient car built in America . . . the Rallye version of its Dodge Omni 0-24 coupe, which achieved a very respectable Cd of 0.395 in comparison tests conducted last year at the Canadian National Research Council wind tunnel in Ottawa, Ontario. Contributing to the sleek hatchback's slipperiness (and that of its Plymouth Horizon TC3 counterpart) are its low hood and sloping nose, "chin" and rear deck spoilers, fastback roofline, windshield pillar contours, close-fitting "flag-style" outside rear view mirrors, and even the grille opening shape, which is a close compromise between engine cooling and aerodynamic considerations.

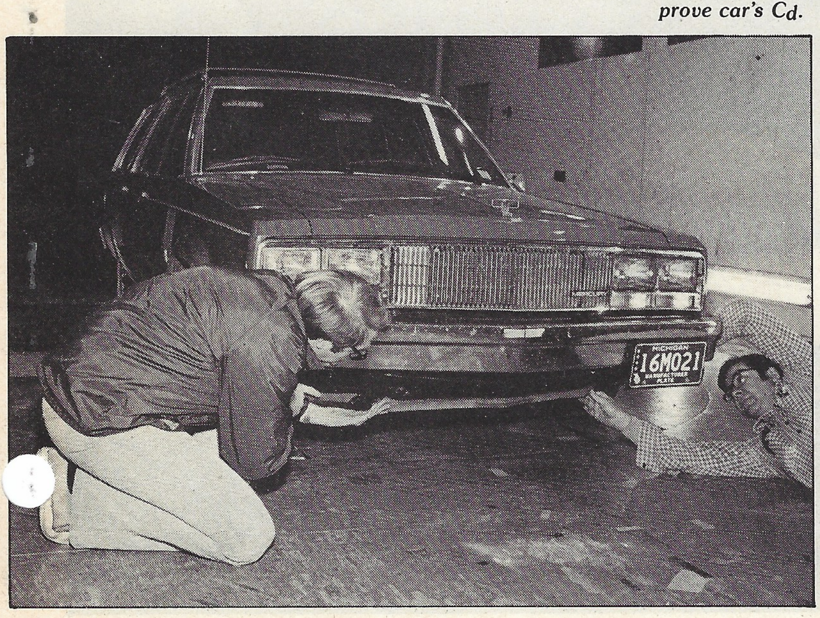
Gary Romberg's group of aero specialists, still small but growing fast, is attached to Chrysler Engineering, but works very closely with the Design people. "Recommendations are often jointly made," he explains. "We're not at odds with the stylists at all, because aero is more in tune with attractive styling than most any other facet of engineering." Chrysler uses its own Chelsea facility for 3/8-scale model work and the Marietta Lockheed tunnel for full-sized car testing.

Romberg laments that, while there is a provision to factor aerodynamic efficiency (based on coast-down tests) into EPA fuel-economy ratings, his group's accomplishments are "reflected more in real life than in the EPA numbers, which is a sad state of affairs because we don't get proper credit for the job we do. As you bring a car's coefficient down from, say, the mid 0.5s, the first 10 percent improvement is easy—high-school kids could do it—but the second 10 percent is tougher and the next increment gets extremely difficult, especially since the aesthetics must be right. Seeing the 0-24 come down to be the lowest-drag domestic car was very satisfying for us," he adds. "I think we're very close to state-of-the-art, and we're monitoring it very closely."

American Motors hasn't done much wind-tunnel development in the past, both because of its sometimes tight money situation and because its small cars were already fairly fuel efficient. Recently, however, AMC has joined the Big Three in booking tunnel time at Marietta, and in designing aerodynamic slipperiness into its future products. "It's a very important facet of designing cars," says Design vice president Dick Teague, "and we're into it with both feet on all our programs, including Jeeps. At the moment, it's kind of an inexact science, but it will get more exact very quickly in the next few years." AMC's first major program, involving a new Jeep vehicle scheduled for introduction in two or three years, consumed some 55 hours of tunnel time between April and September of 1979. It was headed by Bill Metcalf, an advanced powertrain staff engineer with experience in compressible fluids, who had been pushing for establishment of a serious aero program for a couple of years before he got the go-ahead to do it.

