Vehicle Brake Information

Michael Romano, Mechanical Engineer

Contents:

Little background on me: I was a brake engineer working at Continental-Teves (trademark: Ate Brakes) and Ford. The info below is meant to give you a better understanding of brakes and many things in it are just for information purpose.
3 of the best brake info sites I've ever found (don't agree with everything, but some things are subjective so you can decide what you want)
http://www.stoptech.com/technical/
http://www.geocities.com/nosro/abs_faq/
http://www.dba.com.au/technical.asp

Pedal Feel

First some quick definitions: Brake Pedal ratio is the measurement of how much mechanical assistance you are getting from the pedal. Example: a ratio of 4.1 will give you 41 pounds at the booster input rod for a 10 pound load at the pedal itself.

Dead or lost travel is how much pedal stoke is required before you actually start stopping.

Dead Travel or Lost travel and overall poor pedal feel is made up of the following:
[(Travel as measured at the brake service pedal assembly pin (where the booster connects)]
(Imagine traveling from the pedal through the brake system to the rotor, all lost travel must be multiplied by whatever your brake pedal ratio is.)

1. Tolerance between brake pedal pin and booster input rod. This can be quite a bit for systems that use a pin mounted brake light switch. If you do have such a switch do not remove it or take up the slack as your brake lights will be on all the time. If you don't have a pin-mounted switch just get a tighter bushing. If you do, you're out of luck.
* will be felt during first few mm of travel

2. Slack in the brake pedal assembly itself. To see how good or bad yours is, with the car off pump the brakes until hard (2-3 pumps) and then grab the pedal with your hands and see how much it moves around.
* will be felt through first few mm of travel (I hope)

3. Dash flex. This can range dramatically from vehicle model to vehicle model. Not much you can do about this.
*felt during medium and high decelerations stops on most cars, on Fords dashes flex with the breeze

4. Lost travel in booster. This is designed to be there to allow for booster expansion due to climate and use over time. Only adds half an mm (multiplied by the pedal ratio).
*felt only in the first few mm of travel

5. Flex of booster shell. Can be a real problem on some designs. All you can do is try and brace the booster or replace with a better product.
*felt on medium and high deceleration stops

6. Design tolerances in the Master Cylinder. Varies greatly from one to another. Simply, if you want less lost travel in the TMC (tandem master cylinder), you have to pay for a more expensive one. A minimum lost travel of about 1-1.5mm is required for proper and safe operation. However, I've seen some with double that. (Again multiplied by the pedal ratio)
*felt during first 10mm or so of pedal travel

7. The brake tubes and ABS unit. Maybe .0000001mm here. Don't worry about it.

8. Brake hoses. Get steel braided ones, there worth it. Rubber hoses flex quite a bit under pressure.
*felt almost all the time

9. Brake Caliper Piston Roll Back. This is usually the worst offender. Only way to get rid of this is to get better calipers. Roll back is how far the piston moves away from the rotor when pressure is released. The bigger the gap, the more you have to push on the pedal to get contact.

10. Caliper Deflection. The caliper actually flexing under pressure, like 9 you can only improve this with better calipers.
*felt during medium and high deceleration stops

11. Brake pad backing plate. If this is flimsy it will flex and not allow a good contact between the rotor and pad forcing you to apply more pressure and therefore more pedal travel. Fixed by replacing pads with higher quality ones.
*felt most of the time

12. Brake pad material itself. If the material is low density it will compress like a sponge. And if it's a low mu (friction) pad it will require more pressure and therefore more pedal travel.
*felt all the time

13. Rare, but a problem on really cheap brake pads: The bonding process used to bond the brake pad material to the backing plate. A poor process will cause the material to "squirm" around.

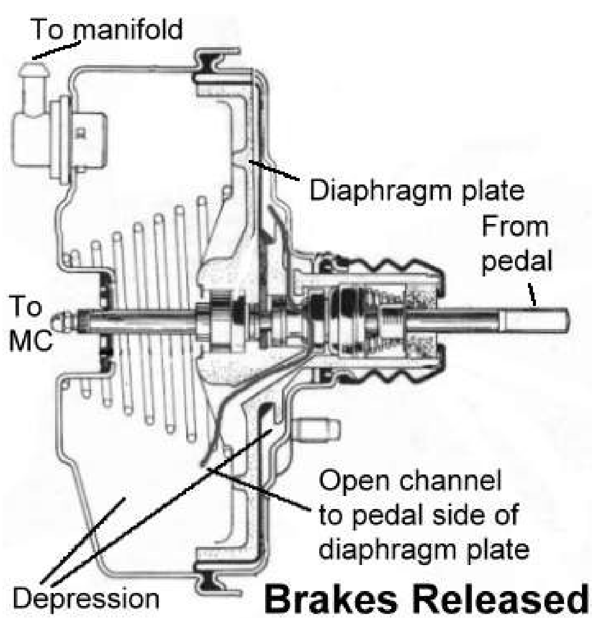
Well those are the biggies, but not the biggest. The biggest is AIR in the system. Before you do anything else do a really good and thorough brake bleed. And only use the fluid it says to use on the cap, DOT 3 or DOT 4 or whatever.

Also, changing the brake pedal assembly to one with a lower ratio. Remember all lost travel is multiplied by the pedal ratio, the lower the ratio the less dead travel at the pedal pad. This also firms up the pedal as you're getting less mechanical assistance. Just be careful, because if you're brake booster fails it will take more force on the pedal to come to a stop.

Pedal feel can also be "tuned" with a different booster.

Cut-in is what sets the initial point of boost (when it kicks in)
2-stage (knee height) is what sets how much initial force
Boost ratio is just as it sounds, it sets how much assist you get
Run-out is the maximum assist

By lowering the cut-in and increasing the 2-stage you get a better initial bite sooner. Just have to be careful you don't go overboard and have the driver eat the steering wheel at every stoplight (like an '80s Audi).



Brake Performance

Brake Performance: Level of brake torque produced and the resistance to brake torque loss, better known as fade.

Brake Torque=Fluid Pressure*caliper piston area*pad coefficient of friction*rotor radius

-For piston area multiply area by 2 for sliding calipers, rotor radius is measured from center of rotor to the center of the pad

For performance I do not use the term stopping distance because that involves more than just the brakes.

I want to make it clear there is a difference between making a brake system feel better and actually perform better.

The stopping distance of a car is not necessarily directly related to the feel. A poor feeling brake system can have very good performance, i.e. Jaguar. While a great feeling system can have lousy performance, i.e. Ford Focus

Basically, you need a bigger rotors and good pads with the best contact patch possible between the two. Also higher friction levels with higher mu brake pads.

And most importantly.........REALLY GOOD TIRES!

And you need a way to get rid of that heat at a faster rate. More rotor mass and/or better conduction (vented, etc.).

How a car stops is simple, it takes Kinetic Energy (energy created by motion) and transfers it to Heat (Thermal) Energy. It does this by the mechanism of friction.

KE=1/2 the mass of the vehicle multiplied by the square of it's velocity

Brake Power is determined by the rate of KE to TE transfer, or also know as WORK.

Simply, to stop sooner you need to transfer Kinetic Energy into Heat Energy faster.

There are no other tricks; you need higher levels of friction and ways to dissipate the heat quicker.

The big things to do to get shorter stopping distance:

1. Best Tires for the conditions (use common sense here, no Pilots in Feb in Alaska)
2. Higher Friction Brake Pads and/or rotors
3. Bigger diameter rotors
4. Calipers with more piston area

The other things you can do that give you that extra advantage:

1. LOSE WEIGHT (the car I mean), less mass, less KE

2. Minimize rotational inertia of wheels/tires. Get lighter wheels and tires (all else being equal). Note: the farther away from the center of rotation the mass is the great the inertia, so a 17" wheel will have greater inertia than a 16" all else being equal.

3. Try and balance out the braking, if the rears can do more work it spreads out the work. Less weight transfer to the front BY MOVING THE BATTERY TO THE TRUNK, stuff like that.

4. Practice! Get to know how your system works so you can best utilize it.

5. Don't drive to fast, remember it the square of the velocity. The amount of KE increase from 40KPH to 80KPH is not 200%, but 400%

The formula below is a decent way to estimate what, if any, increase you have in brake torque after an upgrade:

Brake Torque Increase %=
[(caliper piston area new/old) * (effective radius new/old)* (brake pad friction coefficient new/old)]

-effective radius is the distance from the center of the hub to the center of the brake pad
-For sliding calipers multiply the areas by 2

Any answer equal to 1 means no increase. Any answer less than 1 means you've gone backwards. Any answer greater than 1 means a torque increase.

This will NOT give you the actual brake torque, just the difference.

Things like 2-piece rotors, cross-drilling, slotting, cryogenics, heat-treating are all "at limit" technologies. In other words they only make a noticeable difference (if any) at the very limits. If you drive on the street in a manner that actually utilizes these technologies regularly you're probably dead and not reading this!

Brakes are as much art as science, there are just so many different variables involving not only performance but also feel and consumer wants it becomes a real pain!

Again, you have to know what you want to get out of your system and where you're going to use it.

In the end if you got the cash it won't hurt, but you get to a point of diminishing returns and you have to wonder!

Brake Fade

Brake fade: the loss of brake torque due to items other than mechanical failure

Basically, fade is caused by over use of the brakes to the point where a majority of the fluid pressure and/or pad friction is lost.

This is caused by heat, as heat is created in the brake system it causes the brake fluid to boil and that introduces air into the system. If enough brake fluid is transformed into a gas you will not be able to create the required brake pressure to stop the vehicle.

On top of this the same heat causing the fluid to boil is also breaking down the pad and dropping its coefficient of friction. This is commonly referred to as pad fade.

To avoid fade is very easy, you can use a fluid with a higher boiling point and/or a pad with a more advantageous temperature vs. coefficient of friction curve. You can also introduce cooling into the system with brake air ducts, vented rotors, rotors with more vent surface area and overall better ventilation in the corner area.

Also, venting built up gases under the pad was a big problem, but pad tech has come so far that it's not something I would worry about (assuming your using race pads for racing). Again it's one of those things that are there but only makes a very, very, very minor difference (if any) most of the time.

Brake Feel and it's Benefits

Brake feel: pedal effort and pedal travel for any given desired deceleration. Ease of brake pressure modulation, accuracy and precision of modulation. Feedback through the pedal "describing" pad rotor contact dynamics and pressure fluctuations.

Benefits of "better" feel:

Brake feel is just like steering feel. The better the feel/feedback is the more of the inherent performance you will actually be able to use.

Imagine a car that has 1.0g of lateral grip, but has lousy steering. Too light, completely dead, nothing happens just off-center, poor linear response and too much or too little ratio.

How much of that great 1.0g are you ever going to be actually using with poor steering?

Same with brakes. Improving feel will allow you to better use what you have.

However, it will not objectively increase brake performance. If you are already getting the max out of you system then better feel will not get you more.

Things like steel lines, stiffer calipers affect feel, not performance. Only force applied, torque arm and friction do that. You can change things like lines, calipers, pedals and boosters to change the characteristics. Such as, initial bite point and initial deceleration level, pedal travel and effort, pedal force multiplication. However, these do not actually produce more brake torque.

