PERFORMANCE DICTIONARY

BY MARK WARNER

Coefficient of Drag (ko-e-FISH-ent ev drag) noun [origin: French] A measure of the aerodynamic efficiency of an object traveling through a fluid medium such as air. <the coupe had a higher top speed than the sedan because its coefficient of aerodynamic drag was lower> Also known as Cd, Cx, Coefficient of Aerodynamic Drag, Resistance Factor, Sleekness Value.

We've all seen the effect of aerodynamic drag on bodies in motion. Bicyclists draft behind each other, swimmers try to stay near the edge of their lanes to use its effect and racecars on tracks tuck in behind one another to lessen aerodynamic drag forces. When we read about automotive engineers trying to reduce the aerodynamic drag of a vehicle, we have an intuitive sense of what they're trying to accomplish. But what the heck is a coefficient of drag anyway, and for that matter, what other factors affect the aerodynamic drag on a car?

A LITTLE HISTORY LESSON, AND SOME MATH

Back in the '30s, the German military laid the groundwork for the modern science of aerodynamics as they prepared for their little foray into Europe. Twenty years later, the U.S. government picked up where the Nazis left off and further advanced the field, spending a ton of taxpayer money getting its military aircraft to fly as fast and as high as possible. World War II was long over, but the cold war was alive and well and the United States needed jet aircraft that could fly faster and higher than the planes of the USSR. Born from this massive outlay of tax dollars was the refinement of the science of aerodynamics. Sure, engineers and free-thinking scientists had been playing in this field since the early-1900s, but it wasn't until Chuck Yeager and his now-famous "Glamorous Glennis" rocket plane hit Mach 1 did the field of aerodynamics literally take off.

Fast forward a couple dozen years and surf over from the History Channel to Speedvision. Formula 1 and Indy engineers discovered in the late-'60s and early-'70s that they could apply the lessons learned from aircraft design to the bodies of racecars. The first area looked at by them was the reduction of aerodynamic drag. Less drag meant faster acceleration and higher top speeds. Many schemes at streamlining vehicles were tried by these early engineers, some more successful than others. Everything from chin-spoilers and air dams, to wheel and side skirts, NACA ducts and rear wings were tested. The Holy Grail, of course, was to go faster than your competition, without necessarily having to build more horsepower than them.

Now, high school science teachers like to say that power is nothing more than work divided by time. Playing around with the units a bit, we see that another way to express this idea is to say that power is equal to force multiplied by speed. In the case of aerodynamic drag, the horsepower needed to push a car through air can be thought of as simply:

$$\text{Aero Horsepower} = \text{Drag} \times \text{Speed}$$

OK, you're thinking, Speed is a no-brainer, but how do you compute "Drag?" In basic terms, think of Drag as just a force pushing backward on your car, resisting its forward movement. The faster the car travels, the bigger the Drag becomes and the harder it is to increase speed. What the racecar engineers in the '60s discovered (and what aircraft designers had known for years) was that Drag on any body moving through the air can be expressed as the product of four variables and a numerical constant:

$$\text{Aero Drag} = \text{N} \times \text{Frontal Area} \times \text{Air Density} \times \text{Coefficient of Drag} \times \text{Speed}^2$$

Now if you combine these equations into one big formula, you get:

$$\text{Aero Horsepower} = \text{N} \times \text{Frontal Area} \times \text{Air Density} \times \text{Cd} \times \text{Speed}^3$$

To understand what these four terms (Frontal Area, Air Density, Cd, Speed) actually mean, and how we can use these formulas, let's take a look at a simple example.

A LITTLE BIT OF PHYSICS, AND SOME MORE MATH

Frontal Area

Imagine a school bus traveling down a wide-open country road. For aerodynamic purposes, we can think of this big yellow people mover as just a giant rectangular box on wheels. The first thing we observe about our bus is that the bigger it is, the harder it is to push through the air. It turns out that the drag on a moving body is proportional to its projected Frontal Area. In simple English, this just means that if you double the size of the bus, you double the aerodynamic Drag. This is a case where bigger is definitely not better. If you look at the Streamliner class of land speed record holders, for instance, the fastest cars are those with the smallest Frontal Areas. In other words, they ain't big yellow school busses.

AIR DENSITY

Drive out to the white salt flats at Bonneville some August and you'll witness an amazing sight: cars and drivers of every imaginable shape and type make the trip each year to get their chance at blasting across the flats and setting a class land speed record. One such car is, believe it or not, an 1984 Chevy Chevette owned by John Beckett of Asheville, N.C. This ex-compact car has been stretched, chopped and molded into a 240-mph screamer that set eight world land speed records at Bonneville. Included in the thousands of tips, tricks and lessons learned during 13+ years of land speed racing, one of the more interesting things that John has learned is the magic speed-enhancing ability of hot air. Huh? Hot air is actually a good thing? You bet.

