# Suspension Basics

## Keeping the Rubber on the Road

Suspension and handling are, without a doubt, among the greatest mysteries in performance cars, and yet the components that affect these characteristics are often the first to be changed to make the car look cooler or in hopes that it can be made to handle better.

Tires and wheels are replaced, the suspension is lowered, and shocks and springs are stiffened in hopes of improvement, but more often than not, the car performs worse than if it had been left stock. Why is that? In this and the next article I'll try to demystify suspensions and handling, and make some suggestions about how you can change yours, if that's what you want, in pursuit of your own goals.

### Where Handling Starts and Ends

Last night, I took a tape measure outside. The *contact patch* of my tire (the area of the tire that actually is in contact with the road) is about 4 inches by 6" inches, just about 25 square inches. It was cold (for California) and late at night, so I didn't really do an accurate job, but the numbers are close enough. You can see one of the footprints in Figure 1.

If you think about it, that's about 100 square inches of surface area that is the only thing that keeps a car going where you want it to. Every acceleration, turn or brake event exerts a force on the road through this rather meager patch (four patches really, at least most of the time) of rubber. Kind of scary when you think about it, really. The job of the suspension system is to make sure that this contact patch is optimized and is usable as the car goes through its day-to-day chore of accelerating, braking, turning and driving over bumps.

While this is a pretty simple proposition, it's exceedingly difficult in practice. Both the wheel alignment and suspension settings affect how the car handles, and of course, they interact with each other. So the process of optimization is complex and never-ending.

Because everything is related to everything else, there may be more than one way to make a specific change. And to make matters even worse, the "best" suspension geometry depends on driving style, road condition, temperature and so forth, so what works well for one driver today may fail miserably tomorrow.

Look at professional race teams. Some of them spend millions of dollars a year running the cars, and they may tune the suspension differently for each track and many times during the course of a race, making every effort to stay up on that unstable and illusive pinnacle of performance.

Suspension optimization (also known as *sorting* in race circles) is more of an art than a science, practiced by many and mastered by few. I must admit that I haven't sorted the suspension on my car to my satisfaction yet, and at least for me, it's a harder thing to do than to mod and tune a motor for more power.

But despite the nearly impossible task of becoming a suspension guru, it's not too hard to become a suspension journeyman. There are some basic concepts that are pretty easy to learn, and will help you as you make decisions about if and how to change your car's suspension, and the compromises that will come along for free!

And despite my cautions at the start of this article, suspension optimization can yield huge benefits for all models of Mini. And a well-sorted suspension will always allow you to use whatever power you have better and more effectively, most notably by increasing the speed you can carry with confidence through corners. But it's not all about speed. Better suspension set up can lead to shorter response times and braking distances, as well as more predictable handling in emergency situations, all increasing vehicle safety.

### The Basics

Before we break out the wrenches and credit card to start bolting things up, we need to review the basics. The function of the suspension is to keep as much rubber in contact with the pavement as possible while keeping the occupants comfortable and the car under control.

It needs to do this in a smooth, predictable and controllable manner. When we look at the suspension geometry, we'll really encounter a collection of compromises that the engineers made when they designed your MINI. This isn't a knock on the MINI, as every suspension geometry is a collection of compromises!

This all starts with the tire. The other parts of the puzzle are the springs, struts, bushings and sway bars. Only after the functions and interactions of all these bits and pieces is understood can one hope to make any changes that actually make the car handle better.

### The Tire

The tire is what's between the car and the road. When considered in this regard, it's the single most important part of your car. Don't skimp here, as going cheap here means that you have longer braking distances and a less responsive car, and are sacrificing safety. I'm not going to get into the run-flat vs standard tire debate – each has its advantages – but I will say that if you spend any extra money on your car at all, it should be the tires.

Good tires give you more than just a hole in your wallet. Better tread quality gives you better adhesion to the road, not just for improved track times but for accident/obstacle avoidance and braking. This is some of the cheapest insurance there is, but you will pay more at purchase time, and better, that is, stickier tires will wear out sooner.

by
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Figure 1:This is what the tire patch of a MINI looks like (This is an actual pawprint from my driveway). That's all the rubber that is in contact with the road.

