HIGH-PERFORMANCE BRAKE SYSTEMS

DESIGN, SELECTION AND INSTALLATION

JAMES WALKER, JR.

CarTech®

Edited By: Travis Thompson

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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)

TABLE OF CONTENTS

TABLE OF CONTENTS

Biography

James Walker, Jr. is currently the Supervisor of Vehicle Performance Development at Delphi Corporation. His professional brake system résumé includes employment at Kelsey-Hayes, Saturn, General Motors, Bosch, and Ford.

(Photo courtesy Randall Shafer)

Walker created scR motorsports in 1997, successfully competing in SCCA Club Racing until 2004. Through team scR, he continues to serve as a brake system consultant for StopTech and as a seminar instructor for the Society of Automotive Engineers (SAE).

While this is his first book, Walker contributes to several automotive magazines focusing on high-performance brake system analysis, design, and modification. Originally from upstate New York, he and his family currently reside in southeast Michigan.

Acknowledgments

It was approximately 11:30 PM and I was flying 25,000 feet above Michigan's lower peninsula on a Northwest Airlines commuter shuttle. I was working my way through Chapter 7, finding it difficult to be creative at such a late hour (there's only so much to say about brake hoses), but there's no such thing as spare time when you're on a deadline.

For most of the flight I spent more time keeping my Diet Pepsi from spilling on the keyboard than actually typing. During a particularly long stretch of inactivity, the gentleman sitting next to me leaned over and asked just what exactly I was writing about. When I replied that I was writing a book about high-performance brake systems his eyes got wide in amazement and he asked, "Are you writing it by yourself?"

This was my epiphany. Although my name would be on the cover, at that moment I realized there was no way I could have even contemplated a project of this scope without an enormous cast of characters (and believe me, some of them *are* characters) behind the scenes making me look good. To say thank you to them is not enough; I owe them my gratitude beyond mention.

I first got roped into the field of high-performance brake systems through an unexpected phone call from Bob Lee, then President of StopTech. From day one Bob pressured me to write this book, and with invaluable support from the StopTech technical staff, here we are. A special tip of the hat must also be made to Dan Barnes for parts procurement, Sandor Bota for generating CAD images, and to Matt Weiss for loaning me his couch when passing through town.

Well after getting in over my head, I solicited the services of co-worker Randall Shafer to assist with a photograph or two. What I ended up with was an assistant art director, an image retouch specialist, and a deadline drill sergeant all rolled into one. He is personally responsible for approximately two-thirds of the images in this book—his contribution cannot be overstated. The folks at Delphi Corporation must also receive their own special acknowledgment for allowing us the time and flexibility to work this project into our day jobs.

In addition to Randall's work, prepare to be captivated by the action photography of Wayne Flynn of pdxsports.com. My original request to use 5 to 10 of his shots ballooned over the course of six months to nearly 40 images. There is only so much drama that classic tabletop photography can convey, and Wayne's photos strike the perfect balance between education and entertainment.

Tires receive more than their fair share of coverage in the pages that follow, and Bruce Foss and Steve Boits at Hoosier Racing Tire get their moment in the spotlight for providing images of products made from rubber and string. In addition, much of Chapter 2 was inspired by Paul Haney and his book *The Racing & High-Performance Tire*. If after reading this book you want to know more about tires and tire technology, I highly recommend Paul's book.

Speaking of tires, I also need to thank John Rastetter at The Tire Rack. With the assistance of John and his team, the project BMW in Chapter 11 stops in the shortest possible distance and looks good doing it. Their behind-the-scenes engineering allowed us to take the guesswork out of selecting the best wheel and tire package to fit around our enhanced brake system hardware.

David S. Wallens and the rest of the crew at *Grassroots Motorsports* get two nods. First, I owe them all the thanks in the world for breaking me into the world of freelance automotive journalism back in 1998. The success of that first piece (and the eight-year tsunami of brake system technical articles that followed) led to the book you're holding in your hands. You'll also find a photo or two throughout the book to their credit, but this contribution pales in comparison to the confidence they gave me to put pen to paper in the first place.

Much of the content in Chapter 13 comes courtesy of Nic Cheek and the team at Baer, with additional images to their credit sprinkled throughout the remainder of the book. While I have attempted to reciprocate the favor by answering Nic's endless stream of Corvette brake questions, I'm sure that I have not yet made it up to him in full. I'll keep trying.