What master cylinder and caliper sizing means to pedal feel

Here is how to calculate mechanical advantage:

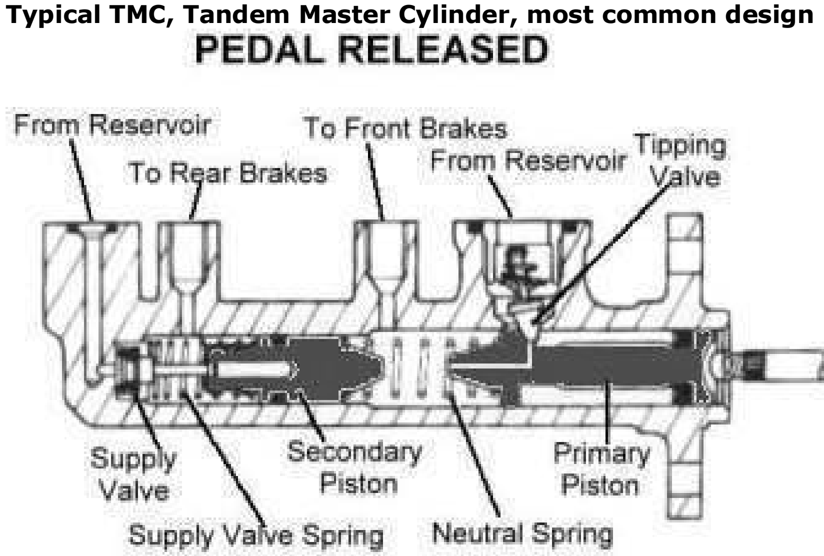
Area of MC * pedal ratio = M
Area of front piston= N

ME= M/N = larger is less effort

(MC-master cylinder)
A larger MC results in...
> less pedal travel
> a higher effort pedal
> less hydraulic advantage
> Works well on vehicles that have high fluid volume requirements since you can get plenty of flow with reasonable pedal travel. Large bore master cylinders tend to give less "feedback" and a somewhat isolated feel.

A smaller MC results in...
> more pedal travel
> a lower effort pedal
> more hydraulic advantage
> Works well in lighter vehicles where fluid volume requirements is low and excessive pedal travel is not a concern. Small bore master cylinders tend to give better "feedback" and less isolation from the system.
As you can see there's more advantage to a smaller bore MC, but some heavy trucks require the fluid only a big bore MC can provide.

Typical TMC, Tandem Master Cylinder, most common design used



Caliper:
Larger caliper piston area results in...
> more pedal travel
> a softer pedal
> more hydraulic advantage

Smaller caliper piston area results in...
> less pedal travel
> a firmer pedal
> less hydraulic advantage

Stainless Steel Braided Brake Lines

SS lines will NOT improve braking distance.

What will SS lines do? They will firm up the pedal and will shift the braking pedal feel curve. The later means that you will reach braking force earlier in the pedal stroke than without the SS lines.

Anyway, SS lines do technically firm up the pedal through out the brake pedal stroke. But the difference may not be noticeable all the time.

SS lines almost always make a difference at braking events at or over 0.25g, this is equivalent to the kind of hard braking you see when driving back roads in an aggressive manner. Regular rubber brake hoses will flex initially under high pressure, this is a volume loss that is expressed as dead travel at the pedal.

With SS lines the harder you push on the pedal the more the level of the improvement felt.

Stopping Force:

Equations: (for ease and consistency try and use meters and kg)

NOTE: Equation 1 does not mean more weight you have more stopping force, it is just to calculate the stopping force required. As you can see in Equation 2, the larger the stopping force is the larger and more aggressive the brakes need to be or can be.

1.
stopping force total = weight of car * longitudinal coefficient of friction of tires

2.
Front Force = weight front + total weight * tire friction * height of CG * (1/wheel base)

3.
Rear Force = weight rear - total weight * tire friction * height of CG * (1/wheel base)

4.
% front = Front Force/Stopping Force

5.
% Rear = Rear Force/Stopping Force

6.
Area of MC * pedal ratio = M
Area of front or rear piston= N
Mechanical Force Ratio= M/N

7.
mechanical force ratio front = mechanical force ratio * %front
mechanical force ratio rear = mechanical force ratio * %rear

8.
Stopping Force = pedal force * brake pad coefficient of friction * mechanical force ratio * (1/radius of the tire) * brake rotor effective radius
.....solve for the parameter you need

Lug Nut Torque

Over-torque of wheel lug nuts is one of the prime causes of brake rotor distortion. This can lead to permanent warping of the rotors, uneven wear of the rotors and pads and lots of brake chatter (NVH).

With today's very stiff alloy wheels, like from BBS, SSR, Volk, etc., when you torque down the lug nuts the wheel-mounting surface will force what ever it contacts to take its shape. Which means whatever that surface looks like will be what the rotor looks like.

Get a torque wrench and check the torques on every lug nut and make sure they are within the specs (which you should be able to find in your owner's manual). And make sure that every lug nut is torqued down exactly the same. Even if all 5 on a wheel are within specs, not having all 5 be equal will introduce distortion.

And if you think that your light alloy wheel can't possibly be that stiff, you wrong they are MUCH stiffer than the brake rotor or even the hub.

WORD OF CAUTION: Don't assume that torque the lugs to the lowest range in the spec is the best. Try and keep it nominal not at the extremes of the range.

Much of the problems with rotor warp, brake chatter, disk thickness variation can be traced back to over-torque and uneven torqued lug nuts.

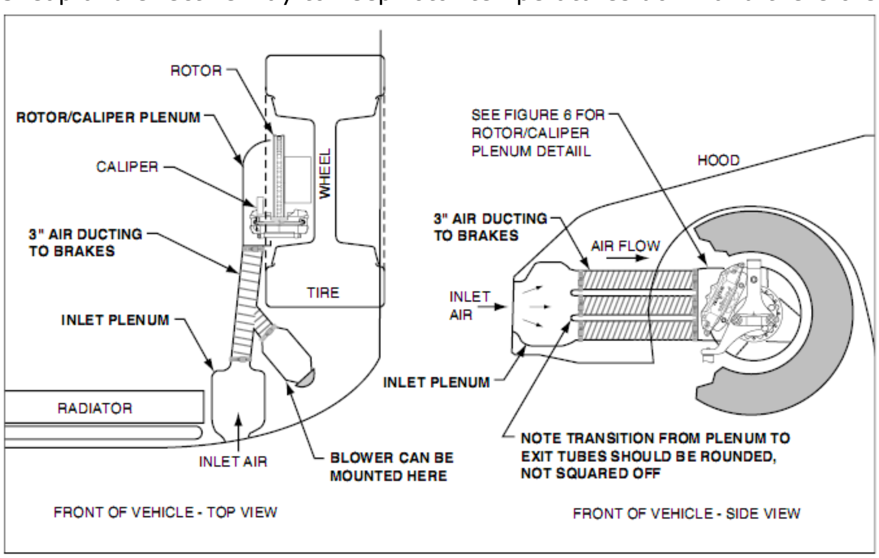
After coming back from the shop, get that torque wrench and check the lug nuts yourself.

Brake Air Ducts

This is only for auto-x and racing.

Getting all that extra air on the brakes going down a straight gets the brakes nice and cool for the next corner.

Cheap and effective way to keep rotor temperatures down and therefore reduce fade.



Rear Brakes

Just want to add a little warning about the rear brakes. Be VERY careful when it comes to making changes back there. Upgrading the rears to increase braking power, not just feel, can be a double-edged knife.

More braking power to the rears will only do you well if; 1. the balance is woefully off and the rears are under-utilized, if you can easily lock-up the rears your already at full potential or 2. you have increased the weight the rear tires carry, the grip of the rear tires and/or minimized the weight transfer to the front.

Putting more powerful brakes on the rear alone do nothing more than cause you to lock up or go into an ABS event sooner. You must increase the rear tires load to benefit from an increase in the rear brakes power. Otherwise, the rears should be looked at only from a "feel" standpoint.

Brake Fluids

Common Brake Fluid Boiling Points

	Wet Boiling Point	Dry Boiling Point
Castrol SRF	518°F	590°F
Earl's HyperTemp 421	421°F	585°F
Motul 600	420°F	593°F
AP-600	410°F	572°F
Neosynthetic 610	421°F	610°F
ATE-Super Blue	392°F	536°F
Valvoline	333°F	513°F
Castrol LMA	311°F	446°F
Earl's HyperTemp 300	300°F	568°F
Ford HD	290°F	550°F
Wilwood 570	284°F	570°F
PFC-Z rated	284°F	550°F
AP-550	284°F	550°F

All brake fluids absorb moisture, some faster than others (except silicone which is not recommended for anti-lock brake systems). Castrol SRF resists moisture contamination (non-hygroscopic) more than any other fluid we tested; therefore change intervals can be greatly extended. This reduces the effective cost over a season of racing. Many drivers say that they can run the same fluid all year long with only bleeding off the fluid in the calipers for each event. This way a can or two will last all year. Other fluids (hygroscopic type) require additional flushing of the system for each track event to maintain the lowest percentage of moisture and the highest boiling point.

FYI - The Castrol SRF is around $77/container versus $10-15/container for the rest.

Silicone Brake Fluids

Fluids containing Silicone are generally used in military type vehicles and because Silicone based fluids will not damage painted surfaces they are also somewhat common in show cars.

Silicone-based fluids are regarded as DOT 5 fluids. They are highly compressible and can give the driver a feeling of a spongy pedal. The higher the brake system temperature the more the compressibility of the fluid and this increases the feeling of a spongy pedal.

Silicone based fluids are non-hygroscopic meaning that they will not absorb or mix with water. When water is present in the brake system it will create a water/fluid/water/fluid situation. Because water boils at approximately 212º F, the ability of the brake system to operate correctly decreases, and the steam created from boiling water adds air to the system. It is important to remember that water may be present in any brake system. Therefore silicone brake fluid lacks the ability to deal with moisture and will dramatically decrease a brake systems performance.

Brake Fluid and Cold Temps.
Kinematic viscosities: All brake fluids (DOT 3, DOT 4 and DOT 5) must meet a minimum viscosity test of not less than 1.5 centistokes at 100° C (212° F) and must not be more than the following to meet their various classifications (the larger numbers indicate higher kinematic viscosities just like with motor oils).

DOT 3 1500 Centistokes at minus 40° C
DOT 4 1800 Centistokes at minus 40° C
DOT 5 900 Centistokes at minus 40° C
Higher kinematic viscosities means it "flows easier" at the cold temps.
A centistokes is 1 mm^2/s

MINIMAL boiling points for these specifications are as follows:

	Dry Boiling Point	Wet Boiling Point
DOT 3	401ºF	284ºF
DOT 4	446ºF	311ºF
DOT 5	500ºF	356ºF
DOT 5.1	518ºF	375ºF

Poly Glycol Ether Based Brake Fluids

Fluids containing Poly glycol ethers are regarded as DOT 3, 4, and DOT 5.1. These type fluids are hygroscopic meaning they have an ability to mix with water and still perform adequately. However, water will drastically reduce the boiling point of fluid. In a passenger car this is not an issue. In a racecar it is a major issue because as the boiling point decreases the performance ability of the fluid also decreases.

Poly glycol type fluids are 2 times less compressible than silicone type fluids, even when heated. Less compressibility of brake fluid will increase pedal feel. Changing fluid on a regular basis will greatly increase the performance of the brake system.

FLUID SPECIFICATIONS All brake fluids must meet federal standard #116. Under this standard are three Department of Transportation (DOT) minimal specifications for brake fluid. They are DOT 3, DOT 4, and DOT 5.1 (for fluids based with Polyalkylene Glycol Ether) and DOT 5 (for Silicone based fluids).

