DRAG QUEENS

FIVE SLIPPERY CARS ENTER A WIND TUNNEL; ONE SLINKS OUT A WINNER.

by **DON SHERMAN**
photography by **MARK BRAMLEY**

ENS

LIKE A THIEF IN THE NIGHT, WIND RESISTANCE IS A STEALTHY INTRUDER THAT SAPS YOUR SPEED AND MURDERS YOUR MILEAGE WITHOUT LEAVING FINGERPRINTS. THE GENTLE MURMUR OF AIR STREAMING OVER, UNDER, AND THROUGH YOUR CAR BELIES THE WIND'S HEINOUS WAYS.

Even if there's no alternative to driving through Earth's atmosphere, we can at least fight wind resistance with science. Aerodynamics—the study of air in motion—can lift our top speeds, curb our fuel consumption, and, if we're smart about it, keep our tires stuck to the pavement.

Long before automotive engineers fretted over aerodynamics, aviation pioneers defined the basic principles of drag and lift. Inspired by birds and airships, early speed demons also toyed with streamlined shapes. The first car to crack 60 mph (in 1899) was an electrically propelled torpedo on wheels called, hilariously, "La Jamais Contente" ("The Never Satisfied"). Grand Prix racers took up the cause in the early 1920s; the following decade, Auto Union and Mercedes-Benz raced toward 300 mph with streamliners developed in German wind tunnels. Half a century after Chuck Yeager broke the sound barrier in flight, Andy Green drove his *ThrustSSC* a satisfying 763 mph across Nevada's Black Rock desert.

Now it's our turn. *Car and Driver* gathered five slippery cars to study their drag and lift properties at a wind tunnel whose name and location we swore not to reveal. We had two goals in mind: first, to learn the fine points of blowing air over automobiles in a test chamber; second, to determine which brand did the best job optimizing its car's aero performance.

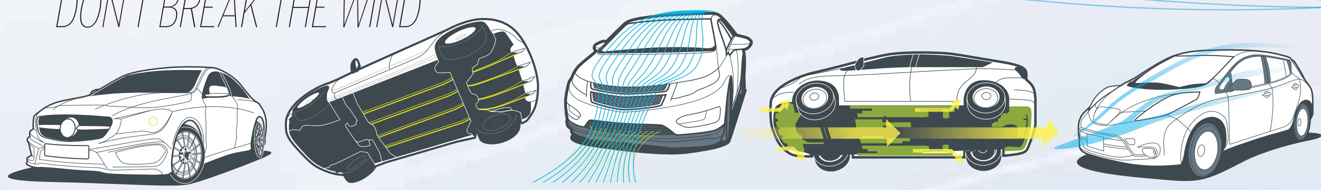
There are reasons why you haven't read this story before. Every major carmaker owns and operates a wind tunnel, but those facilities are busy around the clock, as engineers work to stay ahead of the rapidly rising EPA-mileage tide. Inter-company rivalries are another issue foiling easy access. While manufacturers often tout the slipperiness of their products, comparisons with competitive models are rare.

The expert in charge at our clandestine test location explains: "All wind tunnels strive to accurately quantify the aerodynamics a car will experience in the real world. The vehicle and the tunnel constitute a system with complex interactions. As a result, drag and lift measurements on a particular vehicle can vary from one tunnel to another."

A group of vehicles may rank differently in different tunnels, he says. This is why most manufacturers have so little faith in aero numbers measured outside their own facilities. Coast-down testing, which logs the car's speed as it decelerates, is often touted as the better "real-world" measure of a car's aerodynamic properties. "That may be true in principle, but accurate results are difficult to achieve in practice because variations in wind, driveline temperatures, and tire qualities influence the results. The beauty of wind tunnels is their tight control over variables."

Our winner here will be the car with the lowest drag area, which is the product of the shape's frontal area and its drag coefficient and the true measure of a car's wind-cheating ability [see "A Somewhat Long-Winded Glossary"]. With that, we humbly present our first ever aero comparo.

DON'T BREAK THE WIND



The Mercedes-Benz CLA250's aggressively beveled corners guide air around the side surfaces and into the wake with minimal disruption.

Most modern cars have flat underbody surfaces to minimize turbulence. The Nissan Leaf adds a diffuser behind its rear axle to smooth flow into the wake.

While the Volt smiles at the world with a standard Chevy face, most of its grille is blocked to restrict air entering the engine compartment, cutting drag.

Various covers fill gaps under the Toyota Prius's engine, body structure, and rear bumper. In addition, four small spats nudge airflow around its tires.