I also must give my sincere thanks to Carl Harbert at Hawk Performance for looking over my shoulder through much of Chapter 9. Friction materials are in large part witchcraft and alchemy, but with his help I hope to cut through the marketing propaganda and get to the issues that matter most to the automotive enthusiast.

Finally, Travis Thompson at CarTech receives full credit (perhaps blame is a better word?) for convincing me that writing a book would be a simple ordeal. Only later did I realize that Travis should sell used cars in his spare time. While there's nothing simple about writing a book, his support, encouragement, and guidance kept the fire burning. If this book gets to press on time, it will be purely because of his constant enthusiasm and support of this project.

Dedication

No pain, no gain. While this may be an overused expression, it pretty accurately describes the process of writing a book. The twist here though, is that while the author alone receives the *gain* once the book goes to press, the *pain* during its creation is borne by many others— specifically, those around the author who wonder where he has disappeared to this time to type up a few more paragraphs. Helpful hint to first-time authors: Do *not* start your first book with two children under four years old and a pregnant wife at home. This is not a recipe for family harmony.

For this reason alone I could dedicate this book to my wonderful wife Dana and our three children, Zack, Ethan, and Shelby. The freedom from diaper changes I have received over the past nine months has allowed me the time and energy required to finish on time (okay, more or less on time). However, the support and encouragement I receive from them daily transcends that provided for this book. I am truly blessed to have such an accommodating family and I could not have done this without them supporting me every step of the way. In many ways, their sacrifice was much greater than mine.

I am also deeply indebted to the countless individuals who have helped me to shape and create scR motorsports over the past 10 years. In another classic example of no pain, no gain, I have been graciously afforded the ability to race (and occasionally win) only because of their tireless, selfless, and seemingly endless support. I'm sure that the free beer at Outback Steakhouse helped to lure them in, but they stayed around because of their dedication to my selfish hobby. For this reason, I simply must include the entire scR extended family in my dedication. This is truly *our* book.

FOREWORD

"No, the brakes don't stop the car, the *tires* do!" —James Walker, Jr.

I can't remember the first time I heard Walker utter those words. It was probably in response to an off-handed remark from me. See, even though I'm a writer at *Car and Driver* magazine, I don't always speak in the precise language that we strive to publish each month. Walker, however, loves that kind of precision—and believe me, he knows everything about brakes.

The precise date and time of our first encounter has faded away from my memory. I can, however, remember him coming to my rescue at an SCCA race and helping me sort the brakes on my Honda CRX. Back then I had just finished building the CRX to ITA specifications. I had a lot to learn. I was burning through expensive brake pads at a horrific pace and the pedal feel was horrendously inconsistent and spongy.

You can get all sorts of free advice at every racetrack in the county—and it's usually worth every penny. I had my own ideas, but since I'd spent far more than I could afford on my car, I was desperate to cure my brake problems. I tried everything, hoping I would learn as I went and eventually figure it out.

What struck me first about Walker was that he never tried to push his ideas. He simply explained what he thought I should do and why his techniques would work. He has a knack for cutting through the theory and getting to the practical stuff.

Some say I'm not that bright, but I was smart enough to listen to him about brake-pad management. My Honda has small rotors with flimsy calipers. No matter what you do, the brakes will never feel as good as those on a Porsche 911. But there are certain things you can do that will help—and those tips are just a small part of the information found in this book.

I've always thought that Walker should write a book. In addition to an encyclopedic knowledge of braking systems and vehicle dynamics, he's also quite a good teacher. One time a group of us racers got together and Walker gave us a three-hour class on brake theory. Even though many in the room were automotive engineers, we all learned a great deal. And his lecture was nothing like the painfully boring classes I sat through at engineering school.

Handling is an esoteric, hard-to-define vehicle trait. In a nutshell, it's how a car feels to drive. Almost everything on a car contributes—the driver's seat, the suspension, steering, tires, and yes, the brakes. Brakes that feel and perform the same at every pedal application increase driver confidence, and believe me, confidence makes you go fast. Remember also, that you only have three inputs to control the car: the steering, the throttle, and the brakes.