Wet vs. Dry Boiling Point

WET BOILING POINT - The minimum temperatures that brake fluids will begin to boil when the brake system contains 3% water by volume of the system.

DRY BOILING POINT - The temperatures that brake fluid will boil with no water present in the system.

How does water get in there?

Water/moisture can be found in nearly all brake systems. Moisture enters the brake system in several ways. One of the more common ways is from using old or pre-opened fluid. Keep in mind, that brake fluid draws in moisture from the surrounding air. Tightly sealing brake fluid bottles and not storing them for long periods of time will help keep moisture out. When changing or bleeding brake fluid always replace master cylinder caps as soon as possible to prevent moisture from entering into the master cylinder. Condensation, (small moisture droplets) can form in lines and calipers. As caliper and line temperatures heat up and then cool repeatedly, condensation occurs, leaving behind an increase in moisture/water. Over time the moisture becomes trapped in the internal sections of calipers, lines, master cylinders, etc. When this water reaches 212º F the water turns to steam. Many times air in the brake system is a result of water that has turned to steam. The build up of steam will create air pressure in the system, sometimes to the point that enough pressure is created to push caliper pistons into the brake pad. This will create brake drag as the rotor and pads make contact and can also create more heat in the system. Diffusion is another way in that water/moisture may enter the system.

Diffusion occurs when over time moisture enters through rubber brake hoses. The use of hoses made from EPDM materials (Ethlene-Propylene-Diene-Materials) will reduce the amount of diffusion OR use steel braided brake hose with a non-rubber sleeve (usually Teflon) to greatly reduce the diffusion process.

DOT what?

DOT: Acronym for "Department of Transportation" -- an American federal agency or "Department of Transport" -- a British agency

DOT 3: This brake fluid has a glycol base. It is clear or light amber in color. Its dry boiling point is 401° minimum and wet boiling point of 284° minimum. It will absorb 1 to 2 percent of water per year depending on climate and operating conditions. It is used in most domestic cars and light trucks in normal driving. It does not require cleaning the system and it can be mixed with DOT 4 and DOT 5.1 without damage to the system. The problem with it is that it absorbs moisture out of the air and thereby reduces its boiling point. It can also damage the paint on a vehicle.

DOT 4: This brake fluid has a borate ester base. It is clear or light amber in color. Its dry boiling point is 446° minimum and wet boiling point of 311° minimum. It is used in many European cars; also for vehicles in high-altitude, towing, or high-speed braking situations, or ABS systems. It does not require cleaning the system and it can be mixed with DOT 3 without damage to the system. The problem with it is that it absorbs moisture out of the air and thereby reduces its boiling point. It can also damage the paint on a vehicle.

DOT 5: This brake fluid generally has a silicone base. It is violet in color. Its dry boiling point is 500° minimum and has no wet boiling point in federal DOT 5 specifications. It is used in heavy brake applications, and good for weekend, antique, or collector cars that sit for long periods and are never driven far. It does not mix with DOT 3, DOT 4, or DOT 5.1. It will not absorb water and will not damage the paint on a vehicle. It is also compatible with most rubber formulations. The problem with it is that it may easily get air bubbles into the system that are nearly impossible to remove, giving poor pedal feel. It is unsuitable for racing due to compressibility under high temperatures. If as little as one drop of water enters the fluid, severe localized corrosion, freezing, or gassing may occur. This can happen because water is heavier and not mixable with silicone fluids. It is unsuitable for ABS.

DOT 5.1: This brake fluid has a borate ester base. It is clear or light amber in color. Its dry boiling point is 500° minimum and wet boiling point of 356° minimum. It is used in severe-duty vehicles such as fleets and delivery trucks, towing vehicles, and racecars. It can be mixed with DOT 3 or DOT 4 without damage to the system. It maintains higher boiling point than DOT 3 or DOT 4 fluids due to its higher borate ester content. It is excellent for severe duty applications. The problem with it is that it costs more than other fluids and there is limited availability. It also absorbs moisture out of the air and thereby reduces its boiling point. It can also damage the paint on a vehicle.

What causes a mushy pedal?

DOT 5 fluid is not hygroscopic, so as moisture enters the system, it is not absorbed by the fluid, and results in beads of moisture moving through the brake line, collecting in the calipers. It is not uncommon to have caliper temperatures exceed 200° F, and at 212° F, this collected moisture will boil causing vapor lock and system failure. Additionally, DOT 5 fluid is highly compressible due to aeration and foaming under normal braking conditions, providing a spongy brake feel.

Brake Bleeding/Flushing

One thing that is ALWAYS true never let the TMC (master cylinder) on an ABS, traction control (TCS) or electronic stability program (ESP) car run dry. You'll never get the air bubbles out again by hand. To be honest there is more than one right way and if you found something that works, why fix what's not broken.

Just FYI-

At the factory this is how it's done. They do it all one shot.

First you mount the Evac-Fill head unit to the reservoir then all air is evacuated from the system, creating a vacuum. Then fluid is forced through the system at high pressure.

Then the car is delivered and people complain about mushy pedal!

Just some more stuff:

I e-mailed a Tech at Ford I used to work with on the proper bleed sequence. Since techs do these all the time and engineers don't I'll take his advice.

This is it:

Doing nearest or most distant doesn't matter. What matters is if the brake system is a diagonal or front-rear system.

Quick definition: diagonal means that one circuit in the master cylinder feeds the front driver's side and the rear passenger side. The other circuit the front passenger's and rear driver's. Both circuits are of equal volume. Front-Rear means that one circuit supplies the front calipers, while the other the rear calipers. The Primary circuit (front caliper circuit) is of greater volume.

All you need to do is make sure you do the circuits together. For instance, on most passenger cars it's a diagonal system. So you want to do the driver's front and passenger's rear together, which you do first is not all that important. But he does agree that the tradition is to do the rear first. Or best to get a friend and do both at the same time. And take your time (he told me to make sure I added this).

Same holds true for the Front-Rear systems. Do fronts together and rears together. Usually only trucks, SUVs and very heavy front bias cars (Ford Crown Vic) have a Front-Rear system.

Just FYI- Diagonal is used so that if one circuit fails the vehicle is still stoppable in a stable manner as at least one front and rear wheel is braking and on opposite sides. Front-Rears are used on heavy, front-bias cars require a lot of volume up front.

ABS Bleeding:
Do 3 normal bleeds and then do
An ABS stop if you still feel that air might be trapped. Then do 1 more
Bleed. The ABS stop would have flushed the air out.

2-Piece rotors

I have seen a lot on 2-piece rotors. Some of the information contained in them is correct some is mythical.

Some definitions.

2-Piece rotor: A brake disc rotor that has a separate hat (cap) usually made from a lightweight metal. There are two types of common 2-piece street rotors. One uses a bolted hat and the other a pinned hat (also known as a "floating rotor" design).

The bolted type is just what it sounds like. Usually an aluminum hat bolted to a cast iron rotor. The only real benefit of this design is weight savings. However, weight savings tend to be only 10-20%, all else being equal, but with a 50-75% price increase.

The pinned type has usually stainless steel pins that attach the aluminum hat to the rotors. This allows the rotor to "float" on the pins. The great advantage of this design is that it allows the rotor to move freely. When the rotor expands and contracts there is much less chance of binding or distortion. As you can imagine this cuts down on warping and uneven wear (DTV). The disadvantage of this design is really high costs and increased NVH.

As far as better heat conduction, not really. It does help a bit, buts it's not enough to make it worth the extra cost. The nice think about the weight savings is you can get a larger rotor with out taking a weight penalty.

- It may help keep your wheel bearings cooler.

My opinion:

2 piece floating (pinned) rotor is worth every penny. This is good technology, yeah they cost a ton but they do the job. They keep the rotor even through out operating temperature range and they keep down DTV problems better than anything I've ever seen. Be sure they're the pinned hat type and not the bolted hat type.

Warped Rotors

Note: DTV stands for disk thickness variation, caused by uneven rotor wear and/or pad material deposited on the rotor. Pad deposit usually happens when brakes are hot and you let them "sit cool"; you should drive around at slow speeds while your brakes cool.

Warped Rotor:

Cut an imaginary plane through the center of the disc part of the rotor that is parallel to both surfaces of the disc, this is done when rotor is new.

If the rotor is warped this imaginary plane (now part of the disc) will no longer be parallel to a reference plane, that reference plane was also parallel to both surfaces of the disc when the disc was new.

In essence a warped rotor is a rotor that is deformed throughout its thickness.

A rotor with DTV (surface imperfection) issues:

The imaginary plane above is still parallel to the reference plane mentioned in the warped rotor definition, however the two surfaces of the disc are no longer parallel to each other.

Think of 2 identical planks of wood.

1st plank you take a planer to it in a haphazard way to the surface making the surface wavy.
This is a surface condition.
You can sand the surface down to get back to a smooth surface.

2nd plank you steam heat and then bend around a steel pipe. This plank is warped. You can sand all you want, but you'll never get it straight again.

You can see why it's so easy to mistake one for the other; on the surface it all looks "warped"

Of course if the rotor is too thin then it can't be "sanded" smooth, but a warped rotor can't be turned no matter how thick it is.

Cross Drilled and Slotted Rotors

Cross-drilled rotors:

Disks that have been drilled through with a non-intersecting pattern of radial holes. The objects are to provide a number of paths to get rid of the boundary layer of out gassed volatiles and incandescent particles of friction material and to increase "bite" through the provision of many leading edges. The advent of carbon metallic friction materials with their increased temperatures and thermal shock characteristics ended the day of the drilled disc in professional racing. They are still seen (mainly as cosmetic items) on motorbikes and some road going sports cars. Typically in original equipment road car applications these holes are cast then finished machined to provide the best possible conditions by which to resist cracking in use. But they will crack eventually under the circumstances described in another section (see Cracking). Properly designed, drilled discs tend to operate cooler than non-drilled ventilated discs of the same design due the higher flow rates through the vents from the supplemental inlets and increased surface area in the hole. That's right, inlets, the flow is into the hole and out through the vent to the OD of the disc. If discs are to be drilled, the external edges of the holes must be chamfered (or, better yet, radiused) and should also be peened.

Slotted:

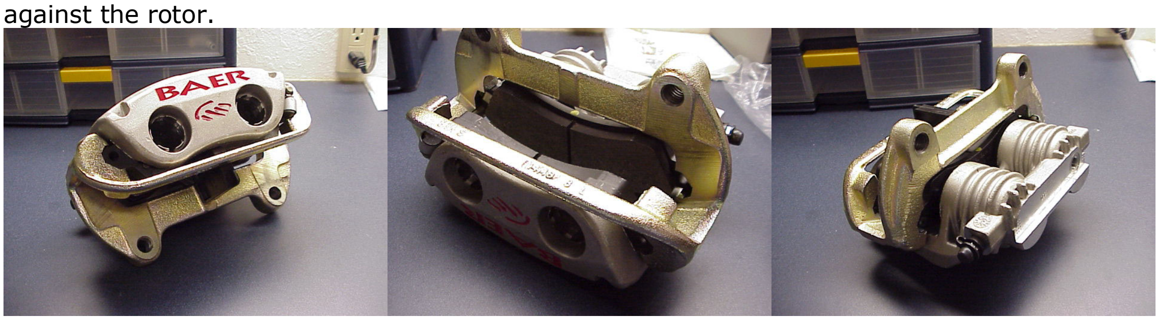
Shallow, sharp edged but radiused bottom grooves milled into cast iron discs to provide leading edges for bite and a path for the fire band of gases and incandescent friction material to be dissipated through. If the slots fill up with pad material, the system is operating at too high a temperature.