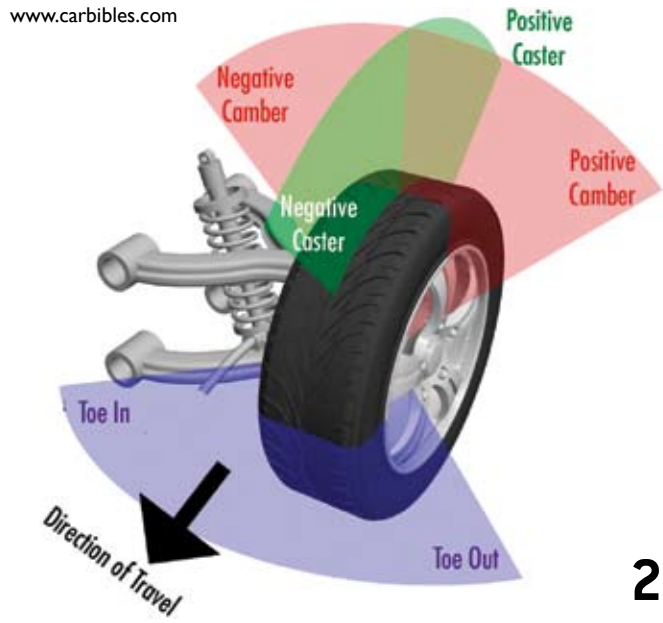



Figure 2: A graphic illustration of a generic suspension showing the three adjustment variables and the terms for their adjustment angles.

But there is more to the tire than just tread. It's an integral part of your suspension. The tire is a spring, and is responsible for a significant portion of the road noise, vibration and harshness (NVH) isolation that keeps you from losing your fillings every time you hit a bump. The side wall is also what transfers most of the road feel and feedback through the steering wheel.

The "springiness" of the tire can be tuned very easily via tire pressure. There are two lessons here. The first is that you should play with your pressures to find what you like best, before spending time or money on the rest of the suspension. (I think this is the single most overlooked thing in suspension modification.)

The second thing is to watch your pressures very carefully, as they change over time. You should check weekly if you drive the car any distance at all. (For you racers-to-be, what really matters is hot pressures, not cold pressures. But for street driving, setting the pressure when cold is fine, as it provides a pretty consistent baseline.)

## Alignment

No matter what parts you have on the car, you have to start with a good alignment. Even if you have the best parts in the world bolted onto you car, the car won't drive worth crap if all four wheels point in vastly different directions!

Like all specialties, there is quite a bit of vocabulary you have to understand in order to "speak the language." And there's no time like the present to start…. New words will be in italics the first time I use them.

So, for alignments, the three basic ideas are *caster, camber,* and *toe.* Before going farther, look at Figure 2. It shows camber, caster and toe better than I could ever explain it! So, what do they do?

*Caster* is what causes your steering wheel to return to center by itself. It works because with negative caster, the steering axis hits the ground in front of the contact patch of the car. (If this sounds confusing, go look at the front wheel of a bicycle.) When you turn the wheels, the friction and drag on the contact patch draw it backwards, straightening the steering. Caster on a stock MINI is fixed, but some aftermarket camber/caster plates that go at the top of the strut assembly make it adjustable.

*Camber* is the inward tilt at the top of the wheel that you see on serious sports and race cars. Increasing the negative camber improves cornering, at the price of tire wear while going straight. With extreme negative camber, most of the weight of the car is on the inner edge when you're going straight, and you'll get uneven tire wear.

So why have any negative camber? Because when you're turning, the negative camber keeps the contact patch flat on the outside tires, where most of the car's weight is while turning. So it's a trade-off: even wear for better cornering.

(On a very important note, this concept of the trade-off shows up all over in suspension tuning. Be prepared to bump into it again. Also, keep the trade-offs in mind as you think about changing the handling of your car. You can make a car handle really well on a track that you'd never want to drive to the corner store for groceries!)