A good braking system can't turn an evil-handling car into a sweetheart, but bad brakes can seriously erode a good setup. Professional drivers use the brakes as much as the steering to get the car to do what they want. Let's say you're negotiating a fast third-gear corner and the front wheels are sliding and the car is drifting off the optimum line. A lift of the throttle might be all it takes to shift some weight to the front wheels and give them more grip, but if the understeer is severe enough, a light dab on the brakes might be required. I'm simplifying things, but in that scenario, you need a brake system that's easy to modulate because too much braking force will make the understeer worse.

I don't want to get ahead myself, because after reading this book, you'll know practically everything there is to know about brakes. You may be thinking that I've left out the most important part of a car's brakes—stopping the car. Of course Walker has explained that in detail too. But as he would say—it's the tires that stop the car anyway!

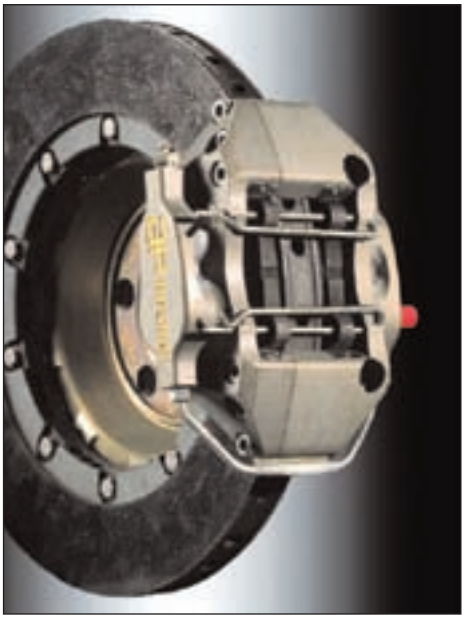
Larry Webster
Technical Director
Car and Driver Magazine

Introduction

Brakes are one of the most important, yet least understood, vehicle systems. Whether you are a commuter, a casual enthusiast, a weekend warrior, or a professional racer, chances are you rely on your brakes day in and day out without giving a second thought to their health and well-being, let alone their function or design. In fact, brakes are typically only given attention after something goes horribly wrong, and in most cases, that's too late.

Fortunately, most factory brake systems are quite robust and reliable under daily driving conditions. However, when used aggressively, brakes can become a problem in a hurry. Be it fluid fade, cracked rotors, tapered pads, or b-b-brake v-v-vibration, a number of maladies are possible and will most likely come to your attention when you can least afford it.

The intent of this book is to help you avoid all of these conditions, and more—but my strategy is to do much more than tell you which calipers, rotors, and brake fluid to install. In other words, the goal is not to give you a shopping list, but to introduce you to the fundamental principles behind each and every component of a modern, high-performance brake system so that you can determine the right parts for *your* application. One size does not fit all, and picking the right parts in most cases is usually much more difficult than actually bolting them on.



When selecting the best brake system components, there's never just one right answer. Whether you're installing new brake pads on your daily driver or upgrading to a full carbon/carbon race system as shown here, the purpose of this book is to introduce you to the tradeoffs and compromises that must be made when modifying your brakes. (Randall Shafer)

Systems, Components, and Installations

This book has been divided into three distinct sections, broken down by the simple questions of why, what, and how. These three sections aim to expand your knowledge, guide your checkbook, and save your knuckles.

Why: Chapters 1 through 4 are dedicated to *brake system fundamentals*. Here you will learn that contrary to popular belief—the brakes don't stop the car! To support this outrageous claim, Chapter 2 goes into the details of what actually occurs to create vehicle deceleration. The answer may surprise you. A complete brake system overview and an explanation of brake balance conclude everything the enthusiast needs to know about the physics of braking.

What: Chapters 5 through 10 join forces to explore *brake component selection*. This is where you'll learn the intimate details of each individual component in a typical high-performance brake system. Calipers, rotors, brake pads, brake hoses, and master cylinders are just a sampling of parts under discussion. Is a floating rotor better than a fixed rotor? What makes DOT 4 brake fluid different from DOT 3? How do I pick the right brake pad? Do red calipers really make the car stop any faster than black calipers? All of these questions and more are answered clearly and concisely to assist in your buying decisions.