To understand why warm air can mean higher top speeds, all you need to understand is that hot air is less dense. Looking at a rather extreme example, 60-degree air has a density of about 0.076 pounds per cubic foot, while scorching hot 120-degree air has a density of 0.068 pounds per cubic foot. The 120 degree air is just more than 10 percent less dense. This will require 10 percent less horsepower to go the same speed!

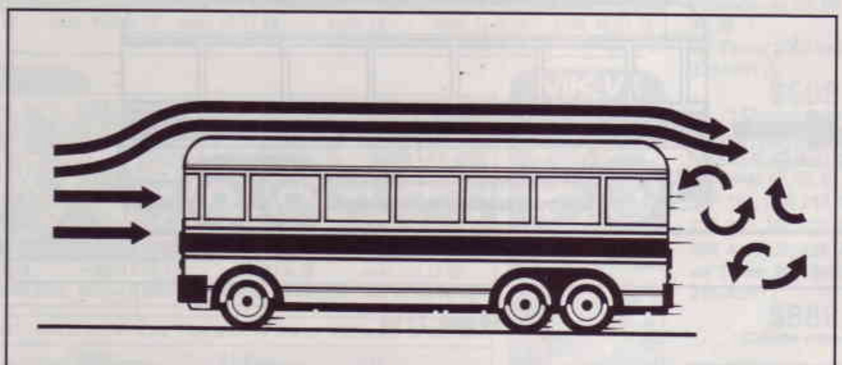
But what about all that talk about hot air making less power? Won't that cancel out the drop in wind resistance? You might think so, but looking at the SAE correction factor for the same huge temperature range, horsepower only drops 5 percent. That means making a top speed run in 120 degree air gives you a 5 percent power advantage over racing in 60 degree air. Not bad.

This benefit has been borne out by hundreds of land speed racers like John Beckett. His yellow Chevette has been known to pick up more than three extra miles-per-hour at the top end when it runs during the heat of the afternoon. Pretty cool—uh—hot, huh?

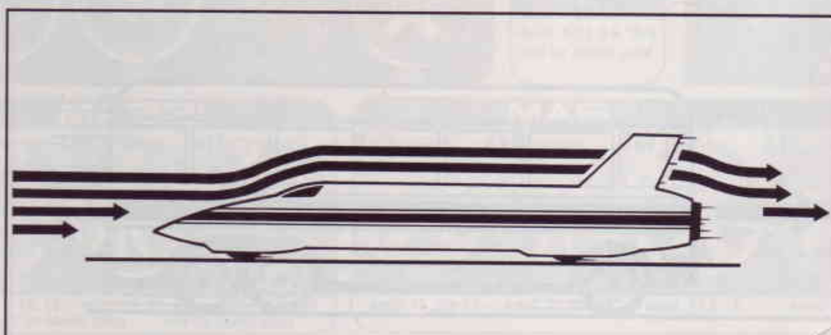
Land speed racing aside, however, most automotive engineers tend to ignore the air density variable in the equation. This is because, short of kneeling in prayer for warmer weather, there's not much that can be done to affect it. Worse, the heavenly wishes of the aero-guys are usually cancelled by the equally weighty prayers of the engine tuners. Those pesky motor guys always seem to want just the opposite of the aero-crowd—namely, cool dense air with which to make maximum horsepower. Regardless, most engineers just assume that the air is at something called Standard Temperature and Pressure, or STP, which means a density of about 0.08 pounds per cubic foot. We'll see how this gets factored into the horsepower equation in a moment.

COEFFICIENT OF DRAG

The third term in our horsepower and drag formulas is the so-called Coefficient of Drag. Most children playing with toy boats in bathtubs know that a pointy-shaped ship moves easier through the suds than a