Camber is fixed in the MINI on the front, and depending on year of manufacture there may be a bit of camber adjustment on the rear. There are lots of parts out there that will change the front camber a fixed amount, or allow you to adjust for a continuous range. Adjustable control arms are available for the rear as well, to provide even more range of adjustability. Front camber is one of the areas where all stock MINIS can be improved. They come with too little negative camber from the factory, and spirited driving eats away the outer front tires very quickly.

Last but not least is *toe.* Street cars are built with a slight amount of toe-in, with the fronts of the wheels turned slightly to the center, so that the car will tend to go straight when there's no steering input.

Toe affects turn-in, high speed stability and top speed. Zero toe, with the front wheels parallel with one another, will cause a car to turn easily, but will be a bit twitchy in daily use. All Minis have adjustable front toe via the tie rods, even my lowly '02! Toe on the rear wheels can also can be adjusted on all Minis via aftermarket adjustable control rods.

## Suspension Geometry

The suspension geometry (which is independent at all four corners) that the Mini uses is called a *MacPherson Strut* in the front, and multi-link in the rear. Figure 3 shows the MINI's MacPherson Strut setup. The key items here are that a lower member (the *wishbone*) pivots on the chassis at two points, and the MacPherson strut (a shock absorber and spring that is one of the support points of the wheel and pivots at the top and bottom to allow the wheel to turn for steering) connects to the chassis high up, just under the hood.

There are a couple of nice features about the this setup. One is its simplicity. It's really just two parts: the wishbone and the strut. But the biggest advantage (to the manufacturers) is that it doesn't poke into the engine bay too much, and the lower member can be placed under the car. This gives lots of room for front-wheel drive systems that connect

Figure 3, *near right*, is a picture of the front suspension, with the Macpherson Strut connecting the wheel at the top, and an a-arm connecting it at the bottom. *Far right*, figure 4 shows the rear suspension from the side. It is easy to see why this is called a "trailing arm" suspension.



the wheels to the engine, crumple zones and the like. While you don't see this on an F1 car, it's a very competent and tunable system.

The rear suspension is called a *multi-link suspension*, but that's just a catch-all phrase for lots and lots of suspension designs that simply means the wheel is fastened to the chassis at several points.

It's really a trailing link suspension, to be more accurate. That means the suspension arm connects to the chassis in front of the rear subframe with the wheel trailing behind the chassis connection point, as shown in Figure 4.

The arm's lateral (sideways) motion is constrained by the control arms, two on each side, as shown in Figure 5. Unlike the front suspension, the rear struts have no role in rear wheel alignment. This is a very nice rear suspension set-up that owes its roots to the BMW Z3 and doesn't take up too much cabin space. This particular design has a pretty high *camber gain* (the camber, or slant, of the wheel changes as it moves up and down), something we'll need to keep in mind later, when we consider modifications to the stock set up.

## The Rest of the Bits

The remainder of the suspension components include the shock absorbers, the springs, the anti-sway bars and, not to be forgotten, the bushings. In simple terms, these are all the parts that are easy to change, whereas suspension geometry can only be varied a little bit by the owner, without getting out the plasma cutter, Sawz-All and welder.

But there's something else too; you can think of the basic geometry as a given, with all the rest of the bits (including the tire and wheel alignment) can be used to tune the suspension and change handling characteristics.

The idea of a *shock absorber* is pretty simple. It dissipates the energy of the bumps away, so the car doesn't just keep bouncing.

But like everything else, it's not as simple as it seems. The amount of energy that a shock dissipates has to be engineered very carefully; not enough dampening, and the car starts to float and feel disconnected from the road; too much and you feel every bump and surface imperfection, and both you and your car get rattled to an early end. A simulation of suspension deflection is shown in figure 5.

(Note that as the dampening increases, the suspension deflects a smaller and smaller percentage of the bump height. That extra amount of required deflection has to be absorbed by the tire sidewall, or it gets transferred to the chassis with quite a whack!) After tire selection, the shock selection or setting is the most powerful variable you can control to affect handling and ride comfort.