The first chapters of this book are dedicated to the overall function and design of high-performance brake systems. Specifically, the information found in Chapters 1 through 4 provides you with the knowledge you need to optimize your brake system for better pedal feel, increased heat capacity, and the ability to out-brake your opponent heading into Turn 1, regardless of what you drive. (Wayne Flynn/pdxsports.com)

How: For those of you who simply want to grab wrenches and head to the garage, leaf back to Chapters 11 through 14, which each showcase a different high-performance *brake system upgrade*. It doesn't matter if you own a slammed sport compact, an exotic performance machine, a big-block muscle car, or a home-built hot rod—these four step-by-step chapters walk you through what it takes to select, install, modify, and maintain your high-performance brake system components. We even get our hands dirty with you along the way.

In summary, whether your objective is shorter stopping distance, reduced brake fade, or you just want the racecar look, there's something in here for you.

Caution: Engineer at Work

Before going any further, one disclaimer must be stated. Although I'm wearing my author hat today, I am an engineer by training and as such, I look at the world a particular way. Consequently, if you thumb through these pages you may find several occasions where I use formulas and equations to reinforce particular points and concepts. Don't panic.

You don't need a calculator while you read these sections, but feel free to play with the numbers if you're into that sort of thing. If not, that's just fine too, as the equations only reinforce what's in the text.

Semi-metallic, non-asbestos organic, ceramic… just to name a few. With so many brake pads on the market, how can you choose? Well, there's more to it than just shape. Armed with the knowledge in Chapter 9, the choice will be that much easier. (Randall Shafer)

If getting your hands dirty is your idea of fun, then Chapters 11 through 14 are just for you. The design, selection, and installation considerations of four unique brake system upgrades, including a drum-to-disc conversion performed on this 1972 Nova, will be explained in detail. There are hints, tricks, and tips here for everybody. (Baer)

Tips, Tricks, and Rumor Control

At scR motorsports, we have personally worn brake pads down through their backing plates and welded them to the caliper pistons. We've spilled gallons of brake fluid underhood. We've used rotors until they cracked in half. Yes, we've even drawn our own blood while bleeding the brakes, as ironic as that may seem. To help you avoid doing the same, the text is periodically interrupted by sidebars to share tips and tricks that we have accumulated over the years so that you can learn from our mistakes. From a stand-alone procedure for brake bleeding in Chapter 6 through the multi-page installation notes found in Chapters 11 through 14, if we've invented a better mousetrap, it's in here.

Finally, I've spent several pages dispelling myths, quelling rumors, and helping you differentiate between hard facts and marketing hype. Advertisements for calipers with *200 percent better stopping power*, rotors that run *400 degrees cooler*, and brake pads with *incredible bite* abound. While there may be bits of truth in all of it, armed with the information you acquire from reading this book, you'll be able to better separate reality from fanciful claims. Braking knowledge is braking power.

Brake system design combines elements of geometry, trigonometry, fluid dynamics, kinematics, and heat transfer, but don't panic! The primary objective of this book is to explain these sometimes confusing relationships in practical and useful ways so that you can apply these concepts to your own vehicle. (Randall Shafer)

Eight years of SCCA club racing tends to destroy a lot of brake system components, and at scR motorsports we sure learned the hard way. Hopefully our lessons learned on the track will prevent you from making the same mistakes. (Dan Gabriel Photography)

CHAPTER 1

ENERGY CONVERSION

If there's just one piece of information you should retain after reading this book, it's that the brakes don't stop the car. Contrary to popular belief, bright red calipers, cross-drilled rotors, and stainless steel brake hoses are not responsible for vehicle deceleration.

That's a pretty hard statement to accept, isn't it? This fundamental concept directly contradicts your own everyday driving experiences. You push on the brake pedal hundreds of thousands of times per year, each time expecting your vehicle to slow down. This is repeated more than one million times over the life of a typical vehicle. You're probably asking yourself right now, "How can those countless observations be wrong?"

Thankfully, the true purpose of brake systems is not based on particle string theory or quantum mechanics. All you need is solid understanding of the First Law of Thermodynamics and the rest will fall into place.

Regardless of their color, size, number of pistons, slots, holes, or sex appeal, the brakes don't stop the car. As you'll learn, they exist solely to convert energy from one form into another. A glowing rotor is a sure sign that the energy conversion process is in high gear. (Hawk Performance)

The Conservation of Energy

The First Law of Thermodynamics says that energy (the ability to do work) can neither be created nor destroyed. In other words, the amount of energy found in the universe is constant, and regardless of what you choose to do with it, you can't change the total amount.