The Nissan Leaf's bugged-out headlamps are no styling gimmick. They serve as airflow splitters to direct the wind around the car's side-view mirrors.

ILLUSTRATIONS BY MARTIN LAKSMAN

	CHEVROLET VOLT	MERCEDES-BENZ CLA250	NISSAN LEAF SL (2012)	TESLA MODEL S P85 (2012)	TOYOTA PRIUS
VEHICLE					
BASE PRICE	$34,995	$30,825	$38,100	$93,390	$29,245
PRICE AS TESTED	$35,995	$35,855	$38,290	$100,520	$33,408
DIMENSIONS					
LENGTH	177.1 inches	182.3 inches	175.0 inches	196.0 inches	176.4 inches
WIDTH	70.4 inches	70.0 inches	69.7 inches	77.3 inches	68.7 inches
HEIGHT	56.6 inches	56.6 inches	61.0 inches	56.5 inches	58.7 inches
WHEELBASE	105.7 inches	106.3 inches	106.3 inches	116.5 inches	106.3 inches
WEIGHT	3766 pounds	3374 pounds	3353 pounds	4785 pounds	3180 pounds
POWERTRAIN					
POWERTRAIN	DOHC 1.4-liter inline-4 + AC electric motor, CVT	turbocharged DOHC 2.0-liter inline-4, 7-speed dual-clutch automatic	AC electric motor, single-speed drive	AC electric motor, single-speed drive	DOHC 1.8-liter inline-4 + AC electric motor, CVT
POWER HP @ RPM	84 @ 4800 (engine)	208 @ 5500	107 @ 10,000	416 @ 8600	98 @ 5200 (engine)
TORQUE LB-FT @ RPM	271 @ 0 (motor)	258 @ 1250	187 @ 0	443 @ 0	153 @ 0 (motor)
DRIVEN WHEELS	front	front	front	rear	front
PERFORMANCE					
0-60 MPH	8.8 sec	6.3 sec	10.2 sec	4.6 sec	10.0 sec
1/4-MILE @ MPH	16.7 sec @ 85	14.9 sec @ 95	17.7 sec @ 78	13.3 sec @ 104	17.6 sec @ 79
TOP SPEED	101 mph (governor limited)	133 mph (governor limited)	94 mph (governor limited)	134 mph (redline limited)	115 mph (drag limited)
EPA CITY/HWY	35/40 mpg	26/38 mpg	126/101 MPGe	88/90 MPGe	51/48 mpg
	Performance results from C/D, November 2011.	*Performance results from C/D, December 2013.*	*Performance results from C/D, March 2014.*	*Performance results from C/D, January 2013.*	*Performance results from C/D, July 2009.*
C/D WIND TUNNEL TEST RESULTS					
DRAG COEFFICIENT	0.28	0.30	0.32	**0.24**	0.26
FRONTAL AREA	23.7 square feet	**23.2 square feet**	24.5 square feet	25.2 square feet	23.9 square feet
DRAG AREA (CD X FRONTAL AREA)	6.7 square feet	7.0 square feet	7.8 square feet	**6.2 square feet**	**6.2 square feet**
DRAG FORCE @ 70 MPH	84 pounds	88 pounds	97 pounds	**77 pounds**	78 pounds
AERO POWER @ 70 MPH	16 hp	16 hp	18 hp	**14 hp**	**14 hp**
AERO POWER @ 100 MPH	45 hp	48 hp	53 hp	**42 hp**	**42 hp**
FRONT-AXLE LIFT @ 70 MPH	-15 pounds	46 pounds	-12 pounds	23 pounds	-4 pounds
REAR-AXLE LIFT @ 70 MPH	26 pounds	44 pounds	11 pounds	17 pounds	17 pounds

REFERENCE AERO STARS

	DRAG COEFFICIENT	FRONTAL AREA, FT^2	DRAG AREA, FT^2
1996 GM EV1	0.21*	19.8	4.2
2001 HONDA INSIGHT	0.30	20.1	6.0
VOLKSWAGEN XL1	0.19†	16.1†	3.1

*GM figure †VW figure

A SOMEWHAT LONG-WINDED GLOSSARY

AERODYNAMIC HORSEPOWER The power required to drive a vehicle through the atmosphere (not including driveline and tire-rolling losses). It increases with the cube of velocity, so aero power at 100 mph is 2.9 times the power requirement at 70 mph.