For the track they work. Not as dramatically as the ads will lead you to believe, but they do a good job of keeping the pad surface "clean" when they get really hot and they do a good job of venting gases. Again though, with modern pads neither of the issues mentioned are that severe now a days.

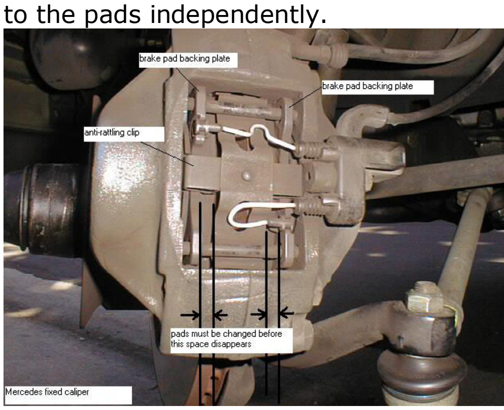
Brake Calipers

The caliper's basic function is to force the pads against the rotor. A caliper is made of 3 basic groups, the housing (body), the pistons and the mounting bracket. The pistons sit in the housing and are the components that directly push the pads against the rotor. The housing is there basically to hold and flow fluid to the pistons and give the piston somewhere to live.

There are 2 families of calipers, the sliding caliper and the fixed caliper:
The sliding caliper is by far the most common and is mostly likely what's on your car. It has pistons only on the inboard side and the caliper slides on guide pins to force the outside pad against the rotor.



The fixed caliper has a single (monobloc) or 2 piece bolted housing and piston(s) on both the outboard and inboard side. The caliper is completely stationary and each side applies pressure to the pads independently.



What's the difference? The major differences between the fixed and sliding calipers is weight and stiffness. A fixed caliper in general weighs less and has significantly less flex. This means better pedal feel. Fixed calipers also tend to have a lower profile allowing a larger rotor in the same wheel. Advantage of a sliding caliper is cost, they are usually much less expensive.

Single piston and multi-piston Calipers:
Most sliding calipers are of the single piston type, which means one large piston does all the work. Dual-piston calipers are becoming more popular. Most fixed calipers are 4 piston type, 2 pistons on each side. There are 2 piston fixed and some go as high as 8 pistons total.

The advantages of multiple pistons is:
1. More piston area more force on pad and you can fit more piston in any given rectangle with smaller diameter pistons (like engine valves in the heads).

2. A lower profile caliper as 2 small pistons have a "lower height" than one big piston. This means less flex since the distance from the point of application to the bridge (top strap) of the caliper is less.

More pistons usually adds more cost and low force braking feel is softer.

Dynamic Brake Control

Is a "Panic Assist Feature" what it does is measure the velocity of pedal travel by using either a sensor on the pedal or in the booster. If a certain threshold is met then the booster (if it's an electronic booster) or the DSC pump will apply max pressure. It doesn't actually stop the car in any shorter distance than you could.

The reason for DBC is that it's been established than many people when emergency braking will ease off the brake pedal a little after the initial stab. DBC keeps the pressure up even if you let off. This can be a real pain when your trying to modulate the brakes yourself as most systems have a pretty low threshold and just aggressive braking is seen as a "panic stop."

This feature also requires a functioning ABS, the expensive systems are electronic so if the ABS fails the feature is disabled, but some cheaper cars have a purely mechanical system and a failed ABS is not detected. You can imagine what happens when you have max brake power and no ABS.

Anti-Lock Brakes

Please go to this website:
http://www.geocities.com/nosro/abs_faq/

It's worth your time, Thank You

Glossary of Braking Terminology

By Stephen Ruiz, Engineering Manager
and
Carroll Smith, Consulting Engineer at STOPTECH LLC

ABS: Acronym for Anti-Lock Braking system. Anti Lock braking systems sense the speed and rate of deceleration of each of the wheels of a vehicle independently and, through a microprocessor control system, act to prevent lock up of any of the tires under braking force by cycling the line pressure to the wheel that is approaching lock up. Most current passenger cars are fitted with ABS.

Aluminum Beryllium: A composite material of exceptional stiffness to weight ratio used for Formula One calipers (and Ilmor/Mercedes engine blocks) in the late 1990s. Now outlawed on health grounds

Aluminum Lithium: A composite material of exceptional stiffness to weight ratio currently being used for Formula One calipers.

Anti-squeal plates: Very thin stiff metallic or composite plates, sometimes coated with a high temperature solid lubricant, inserted between the pad backing plates and caliper pistons on passenger cars to reduce or eliminate brake squeal.

Asbestos: Impure magnesium silicate with very low thermal conductivity - once used as an insulating material and as one of the components in brake friction materials. Now outlawed on health grounds.

Backing plate: The steel portion of a disc brake pad which contacts the caliper piston(s) and to which the friction material is bonded. The backing plate provides the necessary stiffness and mechanical strength to the pad system. Its dimensions, flatness and surface finish must be closely controlled. The longer the pad, the thicker must be the backing plate. Backing plates of less than about 3 mm should be viewed with suspicion unless the pad is very short.

Bedding in: There are two types of "bedding in" with regard to brakes:
1. Bedding of the friction material. All friction materials contain volatile elements used as binders. In the initial thermal cycling of the material these volatiles boil off, forming a gaseous layer between the friction material and the brake. A bedded pad will exhibit a layer of discolored material from 1.5 to 3 mm thick.
2. Bedding of the disc. Before using a new disk, all machining and preservative oils must be completely removed following the disc manufacturer's recommendations. Usually it involves washing with soap and water or using one of the proprietary "brake clean" compounds. The disc should then be mounted and checked for run out. It should be bedded in with a number of moderate stops with lots of cool off time between stops, gradually increasing the severity of the stops until the entire surface of the disc is evenly discolored. This will prevent thermal shock, distortion and the formation of "hot spots" (regional deposition of pad material which results in a permanent transformation of the cast iron underneath the deposit) and ensure maximum disk life.

Bell: See "hat"

Bias bar: A system allowing rapid adjustment of the front to rear braking force on a car. Universal in racing, the bias bar connects the pushrods of dual master cylinders with an adjustable fulcrum allowing crew or driver adjustment of the braking ratio.

Bite: The speed at which the friction material reaches its maximum coefficient of friction when braking is initiated. The amount of bite is a compromise. Too much bite makes initial modulation difficult. Too little causes a delay in braking. In racing, different drivers prefer pads with different degrees of bite.

Blades: See "vanes"

Bleeding: The process of removing overheated fluid and air bubbles from the hydraulic system.

Bluing: Discoloring of cast iron rotors due to heat. Although bluing is evidence of thermal stress and will lead to reduced rotor life, it is normal under repeated hard braking and is not a cause for concern.

Brake bias: The term used to indicate the ratio between the amount of brake torque exerted on the front brakes compared with the rear. Brake bias is normally expressed as a percentage of brake torque at one end of the car to the total brake torque, as in "60% front".

Brake booster: A vacuum device that multiplies pedal effort at the cost of pedal travel and pedal firmness. Virtually universal on passenger cars.

Braking efficiency: The ratio of actual deceleration achieved on a given surface compared with the theoretical maximum.

Brake line pressure: The instantaneous hydraulic pressure within the brake lines. Brake line pressure in pounds per square inch is the force applied to the brake pedal in pounds time multiplied by the mechanical pedal ratio divided by the area of the master cylinder in square inches. For the same amount of pedal force, the smaller the master cylinder and/or the greater the mechanical pedal ratio, the greater the brake line pressure and the longer the pedal travel.

Braking torque: Braking torque in pounds feet on a single wheel is the effective rotor radius in inches times clamping force times the coefficient of friction of the pad against the rotor all divided by 12. Braking torque is the force that actually decelerates the wheel and tire. To increase the braking torque it is necessary to increase the line pressure, the piston area, the coefficient of friction or the effective rotor diameter. Increasing the pad area will not increase the braking torque.

Caliper: The "hydraulic clamp" portion of a disc brake system. Manufactured from either ferrous or non-ferrous material and bolted firmly to the suspension upright (or "knuckle") the caliper holds the pads in place and, through the action of hydraulic pistons actuated by the master cylinder, forces them against the rotating surface of the disc when pressure is applied to the brake pedal.

1. Fixed caliper: A brake caliper in which two or more pistons are arranged on either side of a rigid body with the disc in the center. Due to its inherent stiffness the fixed caliper is the only design suitable for racing categories where it is allowed and is the preferred design for high performance cars.

2. Floating caliper: A design in which a single or dual piston is located inboard of the disc and the outer body of the caliper slides on suitable surfaces in reaction to piston pressure. The piston forces the inboard pad against the disc while the sliding outer body clamps the outboard pad against the disc. The inherent lack of rigidity in the design, compared to fixed caliper design, combined with the friction inherent in the sliding outer body makes this design less suitable for racing and high performance use. The design is well suited for use with front wheel drive as the absence of any outboard pistons allows greater negative (inward) wheel offset. In all applications, this caliper type is simpler to manufacture and affords more packaging flexibility for zero or even negative scrub radius front suspension designs. It is sometimes used in the rear on an application that has a fixed design in the front.

3. Open caliper: The design of fixed caliper in which the "window" through which the pads are inserted is structurally open. This design, while less expensive to manufacture, significantly reduces caliper rigidity.

4. Closed caliper: The design of fixed caliper in which the "window" through which the pads are inserted is structurally reinforced by a bridge.

5. Caliper bridge: The structural reinforcement across the open face of a fixed caliper. In order to be effective the bridge must be rigidly bolted in place with high tensile fasteners.
Sliding - see Floating Caliper

Carbon/carbon brake: A braking system in which both discs and pads are manufactured from carbon composite material. Utilized in every form of racing where they are not outlawed, carbon/carbon brakes offer significant reduction in rotating mass and inertia along with much greater thermal capacity and dimensional stability in use. The disadvantages include cost, a certain amount of lag time while heat builds up (especially in the wet) and some difficulty in modulation. Contrary to popular belief, the coefficient of friction is no better than that of state of the art carbon metallic pads and cast iron discs. A major advantage on super speedways is the reduction of gyroscopic precession on corner entry.

Carbon metallic: This is a trademark of the Performance Friction Corporation. Pad friction compounds containing large percentages of pure carbon along with various metallic elements. Pioneered by Performance Friction Corporation these compounds offer very constant coefficients of friction vs. temperature characteristics along with increased thermal capacity. The disadvantage is that, since they both operate at higher temperatures and their temperature rises to operating temperature faster than other compounds, they increase thermal shock to the disc and increase thermal conduction to the caliper pistons and brake fluid. As a result, it is recommended to not use drilled discs with carbon metallic pads.

Cast iron: Metallic iron containing more than 2% dissolved carbon within its matrix (as opposed to steel which contains less than 2%)and less than 4.5%. Because of its cost, relative ease of manufacture and thermal stability cast iron (sometimes referred to as "gray cast iron" because of its characteristic color, but is actually a more specialized material for brake applications) is the material of choice for almost all automotive brake discs. To work correctly, the parts must be produced at the foundry with tightly monitored chemistry and cooling cycles to control the shape, distribution and form of the precipitation of the excess carbon. This is done to minimize distortion in machining, provide good wear characteristics, dampen vibration and resist cracking in subsequent use.