High Cd

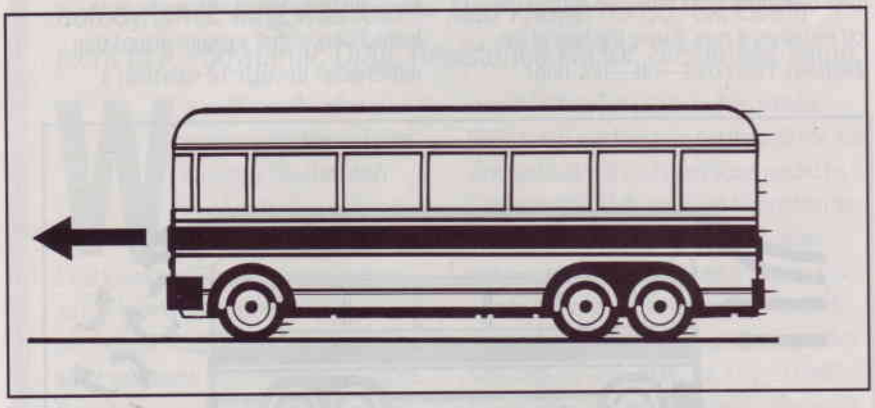


Low Cd

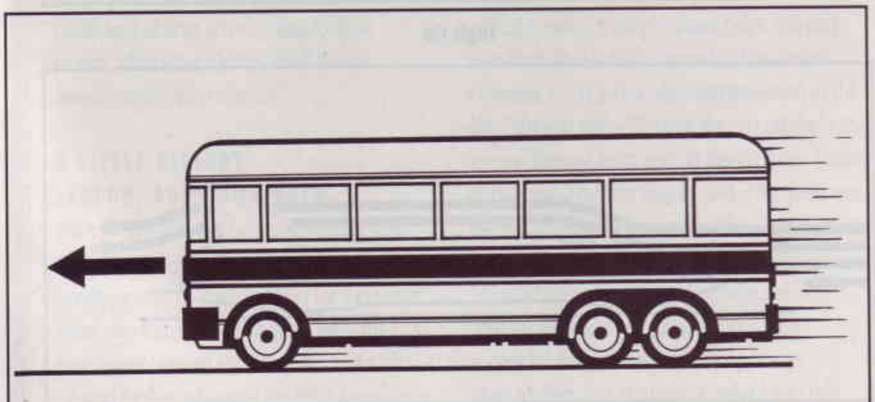
square-ended one. This effect is the same for cars traveling through air. Putting a streamlined nose on the front of our rectangular bus would help to reduce the effect of air drag. Side, or skin friction, as well as how streamlined the rear of the vehicle is also affects the drag. Different body shapes and configurations lead to different air resistance numbers. To simplify all these "shape" effects into a form they can use in the equations, aero-engineers have invented a kind of all-inclusive term known as the Coefficient of (Aerodynamic) Drag, or Cd for short.

Unfortunately, calculating a vehicle's theoretical Cd is pretty hard. Engineers can do it with computational fluid dynamics and other computer-based calculations, but the best way for most of us is to simply go out and measure it. There are two basic ways that this is usually done: coast down tests and wind-tunnel experiments. The problem with the first method—measuring the Cd from the time it takes a car to coast down from one speed to another—is that it's hard to get repeatable results. The Society of Automotive Engineers (SAE) has a very elaborate standard (SAE J1236) for performing the test, but everything from tire inflation changes, to cross-winds and fuel weight differences can affect the results.

OK, so then a wind-tunnel is the best way to measure a Cd, right? Yes, but wind-tunnel testing is very costly, both in terms of time and money. Fortunately, Cd values for most production vehicles are available from a variety of sources, including the Internet. If your vehicle has a heavily modified body, however, you'll either have to perform coast down tests or make assumptions based on published data for standard shapes and cross-sections.



50 mph, 77 hp



100 mph, 616 hp

SPEED

Moving along brings us to the last—and most interesting—term in the equations: Speed. As the second formula states, drag force increases with the square of Speed. This means that doubling the bus velocity, results in a four-fold increase in the drag. Worse, the third equation shows us that we actually have a cube-effect when it comes to how much horsepower is needed to go fast. In other words (and ignoring rolling friction, drive train losses, etc), if we want to increase our bus speed from 50 to 100 mph, we have to somehow come up with eight times more horsepower under the hood. This is why it's relatively easy to go, say, 110 mph in most factory cars, but getting above 130 is a major accomplishment. And you wondered why the land speed record guys took so long to break the sound barrier, which incidentally is around 750 mph. And also, just in case you're wondering, you would need about 290,000 hp under the hood of your typical school bus to overcome the aero drag at 750 mph!

To see how this equation works, let's look at another weird, er, useful example.

PUTTING THE LESSONS TO WORK (A.K.A. STORY TIME)

Dave pulled into his future father-in-law's driveway, and beamed with joy as he slid out of his brand new '01 Acura NSX with the 290 hp 3.2 V6. "Boy, this will finally impress the old geezer," he thought. His soon-to-be father-in-law, Dennis, came out of the garage and chuckled condescendingly as he looked over the sleek new Acura. "Too bad it's only got half an engine, sonny boy," Dennis said as he opened the garage door to reveal his own pride and joy, a 375 hp '86 Lamborghini Countach. "Now there's a real sports car, sonny boy, complete with V12 engine. She's a real racecar—not some toy like yours." Dave's heart sank a little, and he hesitated when Dennis challenged him to a top speed run later that weekend at a regional Land Speed Record track where he knew the director. To make a long (and totally implausible) story short, after the timed passes were over, both Dave and

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Dennis were surprised with a tie—they had virtually the same top speed of 178 mph! Dave was elated that he had kept up with the Countach, while Dennis was left wondering if his big V12 needed another costly tune-up. The Countach certainly was putting gobs more horsepower to the ground. So what happened?