DRAG AREA The product of the drag coefficient and frontal area is the best measure of any car's aero performance because it's directly proportional to the horizontal force measured in a wind tunnel and experienced on the road.

DRAG COEFFICIENT (CD) A dimensionless parameter used to quantify aerodynamic efficiency in the horizontal (drag) plane.

FRONTAL AREA The largest horizontal view of a car. We used a 200-mm camera lens positioned 150 feet from the vehicle to take a digital photo, which we analyzed using Siemens Solid Edge CAD software.

LIFT Air flowing over and under the car and through the grille can diminish wheel loading and, in extreme cases, deteriorate handling. Air dams and spoilers are effective countermeasures.

WIND RESISTANCE (DRAG) A force proportional to the drag area, it increases with the square of the vehicle speed.

STREAMLINES Wind-tunnel operators add small quantities of smoke to the airflow to reveal how the wind moves around, under, or through the test vehicle.

5. NISSAN LEAF

Drag Area= 7.8 ft²

The Leaf is the boxiest shape we wheeled into the wind tunnel, and it has this test's second-largest frontal area at 24.5 square feet. Combined with a 0.32 drag coefficient, that yields a 7.8-square-foot drag area. This is a reasonable figure for a five-passenger wagon and only 30 percent greater than the two-seat, bullet-shaped 2001 Honda Insight we brought along and tested for reference.

Bug-eyed headlamps stand proud of the Leaf's V-shaped nose to nudge air away from the exterior mirrors, which are often a source of turbulence, drag, and noise. To maximize cabin space, the side windows are erect and the roof is as flat as a sheet of plywood. The tail of this hatch looks more like a wind-blocking phone booth than a sleek raindrop.

The Leaf's underbody is flat and slippery (an increasingly common feature in new cars), with diffuser strakes molded into its rear fascia. A large radiator is unnecessary in a pure electric vehicle, so the only air entering the low grille is to cool electrical equipment and to ventilate the battery and interior. Air flowing through a car's internal cavities is a prime source of drag and lift.

Nissan invested $5 billion developing the first mass-produced electric car sold across America. With any luck, there are a few yen left in the kitty to cut drag in the next generation.

↑ A well-tuned spoiler (top) cuts rear lift with minimal increase in drag. Aero tuners spend hours fretting over outside mirror designs.

4. MERCEDES-BENZ CLA250

Drag Area = 7.0 ft²

The CLA 250 has this test's smallest frontal area. The drag coefficient we measured—0.30—is higher than expected for what Mercedes calls the aero benchmark for production vehicles. But it's worth noting that Mercedes does not fit special features such as automatic grille shutters to U.S. models. And even though this sports sedan has a turbocharged engine and an automatic transmission to keep cool, its 7.0-square-foot drag area is competitive with the hybrids and electrics here.

Both ends of the CLA are aggressively tapered to cheat wind. Headlamps wrap back like the eyes of a Botox queen wearing her ponytail too tight. Mini spoilers under the car guide air around the front tires, and fairings smooth airflow beneath the engine and rear suspension.

The CLA's roof sacrifices some rear headroom, but credit Mercedes for giving its entry model an aero design that achieves great fuel efficiency.

3. CHEVROLET VOLT

Drag Area = 6.7 ft²

The Volt's midpack drag coefficient (0.28) and frontal area (23.7 square feet) earn it a drag-area score that's, well, midpack. This plug-in hybrid's conventional-looking grille is almost entirely blocked to divert air over the top and around the sides. That yields a 15-pound increase in front-axle loading at 70 mph, beneficial for highway stability.

The Volt's front lamps extend all the way back to the wheels, and there's a nicely shaped ski mogul from the top of the grille to the hatch's trailing edge, providing a smooth course for slipstreams. Strut-mounted side mirrors make way for the wind. GM sculpted the Volt to keep airflow attached to the side surfaces as long as possible to reduce turbulence. The flat hatch extension helps to stabilize the car's wake.

But even if the Prius and Volt tails look about the same, we measured 50 percent more rear lift in the Chevy. The 26-pound reduction in the Volt's rear-wheel loading isn't alarming, but it's the kind of difference that tells you to trust the wind tunnel over your visual assessment of any car's shape.

2. TOYOTA PRIUS

Drag Area = 6.2 ft²

Toyota's long-running poster boy for hybrid technology finished a close second in our testing, with a tidy 23.9-square-foot frontal area and a clean 0.26 drag coefficient. The third-generation Prius, Prius C, and Prius plug-in are the most efficient hybrids on the market, in large part because they surrender so little energy to the wind. That results in 50 mpg in the EPA's combined fuel-economy ratings and only 42 horsepower (versus the Volt's already low 45) needed to overcome aerodynamic drag at 100 mph.