Ceramic buttons: Insulating buttons inserted in the face of racing caliper pistons to reduce conduction of heat to the brake fluid. Not currently in use, as Titanium buttons have proved more effective.

Ceramic coatings: Some racing calipers feature a ceramic coating sprayed onto the interior surfaces as a radiation barrier to reduce heat transfer from the disc and pads to the caliper and fluid.

Clamping force: The clamping force of a caliper in pounds is the brake line pressure multiplied by the total piston area of the caliper in a fixed caliper and two times the total piston area in a floating design. To increase the clamping force it is necessary to either increase the line pressure or the piston area. Increasing the pad area or the coefficient of friction will not increase clamping force.

Coefficient of friction: A dimensionless indication of the friction qualities of one material vs. another. A coefficient of 1.0 would be equal to 1g. The higher the coefficient, the greater the friction. Typical passenger car pad coefficients are in the neighborhood of 0.3 to 0.4. Racing pads are in the 0.5 to 0.6 range. With most pads the coefficient is temperature sensitive so claims that do not specify a temperature range should be viewed with some suspicion. The optimum is to select a pad with a virtually constant but decreasing coefficient over the expected operating range of temperatures. As a result, the driver does not have to wait for the pad to heat up before it bites, and the pad fade will not be a factor so that modulation will be easy (see "plot shape").

Compressibility: All materials are compressible. Under enough pressure the rock of Gibraltar will compress to some extent. It is important that the friction material of the pad not compress under the expected clamping force. If it does, pad wear will be uneven and braking efficiency will be compromised. Compressibility is seldom mentioned in advertising. It should be. Compressibility of a given material and the wear rates are the two primary factors that are considered in determining the size of a pad for a given application.

Conduction: One of only three heat transfer mechanisms. Convection and radiation are the other two. Conduction is the transfer of heat by physical contact. For example, some of the heat generated by the automobile braking system is transferred to the caliper pistons and thence to the brake fluid by conduction. Some of it is also transferred to the hub, upright (knuckle) bearings, and wheels in the same way. Two-piece or floating discs reduce conduction to the hub, and other parts because of the intervening hat. Conduction is also the strategy used in all designs to move the heat from the disc pad interface to the vanes and in some designs to provide the initial heat sink for the energy generated at the start of a braking cycle. The sacrifices made if this is the primary strategy used for heat transfer are the weight and inertial penalty in a rotating part.

Convection: One of only three heat transfer mechanisms. Conduction and radiation are the other two. Convection is the transfer of heat by fluid flow. Air can be considered to be a fluid in a thermal model of a brake system when it is moving and is contact with the heated surfaces of the disc or drum. In the case of a solid disc the air moving over the surface of the disc is very random and turbulent, but still functions to provide some cooling. In the case of a ventilated disc, by the pressure of a forced air duct or by induced flow that is a result of the centrifugal acceleration of the air already in the vent of a rotating disc, air flows through the vents. The air absorbs thermal energy along the vent path. In this way, the heat generated by the braking system of an automobile is transferred to the moving air stream and away from the brake disc.

Cracking: Cracking is primarily due to heat cycling that weakens the cast iron discs. The exact mechanism of this failure is disputed. Cast iron discs are formed with the excess carbon being precipitated in the form of carbon plates or flakes dispersed throughout the ferrite (iron) matrix. What is believed to happen is that when discs are operated above about 900º F, the carbon becomes more flexible or "fluid" in its shape partly due to the thermal expansion of the enclosing ferrite matrix. Then, as the disc cools relatively rapidly back below about 900º F the carbon is trapped in a changed more random shape then when it was first cast. This creates internal stress on the part and continuously transforms the disc by relieving the stress through the cracking. The cracks begin by appearing between carbon flakes. Nodular or ductile iron would resist this cracking due to the excess carbon being precipitated in a spheroid form, but it, like other alternative materials do not have the mechanical properties needed to function ideally in a brake disc application. In discs that are cast to resist cracking through chemistry and controlled cooling at the foundry, cracking will still occur, but more slowly and take the form of heat checks on the surface. In some cases cracks will begin at the periphery of the disc and propagate inwards. In this situation, propagation can be delayed by drilling small holes at the end of the cracks (stop drilling). We do not recommend this however, because if the cracks continue to propagate unnoticed, catastrophic mechanical failure will result. Replace disc at the first sign of cracks at the outer edge of any size. A historic note, the original purpose of the curved or angled vane disc was to prevent cracks from propagating by imposing a solid vane in the path of the crack. The cooling function was secondary.

Cryogenic treatment: A thermal process in which metallic components are slowly cooled to near Kelvin temperature and then equally slowly returned to room temperature. Proponents claim that the grain structure is refined by the process. There is considerable doubt about the effectiveness of the process. Evidence is largely anecdotal and to date no scientific and quantitative engineering studies have been published.

Differential bores: The leading edge of a brake pad wears faster then the trailing edge. This is due to the migration of particles of incandescent friction material carried from the leading to trailing edge of the pad. In effect the trailing portion of the pad is riding on a layer of incandescent material. By providing an optimally designed larger caliper piston at the trailing edge of the pad, wear can be evened along the length of the pad

Disc: The rotating portion of a disk brake system. Mechanically attached to the axle, and therefore rotating with the wheel and tire the disc provides the moving friction surface of the system while the pads provide the stationary friction surfaces. Except for racing, discs are normally manufactured from one of several grades of cast iron. Some European front drive passenger cars, where the rear brakes do very little work, are using aluminum metal matrix rear discs to save weight. Most professional racing cars use carbon/carbon discs.

1. One-piece disc: A disc cast in one piece with its hat or bell. This is the inexpensive way to manufacture a disc and is perfectly adequate for normal use. There are some tricks to the design to reduce distortion.

2. Floating disc: The norm in racing, the floating or two-piece disc consists of a friction disc mechanically attached to the hat either through dogs or through drive pins. Properly designed this system allows the disc to dilate (grow radially) without distortion and to float axially, greatly reducing drag.

3. Solid disc: A disk cast as a solid piece suitable for light cars not subjected to extreme braking.

4. Ventilated disk: A disc cast with internal cooling passages. The norm in racing, high performance and heavy vehicles.

Drilled or cross-drilled rotors: Disks that have been drilled through with a non-intersecting pattern of radial holes. The objects are to provide a number of paths to get rid of the boundary layer of out gassed volatiles and incandescent particles of friction material and to increase "bite" through the provision of many leading edges. The advent of carbon metallic friction materials with their increased temperatures and thermal shock characteristics ended the day of the drilled disc in professional racing. They are still seen (mainly as cosmetic items) on motorbikes and some road going sports cars. Typically in original equipment road car applications these holes are cast then finished machined to provide the best possible conditions by which to resist cracking in use. But they will crack eventually under the circumstances described in another section (see Cracking). Properly designed, drilled discs tend to operate cooler than non-drilled ventilated discs of the same design due the higher flow rates through the vents from the supplemental inlets and increased surface area in the hole. That's right, inlets, the flow is into the hole and out through the vent to the OD of the disc. If discs are to be drilled, the external edges of the holes must be chamfered (or, better yet, radiused) and should also be peened.

Drum in hat: A disc design in which the internal surface of the hat serves as a brake drum. Often used as a parking brake.

Dust boots: Rubber shields that fit over the exposed portion of the caliper pistons to prevent the ingress of dust and road crime. As no known rubber compound will withstand the temperatures generated by racing brakes, dust boots are not used in racing and should be removed before truly hard driving for extended periods.

Effective temperature range: The range of operating temperatures within which a pad material remains effective. As with coefficient of friction, this should be used for comparative purposes only as measurement procedures very between manufacturers and pad temperatures are strongly affected by disc mass and rate of cooling.

Ether based brake fluid: "Normal" brake fluids are based on Alkyl Polyglycol Ether Esters. Also, sometimes referred to as Glycol Ether Borate Ester fluids. DOT 3 and DOT4 fluids are suitable for high performance passenger car use.

Friction consistency: The variation in coefficient of friction over a range of repeated stops. Minimum variance allows efficient brake modulation.

Friction Mechanisms: For a pad and disc to function as a brake there has to be the conversion of kinetic energy to heat. There are two primary models of the mechanism of this conversion; both involve the breaking of bonds to release energy. In the case of the abrasion model the bonds broken are the ones already existing in a materials. The bonds are broken due to the chafing or abrasion of a harder material or particle in direct contact with it. The second model is the adhesion-breakage model where temperature and pressure at the interface between the pad and disc surface cause the fusion of one material to the other or the diffusion of one material into the other. In this case, the instantaneous bonds formed in the process are broken releasing energy. Pad materials function using both models at the same time or at different times. The abrasive mechanism predominates at lower temperatures but is also necessary to control build-up of low melting point pad materials at elevated temperatures where the adhesion-breakage mechanism is thought to predominate. The adhesion-breakage model requires a transfer layer of pad material to be established on the disc surface to function unless the brake system is designed so that the disc is fusing into the pad. The latter is the case with many high dusting European automotive designs where the disc wears observably as the pad wears. The iron in these discs is typically a "softer" more dampened form of cast iron.

Fade: Loss of braking efficiency from excessive thermal stress. There are three separate and distinct types of brake fade:

1. Pad fade: When the temperature at the interface between the pad and the rotor exceeds the thermal capacity of the pad, the pad loses friction capability due largely to out gassing of the binding agents in the pad compound. The brake pedal remains firm and solid but the car won't stop. The first indication is a distinctive and unpleasant smell, which should serve as a warning to back off.

2. Fluid boiling: When the fluid boils in the calipers, gas bubbles are formed. Since gasses are compressible, the brake pedal becomes soft and "mushy" and pedal travel increases. You can probably still stop the car by pumping the pedal but efficient modulation is gone. This is a gradual process with lots of warning.

3. Green fade: When the pad is first placed in service the first few heat cycles will cause the volatile elements of the material to out gas. The process is continuous throughout the service life of the pad, but it is most pronounced in the bedding in process when the out-gassed materials form a slippery layer between the pad and the disk reducing the coefficient of friction to near zero. Once the pads are bedded in out gassing is so slow as to not be a problem unless the effective temperature range of the pad is exceeded.

Fireband: The name given to the boundary layer of out gassed volatiles and incandescent particles of friction material that rotates with the disc.

Glycol brake fluid: See "ether based brake fluid"

Grooves: See "slotted"

Grooving: A wear pattern of concentric grooves on the surface of a disc. This can be caused by inclusions within the pad material, inappropriate pad material for the operating conditions. Poor initial machining of the disc and/or improper bedding in procedure. Not a major cause for concern on passenger cars.

Heat checking: The precursor to cracking. Heat checks are actually surface cracks caused by thermal stress. By themselves heat checks are not a cause for concern but they are a warning sign that the disk is not receiving adequate cooling air and cracks are sure to follow. See also the section "Cracking".

Hydraulic ratio: The ratio of fluid displacement by the master cylinder to fluid displaced in the caliper pistons. Hydraulic ratio is an important factor in the pedal effort equation, the higher the ratio, the less pedal effort is required (and the longer the pedal travel to achieve a given clamping force). The stiffer the caliper and the stiffer the pad, the higher the hydraulic ratio that can be employed.

