HIGH-PERFORMANCE
BRAKE SYSTEMS
DESIGN, SELECTION AND INSTALLATION

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Front Cover:
There is more to upgrading your brake system than just shopping for the best looking parts. While aesthetics certainly are important, consideration must also be given to system-level performance. Picking the right parts is usually more complicated than physically bolting them on–they have to work together. (Randall Shafer)

Title Page:
During track use, rotors are squeezed with thousands of pounds of clamp force, twisted by thousands of foot-pounds of torque, and heated to over 1,200 degrees F. Heavy cars with large engines such as these only make the demands that much more intense. (Wayne Flynn/pdxsports.com)

Back Cover, Top:
Designing a hot rod brake system from scratch may seem intimidating at first, but the fundamental concepts of gain and balance still apply. What really differentiates these brake systems are unique design and operating requirements that may require different compromises than would be appropriate for an all-out racecar. (Randall Shafer)

Middle:
Because experience is the best teacher, the final four chapters of this book are dedicated to sharing our years of upgrade know-how with you. Whether you are upsizing your front rotors for track use or converting your muscle car from rear drum brakes to rear disc brakes, grab your wrenches and head out to the garage with us. Just be sure to wear your safety glasses! (Randall Shafer)

Bottom:
Motorsports can place extreme demands on your brake system, and if your hardware is not up to the task, performance can suffer dramatically. A solid understanding of brake system fundamentals greatly increases your likelihood of ending up in the winner's circle on race day. (Wayne Flynn/pdxsports.com)

CHAPTER 4

Brake Balance

One of the most critical, yet least understood, brake system attributes is brake system balance. This single design parameter can make or break (no pun intended) a vehicle's stopping distance performance. Even with the very best brake system components installed on your vehicle, improper brake system balance can prevent the tires from operating at their maximum decelerations simultaneously, resulting in vehicle deceleration performance that is far from optimized.

Improper brake system balance can also create undesirable vehicle dynamic responses. From a premature loss of vehicle steering during braking to dynamic instability while braking in a turn, the ramifications of improper balance can extend far beyond a few additional feet of stopping distance.

Unfortunately for the automotive enthusiast, screwing up a vehicle's brake balance is pretty darn easy to do. Later in this chapter you'll be presented with a table of those factors that can influence brake balance, but let it suffice to say that just about anything and everything brake related, suspension related, and tire related can have an effect (both positive *and* negative) on brake balance.

A vehicle with a balanced brake system creates brake forces at all four tires simultaneously that are equal to the maximum forces that each tire can sustain independently. You could also say that a balanced brake system is one that brings all four tires to their independent maximum coefficients of friction at the same time. In either case, defining perfect brake balance is quite a bit easier than designing a system that can pull it off.

Brake Force and Corner Weight

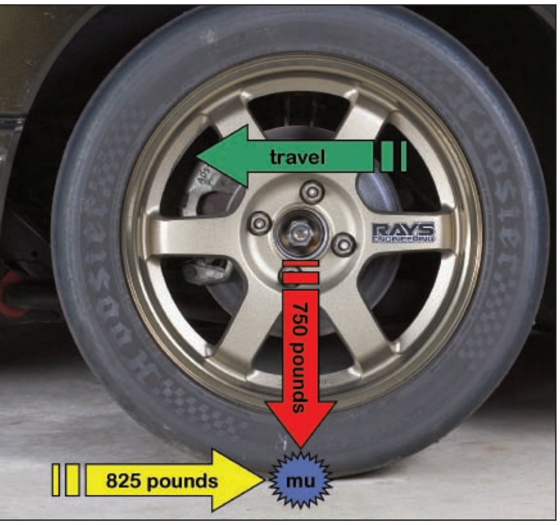
In Chapter 2 you learned that the maximum brake force a particular tire can generate is equal to the coefficient of friction of the tire-road interface (mu in the equation below) multiplied by the amount of weight being supported by that corner of the car:

Brake force at one tire (lb) =
corner weight (lb) x mu (unitless)

To use real numbers, a single tire supporting 500 pounds of the total vehicle weight with a peak coefficient of friction of 0.9 (a typical value for an all-season tire on a dry asphalt road) could generate, in theory, a maximum of 450 pounds of braking force. Recall that this also would result in

Even with the very best brake system components, improper brake balance can wreak havoc on vehicle braking dynamics. Stopping distance certainly can suffer as well. (Wayne Flynn/pdxsports.com)

Tires generate brake forces through adhesive, deformation, and mechanical wearing modes of operation. Based on the surface, condition, and level of slip, a tire may be operating in one, two, or all three modes simultaneously. Tire smoke usually indicates too much mechanical wearing! (The Tire Rack)



In this example, a single tire is supporting 750 pounds of vehicle weight (red arrow) with a peak coefficient of friction, or mu, of 1.1 (blue star). Therefore, this tire could generate, in theory, a maximum of 825 pounds of braking force (yellow arrow). The brake force would oppose the direction of travel (green arrow). (Randall Shafer)

a maximum deceleration contribution of 0.9g at that one wheel.

Now if you were to place an additional 200 pounds on the same tire (700 pounds total), the maximum brake force rises to 630 pounds (this assumes that the peak coefficient of friction remains at 0.9). From this calculation you can see that an increase in maximum brake force does not result in higher deceleration (still 0.9g in this case). Why? Because the tire has more weight on it, and that additional weight requires its own additional force to decelerate.

Based on this relationship, you can also predict that reducing the weight on the tire reduces the maximum brake force sustainable by that corner. In the example above, if the weight were reduced to 300 pounds, a maximum of only 270 pounds of brake force would be available at that corner (again, assuming the same coefficient of friction).

Perfect Balance

From all of these equations, ideal brake balance can be boiled down to one simple relationship. For perfect brake balance under all conditions:

Real-Life Brake Balance Success Story

How big of an impact can brake balance have on vehicle performance? It varies by application, but even with the very best brake system components, super sticky tires, and impeccable installation, skewing your brake balance can lengthen stopping distances dramatically. So much for those fancy red calipers…

To illustrate this point, here is a real-life brake balance success story reproduced with permission from *Grassroots Motorsports* during their Porsche 914-4 restoration.

"Our initial stopping distance measurements were not quite world-class. Even though we had installed Yokohama AVS Intermediate 195/60ZR15s at all four corners, we were recording stopping distances of 150 to 160 feet from 60 mph. There was obviously room for improvement.

"We then began to slowly adjust the proportioning valve until we were just barely on the verge of rear lock-up. We dialed back a tiny bit for a safety factor and again ran our stopping distance tests. Note that if you are doing this at home, you should be prepared just in case you go a bit too far and need to deal with the back end of the car getting all out of shape. A large parking lot or airstrip (as opposed to a crowded four-lane highway) is really the best place for this sort of thing.

"As stated earlier, the adjustable proportioning valve is a must-have item for anyone performing a 914-4 caliper swap. Our new stopping distance from 60 mph was now a scant 121 feet—on par with many of today's premier sports cars. Apparently the brake bias was significantly holding us back from optimizing our new components."

Paying attention to brake balance can pay huge dividends at the track. The 60 mph stopping distance of the Porsche 914-4 shown here went from 160 feet to 121 feet simply by setting the brake proportioning valve to an optimum position. (David S. Wallens/Classic Motorsports)

In this particular application, the stopping distance from 60 mph was reduced by approximately 34 feet—a whopping 22 percent! If you consider that out-braking your opponent by just two feet every lap for a twenty lap sprint race can result in a three to four car-length advantage at the checkered flag, a 22-percent decrease in stopping distance in every braking zone is sure to get everyone's attention.