Cd is what happened. Both cars have about the same frontal area of 19 square feet, the air density was the same, the velocity in mph was the same, but the fourth variable in our equation, Cd, was different. The newer NSX has a sleek Cd of 0.32, while the older Countach has a much higher Cd of around 0.40. Never underestimate the power of aerodynamics!

Before plugging in the numbers, remember that we have an unknown constant in our aerodynamic horsepower equation. Accounting for the STP air density info, and doing lots of mathematic gyrations to ensure that the units all work out right, a real, hardcore engineering nerd would tell you that N=0.000007, so our aerodynamic horsepower formula looks like this:

$$\text{Aero Horsepower} = 0.000007 \times \text{Frontal Area} \times \text{Cd} \times \text{Speed}^3$$

Here's how the numbers work out. First, for the Lamborghini:

$$\text{Aero Horsepower For Laborghini} = 0.000007 \times 19.16 \text{ sq.ft} \times 0.40 \text{ (Cd)} \times 178 \text{ mph} = 302 \text{ hp}^3$$

Of course, that's 302 rear wheel hp, which could well be 365 crank hp.

And for the Acura NSX:

$$\text{Aero Horsepower For NSX} = 0.000007 \times 19.16 \text{ sq.ft} \times 0.32 \text{ (Cd)} \times 178 \text{ mph} = 242 \text{ hp}^3$$

Again, 242 rear wheel hp is probably about 291 crank hp.

See how the NSX needed 74 fewer hp at the drive wheels to go the same top speed as the brawnier Lambo? That, my friends, is the all-powerful effect of reduced Cd: less power is needed to go fast.

For all us techno-geeks that can't get enough of this stuff, we can just as easily apply the formula to our big yellow bus (if it actually did make it out to the Bonneville Salt Flats). We've been assuming that the bus is just a giant rectangular box on wheels. This is actually not a bad starting point for something big and bulky like a square-ended school bus. A shape like this likely would have a Cd of around 1.1 and a frontal area of about 80 square feet. If our target speed were 100 mph, we would need a whopping 616 rear wheel hp to overcome aerodynamic drag. And that doesn't include rolling and frictional losses.

$$\text{Aero Horsepower For Bus} = 0.000007 \times 80 \text{ sq.ft} \times 1.1 \text{ (Cd)} \times 100 \text{ mph} = 616 \text{ hp}^3$$

It would cost a lot to build a bus motor that put 616 hp to the wheels, so let's see how we can reduce the Cd number and save some money. For instance, taking the mirrors and extra lights off the bus could get the Cd down to 1.0. A spherical nose cone to the bus might drop our Cd to around 0.70. Putting a similarly shaped tail-cone on the bus might reduce the coefficient even further. A low frontal air dam would add some Frontal Area, but could help get our Cd down to about 0.60. Lets see what that would do for our horsepower requirements:

$$\text{Aero Horsepower For Streamlined Bus} = 0.000007 \times 80 \text{ sq.ft} \times 0.60 \text{ (Cd)} \times 100 \text{ mph} = 336 \text{ hp}^3$$

SUMMING IT ALL UP

What's all this aero-talk really mean to the average Joe? If you want to go fast in that "big bus" of yours, you've got a few things to try. First, you can bolt some functional body kit accessories like an air dam or side skirts on the car. This should help drop the coefficient of drag to a lower value. Next, you can try temporarily removing the rear-view mirrors, antennae (and fold-out octagonal stop sign, if you really are driving a bus!). This will drop your frontal area and further increase top speed. Another thing to do is slap some top-end horsepower-increasing mods, like headers, nitrous and better camshafts on the engine to get more horsepower to the ground. And finally, you can always kneel and pray for warm weather on the car body (and cool intake air to the engine). Hey, we never said going really fast wasn't going to require divine intervention... ■

Car	Frontal Area	Cd	Hp needed at 100 mph	Hp needed at 125 mph	Hp needed at 150 mph
2000 Subaru Impreza 2.5 RS	22	0.35	54	105	182
1998 Ford Mustang GT	22.5	0.34	54	105	181
1996 Honda Civic DX Hatchback	20.5	0.32	46	90	155
2001 Volkswagen Golf GL	20.5	0.31	44	87	150
1997 Acura NSX	19.2	0.32	43	84	145
2000 Honda Insight	20.4	0.25	36	70	120

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