Hygroscopic: The property of readily absorbing water. All non silicon based brake fluids are hygroscopic in nature. The adsorption of a minute amount of water will dramatically lower the boiling point of brake fluid. For this reason brake fluid should be completely replaced annually or more frequently in conditions of severe use. In professional racing, the fluid is replaced at least daily.

Knock back springs: Small coil springs fitted inside the caliper pistons of some brakes to prevent the pads from excessive knock back from flexing of the suspension system or run out in the discs. If the disc run out is within specification and the upright/axle assembly is sufficiently rigid, there should be no need for knock back springs. However, when operating conditions are severe with regard to either generated side force or bumps, they may be required on the best of designs.

Leading edge (of pad): With respect to disc rotation the leading edge is that edge of the pad that first comes into contact with the disc when pedal pressure is applied. Unless multiple pads or differential piston diameters are used the leading edge wears faster than the trailing edge. See "Differential pistons" and "Taper wear".

Line pressure: See "Brake line pressure"

Master cylinder: The hydraulic cylinder that transmits and multiplies the driver's pedal effort to the operating end of the braking system at the calipers.

Material transfer: Please see "Friction Mechanisms", where beneficial material transfer is discussed in context with the adhesion-breakage model. Otherwise, when the operating temperature of the pad (particularly organic pads) is exceeded, friction material may be deposited onto the surface of the disc in a non-uniform manner while degrading the braking capacity and causing noticeable roughness. The only cure is to either upgrade the pad material or increase the cooling (or both). "Pick up" should never be removed with ordinary sandpaper, which uses aluminum oxide as the abrasive. The same is true of sand blasting, don't do it. The correct way to remove pick up is by grinding (not turning) the disc. When that is not practical, the major portion can be removed by scraping and the remained sanded off with garnet paper.

Mechanical pedal ratio: The brake pedal is designed to multiply the driver's effort. The mechanical pedal ratio is the distance from the pedal pivot point to the effective center of the footpad divided by the distance from the pivot point to the master cylinder push rod. Typical ratios range from 4:1 to 9:1.The larger the ratio, the greater the force multiplication (and the longer the pedal travel)

Metal matrix (MMC): Term applied to a family of composite materials consisting of metallic cores infused with "whiskers" or "grains" of very stiff non-metallic elements resulting in a light and strong material. The most popular of the metal matrix composites is Aluminum Ceramic metal matrix, the ceramic typically but not exclusively being composed of Silicon Carbide, Aluminum Oxides and Boron Carbides, which are well suited for use in racing calipers. Also, lightweight disc have been made for Original Equipment and aftermarket applications using Silicon Carbide and Aluminum Oxides, but with only limited success due to two factors. The first being a low maximum operating temperature of the materials mentioned of around 900 o to 1000o F. Second the much greater expansion rate of the typically aluminum based MMC material results in thermal distortion or cracking. One OE application actually has small slots and stop drill holes positioned radially around the disc periphery. In all cases of MMC discs, the primary friction mechanism is the adhesion-breakage model. Please refer to the section, "Friction Mechanisms".

Modulation: The term given by the process by which the skilled driver controls the braking torque to maintain maximum retardation without locking wheels. Because the human being modulates most efficiently by force rather than displacement, effective brake modulation requires minimum pedal travel and maximum pedal firmness.

Monobloc caliper: A caliper machined from a single piece of billet, cast or forged material.

Multi pad systems: Caliper systems utilizing multiple pistons (either four six or eight) with separate pads and abutment systems for each pad. The design, almost universal in professional racing, provides multiple leading edges for better "bite". At the same time the very short pads ensure even longitudinal wear without the necessity for differential piston diameters

OE: This is an abbreviation for Original Equipment. Please see the section "Original Equipment". Sometimes it is used as an abbreviation to refer to the Original Equipment Manufacturer (but more correctly referred to as the OEM).

OEM: This is an abbreviation for Original Equipment Manufacturer.

Off brake drag: A condition in which the caliper pistons do not fully retract when line pressure is released. Off brake drag increases temperature and wear while decreasing acceleration, top speed and fuel mileage. It is caused by either non-optimum seal design, seals that have been hardened by thermal stress or excessive disc run out.

Original Equipment: This is an industry standard term for that equipment that was installed on the model(s), being referred to in context, at the time of manufacture.

Organic (pad material): A family of friction materials, often containing asbestos, used for both drum linings and disk pads through the 1980s. Now largely replaced by semi-metallic materials with better temperature characteristics.

Outgassing: The boiling off of the volatile elements in friction materials. Out gassing, while it is continuous over the useful life of the pad, is only noticeable during the bedding in process or when the temperature capability of the pad has been exceeded. Under those conditions the volatiles form a layer between the friction materials and the disc surface, smelling bad and causing "green fade".

Pad: The stationary element of the disk brake system. The pads, consisting of friction material bonded to steel backing plates are held in place by the caliper and forced against the disc by the caliper pistons when pedal pressure is applied.

Pad abutments (or pad abutment plates): Mechanical elements that locate the pads in the caliper and provide hard surface for the pads to slide against. Non-ferrous (Aluminum or MMC) calipers, which do not provide hard and smooth surface to locate the ends of the pads and provide an efficient sliding surface, should be viewed with great suspicion.

Pad retraction: To prevent drag and premature pad wear the properly designed seal systems retract the caliper pistons a few thousandths of an inch when the pedal pressure is released. This allows what little disc run out there is to "knock" the pads back from contact with the disk. When everything works right the amount of retraction is so slight that the free play in not noticeable when pedal pressure is applied.

Pick up: See the section Material Transfer.

Caliper Pistons: The hydraulic cups that transmit line pressure to the pads to clamp the pads against the rotating disc. Manufactured from Aluminum, steel or Titanium and sealed in the caliper bores, the mechanical design of the piston is critical. The inescapable drag of the pad against the disk tends to "cock" the piston in its bore so the piston to bore clearance, thermal coefficients of expansion between piston and caliper as well as seal design and location are crucial. Care should be taken in using pistons or seals from a supplier other than an OEM. In all cases that a Stoptech part is listed as a direct replacement for the OE part, it will work as well as the OE part.

Plot shape: The shape of the friction plot during a long brake application it is easier and more efficient for the driver to add pedal pressure than to remove it. Therefore the easiest pad to modulate exhibits a high initial bite followed by a gradual decrease in coefficient throughout the stop. If the level of friction rises throughout the stop, brake modulation will be very difficult.

Pressure bleeder: A tool allowing rapid bleeding of the system and replenishment of the fluid. Pressure bleeders should never be used on racing or high performance cars as the rapid forcing of the fluid through small passages may cause cavitations and the formation of air bubbles rather than their removal.

Proportioning valve: A rear brake line proportioning valve is found on most cars that do not feature anti lock brakes. Its function is to limit the amount of pressure transmitted to the rear brakes under very heavy retardation. Front and rear line pressures are the same until some pre-determined "knee" point is reached. After this point, rear line pressure, while it still increases linearly with pedal effort, increases at a lower rate than front. The purpose is to avoid rear wheel lockup and the attendant unstable oversteer. It is not a good idea to remove the proportioning valve from a road going automobile for highway use. If you feel that you must do so, the best way is to remove the OEM rear brake line proportioning valve completely and replace it with one of the adjustable units manufactured by Tilton Engineering or Automotive Products. Do not place a second proportioning valve in line with the OEM unit.

Radiation: One of only three heat transfer mechanisms. Conduction and Convection are the other two. Radiation is the transmission of energy by the emission of waves. In the case of braking systems, thermal energy is emitted by both the discs and the pads at elevated temperature. In the case of the disc, as temperature increases, radiation is the predominant heat transfer mechanism. The focus in disc designs is on the vent or the vanes because it is something that can be changed significantly at a reasonable cost. While radiation is a function of the material choices made, keeping in mind the other functional parameters necessary for the application. A large portion of this radiant energy can be reflected into the air stream by "radiant barriers", such as ceramic coatings on the internal surfaces of calipers.

Release characteristics: The opposite of "bite", release characteristics become important when braking into turns either on the track or on the road. If the braking torque does not decrease linearly with decreasing pedal pressure "trail braking" becomes difficult at best.

Reservoir: The container in which brake fluid is stored to provide a source of fluid for the master cylinder(s). The reservoir must have sufficient volume to allow fluid displacement equivalent to wearing the pads down past the backing plates. It must also be sealed to prevent the absorption of moisture by the highly hygroscopic brake fluid. Typically the reservoir cap is fitted with an electrometric bellows open to atmosphere but sealed from the fluid.

Residual pressure valve: Some passenger cars, particularly those equipped with drum rear brakes, are fitted with a "residual pressure valve": which functions to ensure that the pads are kept in close proximity to the discs despite run out, knock back, etc. The residual pressure is very small (2-4psi.) so off brake drag is not a problem for street use.

Rotor: see "Disc"

Run out: The amount of axial dimensional variation of the surface of the disc as it rotates. Measured with a dial indicator, normal specification is 0.000 to 0.005" total run out. Excessive run out results in inefficient braking and perceptible pedal pulsation.

Seals: Caliper pistons are sealed in their bores by electrometric rings seated in grooves. The seals fulfill a secondary function of slightly retracting the pistons when line pressure reduced to zero at the end of braking. This prevents "off brake pad drag", reducing both temperature and wear. Both the compound and the mechanical design of these seals are critical. The cross section of properly designed caliper seals is square, not round. "O" rings cannot be substituted.

Seal grooves: The caliper seal grooves can be either in the caliper bore or on the piston (or both). The mechanical design of the grooves is critical to ensure optimum piston retraction. The cross section of a proper caliper piston seal groove is trapezoidal, not square.

Semi-metallic: Friction materials compounded with significant amounts of metallic elements to increase the operating temperature range.

Silicon brake fluid: Brake fluid based on silicon. While silicon based fluids are less hygroscopic than ether based fluids, they are subject to "frothing" when subjected to high frequency vibration and when forced through small orifices. This makes them unsuitable for racing or high performance use.
Sliding caliper: See "Caliper, Floating Caliper"

Slotted:

1. Disc: Shallow, sharp edged but radiused bottom grooves milled into cast iron discs to provide leading edges for bite and a path for the fire band of gases and incandescent friction material to be dissipated through. If the slots fill up with pad material, the system is operating at too high a temperature.

2. Pad: Radial grooves molded or cut into the surface of the pad to provide a path for fire band dissipation and to double the number of leading edges and improve bite. Some long pads also have a longitudinal groove.

Squeal: Annoying high-pitched noise associated with some combinations of friction materials at low brake torque values. Reduced by the use of anti squeal plates. Can be improved by a different pad material, but also made worse if the former and current pad materials are incompatible.

Squeeze form casting: A casting process that is a cross between die casting and forging. Liquid aluminum is poured into a die and, just before it begins to solidify, the die is forced closed under very high pressure. Alternatively a second cylinder is filled during the molding other than the primary injection cylinder that is then compressed at high pressure to increase the molding pressure. The process reduces porosity and leaves the grain structure more like a forging than a casting - resulting in a stronger and stiffer part.

Stainless steel brake lines: Flexible brake hoses made of extruded Teflon™ protected by a tightly braided cover of stainless steel wire. Because these hoses virtually eliminate line swelling under pressure, they are universally used in racing applications to reduce pedal travel, increase pedal firmness and allow more efficient brake modulation. A few manufacturers offer stainless steel braid protected hoses of extruded Teflon, which meet all of the DOT requirements for passenger, car use. Several more offer hoses that claim to meet the specification but do not. Let the buyer beware.