This car's upper surface mimics an airfoil, one of the most efficient shapes for punching a clean hole in the atmosphere. The windshield blends into the roof with no extra moldings to trip airflow. Egg-shaped mirrors are well separated from the nearly flat side surfaces. The wheel-cover spokes are smooth to minimize churn.

A steeply inclined hood and controlled airflow through the engine/motor compartment yield 4 pounds of front downforce at 70 mph. Rear lift is only 17 pounds.

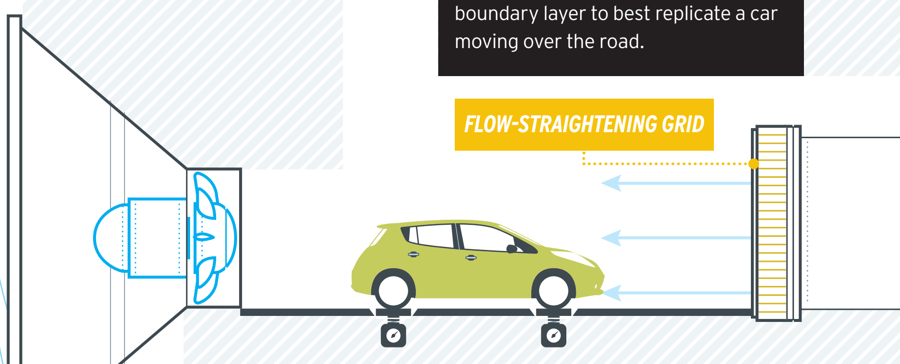
HOW A WIND TUNNEL WORKS

BIG-ASS FANS

All wind tunnels use one or more electrically driven fans to push or pull air through a test section. GM's six-blade fan is 43 feet in diameter; other tunnels have 20 or more small fans. Some tunnels recirculate the air in a closed loop (called a "Göttingen type"); others draw it from the surrounding room at one end and exhaust the air after the test section ("Eiffel type").

PARK IT

Wind tunnels reverse atmospheric circumstances out of necessity; the test subject is static while wind flows over and around the car, posing an issue with the ground surface. Some wind tunnels replicate the real-world speed difference between the vehicle and the pavement with a moving belt. This is common in Formula 1 testing, where ground effects are crucial to performance. Other facilities achieve good results by evacuating what aero engineers call the "boundary layer" of air. In the boundary layer, flow velocity changes from zero at the floor surface to the undisturbed wind velocity at the top of the layer. The goal in any wind tunnel is to have the thinnest possible boundary layer to best replicate a car moving over the road.



SCALE MODELING

Under the tunnel's floor, sensitive scales accurately measure the horizontal (drag) and vertical (lift) forces and moments acting on the test vehicle. Other sensors record air temperature and pressure at key points in the test section. In addition to the electrical power needed to spin the fan(s), energy is expended in some tunnels maintaining air temperature and humidity.

1. TESLA MODEL S

Drag Area = 6.2 ft²

The Tesla's margin of victory over the Prius is buried in the margin of error common to wind tunnels. The S earns our top slot by virtue of its larger 25.2-square-foot face and lower 0.24 drag coefficient, which yield the same 6.2-square-foot drag area as the Prius. Low drag is a tougher challenge with a larger frontal area, hence the Tesla's overall win. Exercise care when checking our math because the measurements were rounded at the end of calculations.

There's more to the Model S than a pretty face and sleek exterior. The air suspension drops ride height at highway speeds (we tested in the low position). A contoured chin below the grille helps to keep airflow attached as it sweeps under the car's flat bottom. The front fascia's outboard corners deflect air around the tires. Shutters block three grille openings until internal heat exchangers require airflow. Spoilers and fences guide air away from the front wheelhouses, and exiting air is routed under the car instead of out the wheel openings. A rear diffuser straightens flow to minimize lift and drag while, on top, the optional carbon-fiber spoiler diminishes lift without penalizing drag.

The Model S's aero polish came from computer simulations supplemented by wind-tunnel visits. Our road test of the Model S revealed a 134-mph top speed and a real-world 211-mile driving range. With taller gearing, a P85 Model S might reach 200 mph. Clearly, this is the aerodynamic electric car that merits intense scrutiny by the world's carmakers. It proves that you can look slick and be slick at the same time.

ILLUSTRATION BY MARTIN LAKSMAN