A *spring* is an even easier concept to understand. It's what provides the compliance of the suspension. Stiff spring, little compliance; soft spring, lots of compliance. From the factory, the MINI uses linear rate springs (where the spring constant is the same through the whole range of motion, more about that later) that are tuned for the suspension type you have (Sport or Sport Plus) as well as the weight of your car.

The key thought here is that the springs that come on the car are matched to the struts and the car. This is so that the combination of springs and struts will create a suspension with optimum dampening and ride quality. The bad news here is that if you start changing just one and not the other, you may run into some unintended (read bad) effects.

The bushings, or rubber bits in between the metal pieces, are often ignored as well when it comes to suspension function. But deflection in these softer parts really improves NVH to a degree that is hard to believe. If you've ever ridden in a race car with solid Heim-joint suspension, you'll know exactly what I mean. The price of bushed suspension component compliance is a geometry that varies by load and deflection, and this invariably comes with some loss of handling precision.

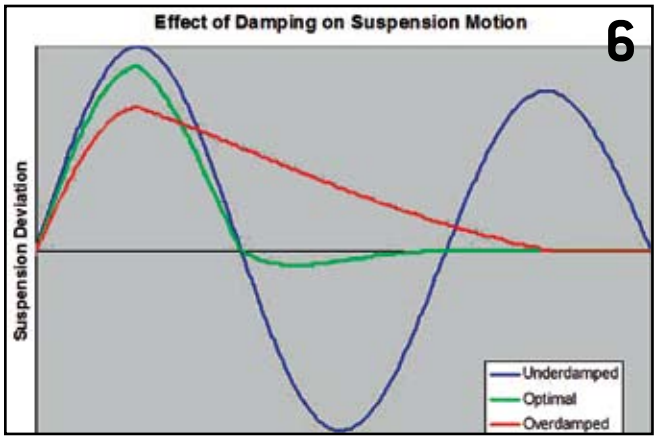
The *anti-sway bar* is used to reduce body lean in turns. Now the reason a car leans is pretty obvious, but to put it in suspension language, it's because the car's *center of mass* is above its *roll axis*. The roll axis is the axis about which the car rotates when it leans during a turn. It is defined by drawing a line through the *roll centers* of the front and rear suspension. The roll centers, and hence the roll axis, are determined by the suspension geometry. Another interesting point is that the roll axis changes as the car suspension extends or compresses. This will be important later when we start making changes.

Fastened to the chassis and to the wheels, the anti-sway bar works by transferring some of the cornering force from the outside to the inside wheel when turning, which helps keep the chassis level in corners.

The anti-sway bar is also used to exert some control on weight transfer when cornering. We have recommended the installation of a stiffer anti-sway bar for most drivers interested in more responsive handling, since it helps tune out the biggest deterrent to enthusiastic driving of the stock MINI suspension, and that is *understeer*. Understeer is when the car doesn't turn as much as you want it to as you turn the wheel. The car plows and doesn't turn as readily as you might wish. And that leads us to handling dynamics.

## Handling Dynamics

The suspension really has to perform its job in three different cases. One is the turn, another is when one wheel is going over a bump, and the third is braking and acceleration. All real world suspension events are a combination of some or all of the above. I'm going to skip over straight line acceleration and braking since these are relatively benign events (the reason you should try to do most acceleration and braking while the car is going straight), and focus on the two items that are most im-




*Far left,* Figure 5 shows the rear suspension from the back of the car. The blue piece is an adjustable lower rear control arm. *Near left,* Figure 6 shows the movement of the suspension when the wheel hits a bump; the best allows the wheel to come back to position without oscillating.

> "The function of the suspension is to keep as much rubber in contact with the pavement as possible while keeping the occupants comfortable and the car under control."

portant to most drivers, turning and going over bumps.

So, what really happens when you turn your steering wheel? Simply, the front wheels turn (the inside wheel a different amount than the outside wheel), the tires deform to exert a lateral force via the contact patch and the front end of the car is literally pushed off of a straight path. (Well, the outer tire pushes, and the inner one pulls, to be accurate, but you get the idea.)