Stiffness: Stiffness is the resistance of a material or a structure to deformation. It is not the same as strength. The stiffness of a material is indicated by its "modulus of elasticity" - the measure of the elasticity of the atomic bonds within the material. It is essential that calipers (and caliper mountings) be stiff. Which is why metal matrix composite materials are used for racing calipers.

Strength: Strength is the resistance of a material or structure to rupture. It is defined as the stress required to rupture the atomic bonds of a material. It is not the same as stiffness.

Taper wear: Uneven wear of brake pads caused by geometry, by the difference in temperature between leading and trailing edges and/or by lack of stiffness in the caliper. When pads are taper worn, the first increments of caliper piston travel are used up in forcing the pad against the disc, increasing pedal travel. Additionally the piston tends to cock in its bore resulting in bore scoring and wear.

1. Radial taper: Radial taper is apparent when the pad is viewed from either end. The linear speed between pad and disc is greater at the periphery of the disc and so the outer surface of the pad wears faster. In addition any tendency for the caliper to "open up" under pressure like a clamshell results in more pressure being placed on the outer portion of the pad, further increasing relative wear. For this reason many pads are trapezoidal in plan view with less surface area toward the inside.

2. Longitudinal taper: Longitudinal taper is apparent when viewed from either the inner or outer surface of the pad. The trailing section of the pad is partially floated in the boundary layer of out gassed volatiles and incandescent particles of friction material torn from the leading section. The leading edge of the pad will therefore always run hotter and wear faster than the trailing edge. This phenomenon is more pronounced in long pads and is one of the major reasons why racing calipers are designed with a multitude of small pads. (See "Multi piston calipers")

Thermal shock: Disc materials, particularly cast iron are degraded not only by the magnitude of temperatures reached, but also by the "delta" temperatures the speed at which the temperature increases and decreases. Cracks are largely caused by weakening of the bonds between the grains of the metal brought about by rapid change in temperature.

Threshold braking: Braking at maximum possible retardation in a straight line.

Titanium: A very light, very strong metal will very low thermal conductivity. Almost universally used to make caliper pistons for racing applications in order to reduce heat transfer to the fluid within the caliper.

Trail braking: The process in which the skilled driver "trails off" the brakes as he enters a corner, thus combining braking and turning in the initial phase of the corner and maximizing the total traction available from the tires. The technique, universal in racing, although not always admitted, also effectively lengthens the straight preceding the corner.

Trailing edge (of pad): That portion of the pad located away from the direction of rotation of the disc.

Two part caliper: A caliper manufactured from two essentially mirror imaged parts rigidly bolted together. To perform as well as a monolithic caliper, the assembly must result in a rigid structure by design, bolt selection and materials.

Vanes: The term given to the central webs which serve to separate the inboard and outboard friction surfaces of ventilated disks

1. Straight vanes: Straight vanes are the easiest to manufacture. They extend in straight lines radially outward from the inner surface to the outer surface of the disc. This design is often used in production automobiles and trucks because the same part can be used on both sides of the vehicle.

2. Curved vanes: Curved vanes are shaped as curves to act as more efficient pump impellors and increase mass airflow through the central portion of the disc. They also act as barriers to the propagation of cracks caused by thermal stress and, as each vane overlaps the next, they dimensionally stabilize the disc. Curved vane discs are more expensive to produce that straight vanes and must be mounted directionally. They are universally used in racing where carbon/carbon brakes are prohibited.

3. Islands: Some designs utilize "islands" to separate the friction surfaces rather than vanes. Properly designed the island system is dimensionally stable but inefficient from the viewpoint of airflow.

4. Differential vanes: Some discs are designed with alternating vanes of different length. This modern design feature that was the dictated by flow studies. It was found that the volume of air that a disc can flow increases by alternating the length of the inlet without much of a sacrifice in surface area. The more air a vent flows, the more convective cooling can be realized.

Wear sensors: To ensure that pads are replaced before they are worn down to the backing plates, several types of wear sensors are employed. Most production cars are designed with a float in the master cylinder reservoir. When the pads have worn to the minimum permitted thickness, enough fluid has been displaced to ground the float and complete an electrical circuit that activates a warning light on the dash. Alternatively some cars use an electronic wear sensor in the pad. This type of sensor typically is worn through when wear limits are reached, breaking continuity in the sensor circuit. As such, it needs to be replaced if the light has come on. There is another less expensive method used where the pad has a thin but stiff tab riveted to the pad backing plate that rubs on the disc face and squeals when the wear limit is reached. In some modern racecars used in long distance events, calipers are fitted with more complex electronic sensors and circuitry to warn the drivers and, by telemetry, the crew of the pad condition.

"Mini brake test"...(I no longer own the 328i)

2 friends and me performed a little brake test this morning.

I have a friend that works at a small airport and was able to gain access to a nice flat and large area. Not a runway.

We brought my 2000 BMW 328i with sport package and new WRX.

Atmosphere Conditions at the time (benefit of being at an airport):

Temp: 54 F, Humidity 55%, Barometer 30.28in and rising, Wind 6 MPH East, partly cloudy

Surface was perfectly dry and smooth. Surface was concrete.

The vehicles:

2002 Impreza WRX Sportwagon with manual transmission, SSR Competition wheels, 225/45ZR17 Bridgestone Potenza S-03 PP tires, Tein H-Tech springs, rear 20mm anti-roll bar. All else stock, including brakes.

2000 BMW 328i with manual transmission and the sport package, all stock. The tires: 225/45ZR17 Michelin Pilot Sports.

The WRX tires have 650 miles on them; the BMW tires have 7000 miles on them. All pressures where set at the recommended settings as posted on the driver's doorjamb.

WRX has 720 miles on the pads; the BMW has 7000 miles on the pads.

Some important numbers on the BMW:

Curb Weight: 3197lbs, Weight distribution front/rear: 50.5/49.5, brake setup: single piston sliding calipers front and rear with 11.8 inch front rotor and 11.6 rear rotor both ventilated.

Some important numbers on the WRX Sportwagon:

Curb Weight: 3165lbs, Weight distribution front/rear: 58.5/41.5,
brake setup: dual piston sliding caliper up front and single piston sliding caliper in the rear with 11.4 ventilated rotor in front and 10.3 inch solid rear rotor.

Test procedure:

10 consecutive stops from 60MPH (using the car's speedometer, so chances are it wasn't exactly 60MPH). That's all I had the time to do.
Consecutive means the time it took to turn around get back to the start and then 30 second wait.

3 drivers. Myself, worked as a brake engineer and have experience. Driver 2 is a "car guy" and knows how to drive. Driver 3 is good driver but not a "car guy."

All numbers are rounded to nearest whole number, so no 120.5 feet, that would be listed as 121 feet. I do this because of the nature of the test and the measuring equipment. Which consists of 10 cones spaced 15 feet apart and a tape measure.

The BMW's DSC (ESP system) was turned off, so both cars had ABS only working.

For time reasons I was the only driver to do all 10 runs.

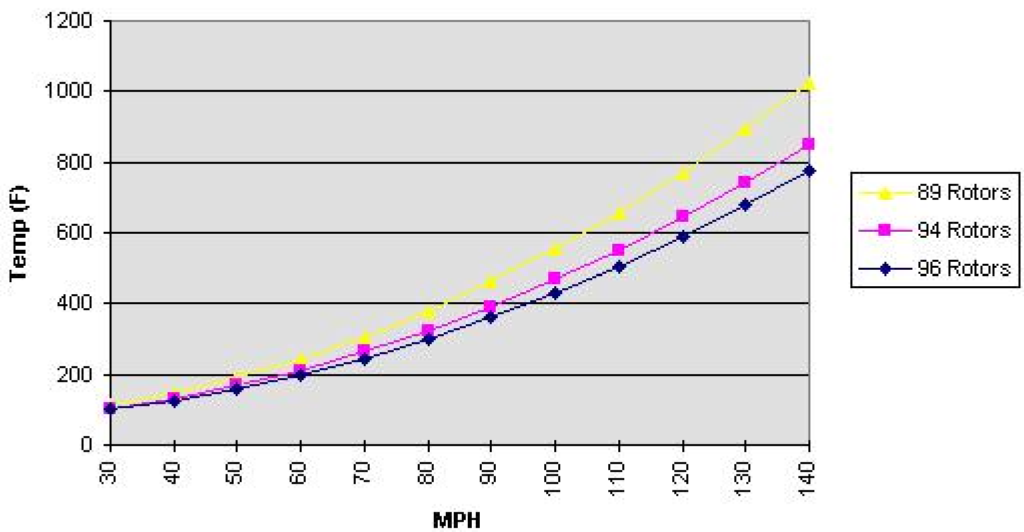
The results (all in feet):

------------------------WRX---------------------BMW
Run 1......................121..........................117
Run 2......................121..........................116
Run 3......................121..........................116
Run 4......................123..........................117
Run 5......................125..........................117
Run 6......................125..........................119
Run 7......................128..........................121
Run 8......................133..........................121
Run 9......................133..........................121
Run 10.....................133..........................121

Take these numbers for what their worth. Please keep in mind the difference in tires and miles on them. And the "test equipment" used. Disclaimer: This is for entertainment purposes only.

Appendix

Typical Temperature Curve for a Rotor



DOT Pad Codes

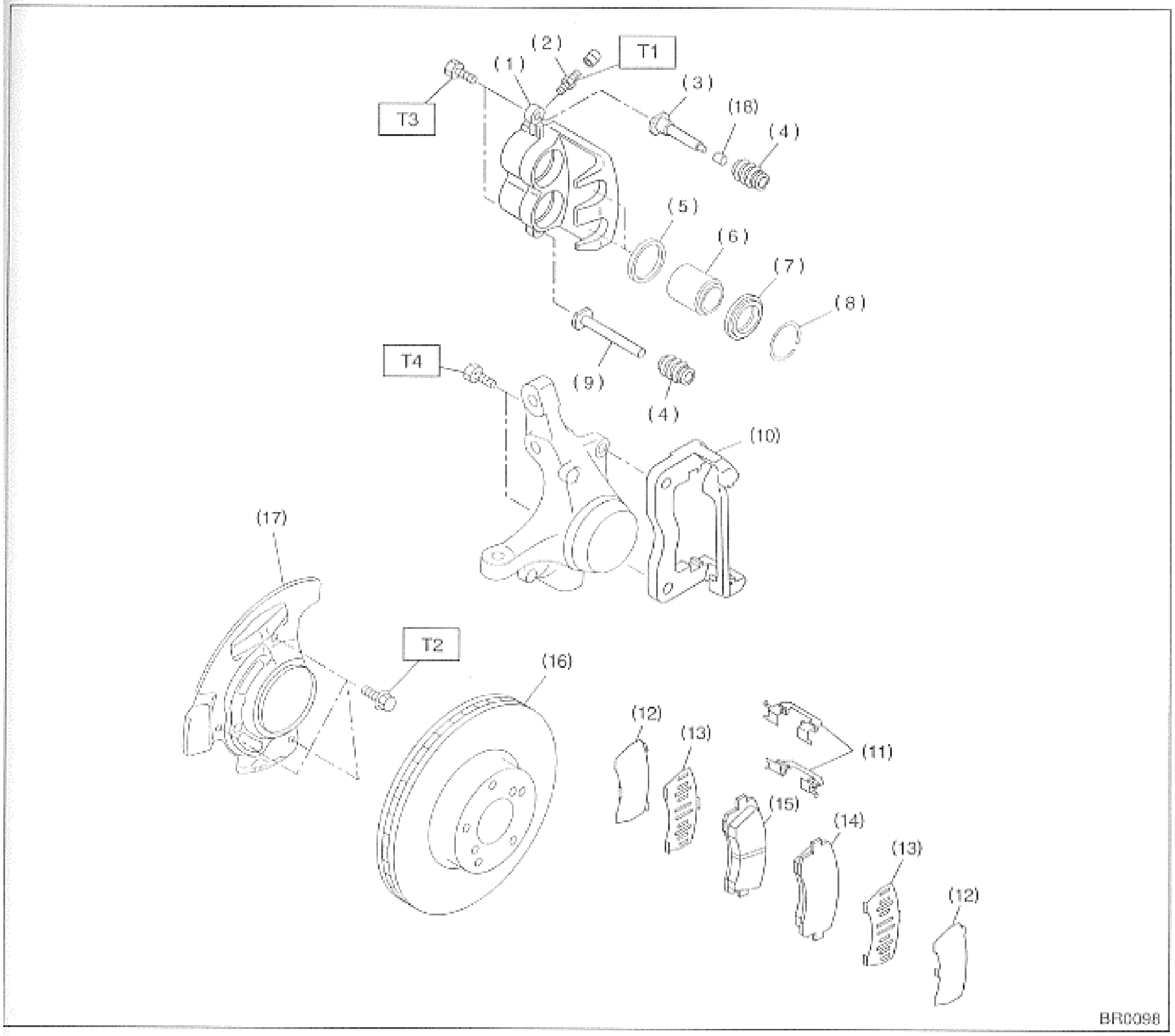
This two letter edge code mandated by the DOT, and painted on all street legal brake pads, will give you some indication of their ability to resist fade. But only if you know how to read them. However, because of the wide range involved in each letter, it is only a rough indication.