The country's newest automaker, Volkswagen of America, has no wind tunnel facilities and does little aero work here, but its parent company





Right, VW's huge wind tunnel deflector duct is 45 feet in diameter. Below, Ford engineers make front end changes to improve car's Cd.

boasts the world's largest climatic wind tunnel at its headquarters city of Wolfsburg, West Germany. Long in the business of building small, fuel-efficient vehicles for distribution in Europe and other parts of the world far more gas-conscious than North America, VW conducts extensive aero development on all its products, which is one reason VW has always maintained an excellent reputation as fuel savers.

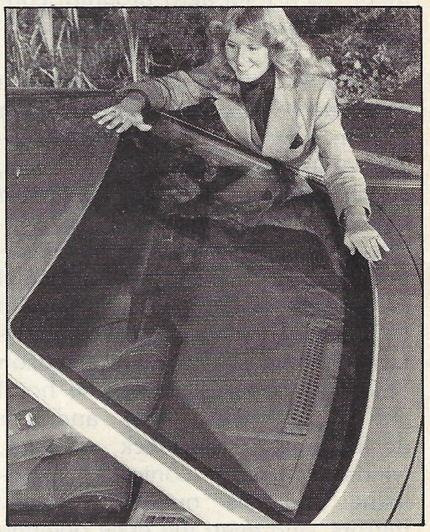
Aided by computer technology and such space-age methods as three-dimensional surface recording through electronic light probes, automakers here and abroad are fast advancing the science of vehicle aerodynamics. The wind-tunnel balance pads accurately measure "headwind," side, lift, roll, pitch and yaw forces on the vehicles, and sophisticated scale model testing provides feedback on quickly accomplished clay surface changes accurate to within 2 percent of the effects on full-scale vehicles.

Not only a vehicle's exterior shape, but also its underbody, underhood and interior airflow characteristics are important to its wind resistance, and therefore its fuel economy. Conversely, aerodynamic studies are useful in optimization of engine cooling, interior ventilation, wind-rush noise, crosswind stability and handling, and even to control the deposition of dirt on side windows and taillamps. Tufts of yarn or spots of dyed oil on the surface indicate flow and separation patterns, while smoke from a moveable "wand" gives a visual representation of airflow over body contours.

When GM begins using its own new tunnel later this year, its aerodynamic programs will be streamlined considerably. People will walk instead of fly to the tunnel, and models will be rolled back and forth underground instead of shipped with great care and at great expense to Marietta. The event will be welcomed also by other automakers because it will free a great deal of time at the Lockheed facility, which has been booked a year or more in advance in recent years. If Ford, too, builds a tunnel as planned, the burden on the few existing facilities will be lightened even more, giving smaller automakers greater opportunity for development and probably lowering tunnel rental costs as well.

A glance at the future is provided by a Ford concept car called "Probe I," the designers of which consider it to have an ideal aerodynamic shape. It is a three-door hatchback about the size of Ford's current Mustang and Capri, with comfortable accommodations for four adults and a near-incredible drag coefficient of 0.25. Although it has a large, low flush-mounted windshield with no pillars, plus some other features not likely to be practical at least in the next few years, it does provide some very interesting food for thought.

Clearly, the automakers are dead serious about aerodynamics—they have to be—and they're spending a great deal of time and money in tuning their new products' shapes, not only to satisfy the government's tough CAFE standards, but also to better compete in an increasingly fuel-conscious American market. As applied to land vehicles, the science has advanced rapidly in the past few years, and what has emerged so far is just the tip of the proverbial iceberg. Experts predict that aero improvements will contribute about two-miles-per-gallon toward meeting the 27.5-mpg CAFE standard for 1985, and there's no question that they will play an increasingly important role in the future. **MPG**



Right, flush-mounted windshield on GM car reduces wind drag.

Below, Ford concept car, Probe I, has an ideal aerodynamic shape.