*Centripetal acceleration* (the force you feel pressing you sideways as you corner) pushes on the car and it leans to the outside of the turn, transferring more of the weight to the outside wheels. The outer suspension compresses, and the inner suspension expands. When all the transition is done, this is known as the car *taking a set.* If you are lucky and good, the roadway will be smooth enough and your turning line will be good enough that you can keep the set until you unwind out of the turn, gassing it for the straight or starting to take a set for the next turn.

Now there's a lot going on here. The amount of lean for a given speed and turn is determined by the weight of the car fully loaded, the distance from the center of gravity to the roll axis and the *roll stiffness.* In English, this is how hard the car is pushed, the lever arm that's doing the pushing, and what's resisting the pushing.

The roll stiffness (what's resisting the pushing) is a function of the geometry, the springs, tires, struts and sway bars. Leaning less is nice because with less suspension deflection, the compromises in design don't affect the car as much, and the car can take a set more quickly. This is really nice with a smooth track.

But too stiff is bad as well. Even if you didn't mind the ride, really stiff suspensions tend to have trouble with rough terrain, so too stiff may actually be slower around most real world turns, as the car tends to bounce over the surface, like a rock skipping on water. This is yet another example of the trade-offs of suspension tuning.

Now let's imagine the car going over a bump. The front driver's-side wheel to be specific. If you're speeding up or slowing down, you want the tire to remain in contact with the road, and you don't want to have your head hit the roof of the car. Not only that, but you want the car to keep going along your intended path.

So as the tire encounters the bump, it starts to deform, and eventually there's enough force to start the wheel and the rest of the suspension items moving. All the stuff that has to follow the road is called *unsprung weight.* If you lower the unsprung weight, it's easier for the suspension to follow contours of the road. (The reason I bring this up is that it illustrates that not only do all the suspension items interact with each other, but the suspension interacts with the braking and steering systems too! So lighter tires, wheels and brakes are factors in suspension performance as well.) Anyway, eventually the suspension responds to the bump, and it moves up. The shock tries to resist this motion so as to keep the tire in contact with the surface as you drive over the bump.

But if the suspension is too stiff, it will pinch your tire's sidewall, transfer too much of the impact to the chassis or both (*compression dampening* is too firm), and won't allow the suspension to expand fast enough after the bump has passed to keep the tire in contact with the road (too much *rebound dampening*). If the car wants to change direction as one wheel goes over a bump, this is called *bump-steer*, and thankfully isn't really a problem for our cars.

There's one other suspension component to keep in mind here, the anti-sway bars. While they help control lean and weight transfer in turns, they couple the suspension motions of one side of the car to the other.

Huh? Didn't we really like the fact that the car came with independent suspension at all four corners? This illustrates one of the downsides of suspension tuning with anti-sway bars. Going stiffer with them means that you give up some of the independence of motion of the two sides of the suspension.

There's an important lesson buried in here: It would be nice to modify the geometry because it can affect the desired change without shorting the suspension. The sad part is that you can't really modify the geometry much on our cars from the factory (just the alignment adjustments) and that even with camber/caster plates and adjustable control arms, the range of geometry is relatively small.

## Some Reminders

While this is by no means a comprehensive tutorial on the ins and outs of the MINI's suspension systems and their function, it should give you a good idea of what it's trying to do and where it can be improved. I hope I've succeeded in planting a few ideas deep into your gray matter never to be dislodged.

- **Everything** in suspension implementation is a balance of interconnected compromises, so a change you make in one part of the suspension *will* affect other parts as well.
- **Don't forget** the role your tires play, and check your tire pressures regularly.
- **Match your suspension** to your skill level. No matter what, you want a safe and fun ride, with the emphasis on safe.
- **Changing one part** of your suspension without understanding the basics of how it interacts with the rest of the system can just as easily degrade other parts of suspension performance as enhance the one characteristic you're trying to improve, so do your suspension modifications carefully.

Now that we've covered the basics and introduced some terms, in the next issue I'll discuss most of the more common suspension modification that people do to MINIs and why, and the pros and cons associated with each one. MC²