Explanation of D.O.T. Edge Codes Located on all Brake Pads

Official D.O.T. Edge Code	Coefficient of Friction (C.F.) @ 250 F and @ 600 F	Comments
EE	0.25 to 0.35 both temps	0-25% fade at 600 F possible
FE	0.25 to 0.35 @ 250 F 0.35 to 0.45 @ 600 F	2% to 44% fade at 600 F possible
FF	0.35 to 0.45 both temps	0-22% fade at 600 F possible
GG	0.45 to 0.55	Very Rare NOT ANYMORE
HH	0.55 to 0.65	Carbon/Carbon only. O.K. up to 3000 F where it glows

Notes: These edge codes are located on the edge of the friction material of every brake pad by government regulation, along with some other codes. The first letter is a grading of the C.F. at 250 F and the second letter is a grading of the material at 600 F. Each letter grade can actually have quite a range of C.F. But a difference in the letter grade from medium to hot temperature could be an indicator of fade. The letters can be in any order. Therefore FE pads fade when hot, and EF pads would not grab when cold.. Also, you should know that Steel on Steel has a C.F. of 0.25!! So EE pads have only marginally more torque than no pads at all! Therefore FF pads are usually considered the minimum for a high-performance pad.

Typical Front Brake Setup

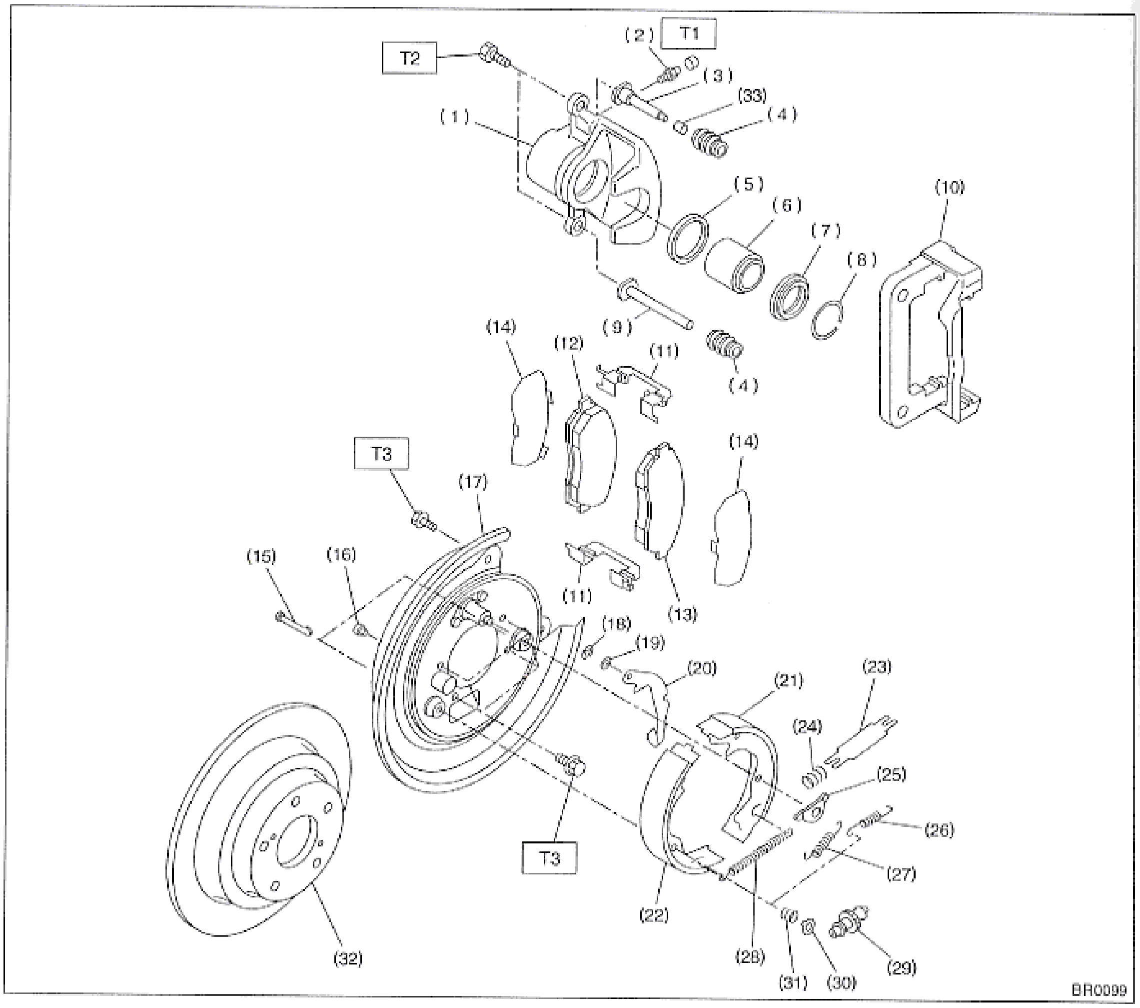


(1)	Caliper body	(9)	Lock pin (Yellow)	(17)	Disc cover
(2)	Air bleeder screw	(10)	Support	(18)	Bush
(3)	Guide pin (Green)	(11)	Pad clip		
(4)	Pin boot	(12)	Outer shim		
(5)	Piston seal	(13)	Inner shim		
(6)	Piston	(14)	Pad (Outside)		
(7)	Piston boot	(15)	Pad (Inside)		
(8)	Boot ring	(16)	Disc rotor		

Tightening torque: N·m (kgf-m, ft-lb)

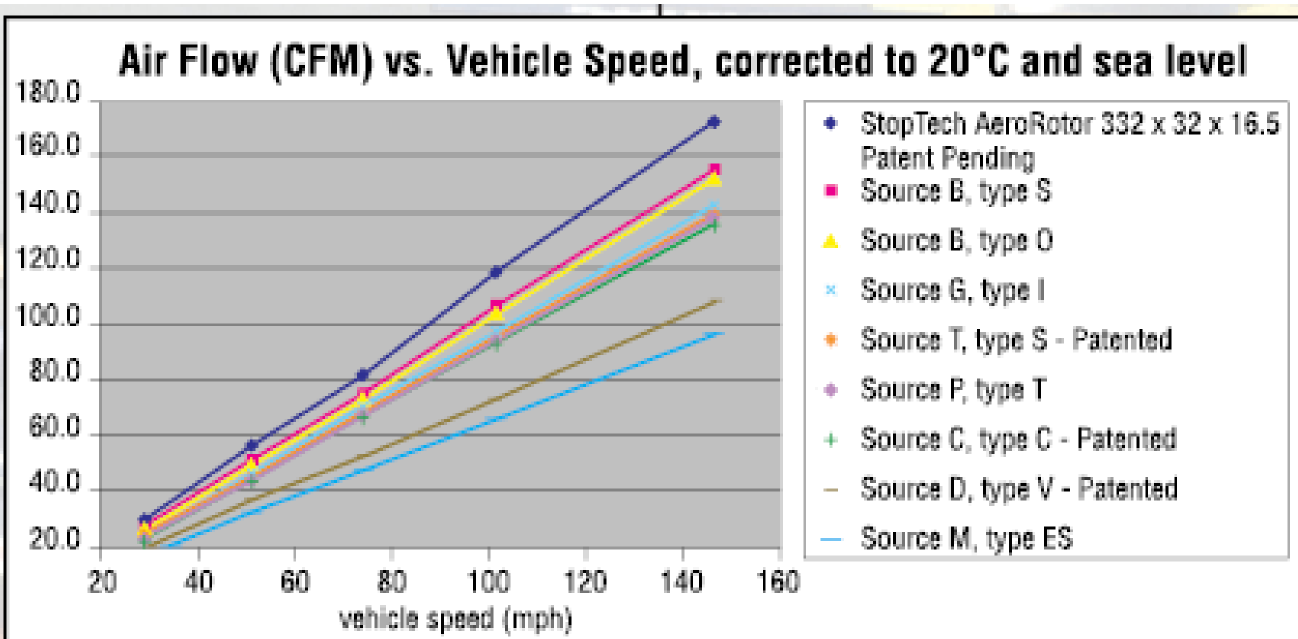
T1: 8 (0.8, 5.8)
T2: 18 (1.8, 13.0)
T3: 37 (3.8, 27.5)
T4: 80 (8.2, 59)

Typical Rear Brake Setup



(1) Caliper body
(2) Air bleeder screw
(3) Guide pin (Green)
(4) Pin boot
(5) Piston seal
(6) Piston
(7) Piston boot
(8) Boot ring
(9) Lock pin (Yellow)
(10) Support
(11) Pad clip
(12) Inner pad
(13) Outer pad
(14) Shim
(15) Shoe hold-down pin
(16) Cover
(17) Back plate
(18) Retainer
(19) Spring washer
(20) Parking brake lever
(21) Parking brake shoe (Secondary)
(22) Parking brake shoe (Primary)
(23) Strut
(24) Strut shoe spring
(25) Shoe guide plate
(26) Secondary shoe return spring
(27) Primary shoe return spring
(28) Adjusting spring
(29) Adjuster
(30) Shoe hold-down cup
(31) Shoe hold-down spring
(32) Disc rotor
(33) Bush

Tightening torque: N·m (kgf-m, ft-lb)
T1: 8 (0.8, 5.8)
T2: 37 (3.8, 27.5)
T3: 53 (5.4, 39.1)



Leading after market & original equipment rotors were tested for airflow from 30mph to 150mph. AeroRotor™ dramatically out performed all other rotors, with improvements from an impressive 11% to a staggering 80% increased air flow.