(Note here that Albert Einstein later proved that isn't necessarily the case, but exceptions only occur when traveling at the speed of light. Since the vehicles you drive are most certainly *not* traveling at the speed of light, you can ignore Einstein's accurate but irrelevant observations without worry.)

These vehicles are sitting on the grid, ready to head out on the track. Even if they all were to attain the same top speed on the main straight, they would all have different amounts of kinetic energy because of their differences in weight. (Wayne Flynn/pdxsports.com)

While complex in design and operation, the internal combustion engine only exists to convert the stored chemical energy of gasoline into vehicle kinetic energy. The higher the rate of energy conversion, the more power (and acceleration) the vehicle is capable of producing. Turbochargers certainly add to the excitement. (Randall Shafer)

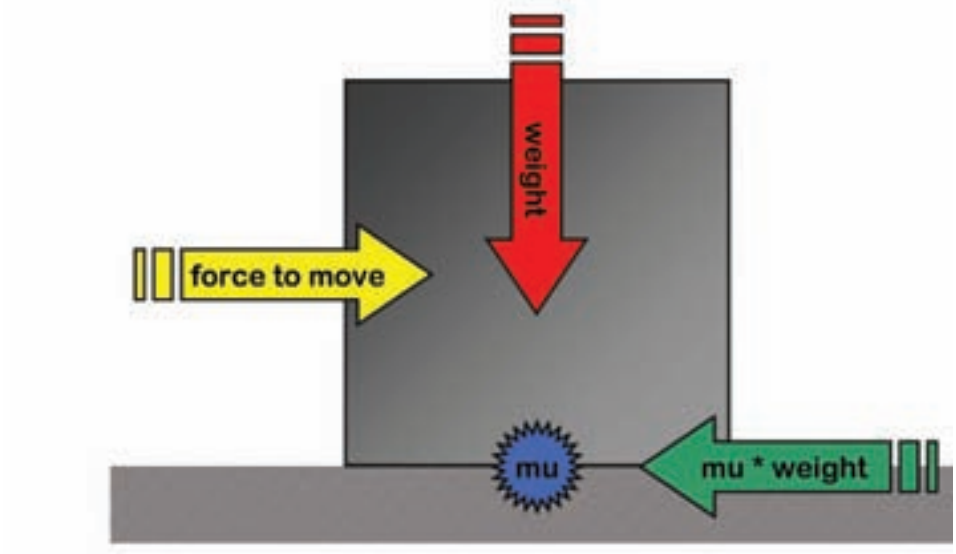
While the law as stated refers to the universe as a whole, the focus of automotive enthusiasts is quite a bit narrower. From this perspective, *the universe* can be replaced with *the vehicle* and the law still holds true.

In summary, the amount of energy in and around your vehicle is constant, and while you can't change the total amount, you *can* influence which forms that energy takes.

Where Energy Comes From

The primary source of energy in most vehicles comes from the *chemical energy* stored in the bonds holding together molecules of gasoline in the gas tank. The internal combustion engine is a device which takes this stored chemical energy and converts it into a variety of other energy forms with the intended effect of accelerating the vehicle to a given speed and maintaining that speed as long as the driver intends—or until the gas tank is empty.

In this regard, the most useful form of energy coming from the internal combustion engine is *kinetic energy*—the energy of the vehicle in motion. Unfortunately, this only accounts for about 25 to 35 percent of the total energy stored in the fuel. The remaining 65 to 75 percent is converted into relatively useless *thermal energy* (such as heat) lost to the cooling system and stored in the exhaust gasses.



The force due to friction (green arrow) is equal to the coefficient of friction, or mu (blue star), multiplied by the object's weight (red arrow). This is equal to the force required to move the object along the surface (yellow arrow). As a result, the lower the coefficient of friction, the easier the object will be to move.

Friction

Since friction is discussed at great length in this book, it makes sense to define it now. In simple terms, friction is the resistance to movement that occurs between any two objects that are in contact with one another. More specifically, any time you attempt to generate relative motion between two objects, there will be a force generated which resists the motion you are trying to achieve. This force is called the *frictional force*.

The simplest example is a block of wood sitting on a table. In order to move the block along the surface of the table, you need to push it with a certain amount of force. The force required to get the block to move is equal to the weight of the block multiplied by the amount of