SUSP-15, Suspension Information and Upgrades

Introduction

The intent of this article is to provide a discussion regarding suspension dynamics in general and information regarding potential upgrades to the 944 suspension.

Suspension Dynamics

To optimize the performance of your car's suspension it's essential to have an understanding of suspension dynamics. This includes and understanding of the concepts of "oversteer" and "understeer" and what must be done to correct these conditions when necessary. Now, I'm sure many of you know what oversteer and understeer are, but you may not have a complete understanding of what causes these conditions. Still others may have no idea what understeer and oversteer are. So, we'll start by discussing some suspension basics and work our way on from there.

If you follow any type of auto racing, you may have overheard conversations between the driver and pit crew where the driver tells the crew that the car is "pushing" or the car is "loose". There are actually referring to understeer (push) and oversteer (loose) conditions.

During hard cornering the weight of the car shifts away from the inside wheels toward the outside wheels. The softer the suspension, the more weight is transferred to the outside wheels. The added weight on the outside wheels causes the outside tires to grip better allowing the car to steer safely through the turn. With a perfectly "neutral" suspension setup, the weight would transfer such that the front and rear tires would have the same amount of grip and, at the limit, both tires would lose traction at the same time.

If the suspension is set up so that, during cornering more weight is shifted to the outside rear tire than the outside front tire, then the rear tire will have more grip during cornering than the front tire. So, the front tire will lose traction before the rear. This is referred to as ***understeer***. The effect is that the car takes a wider radius curve than the drive intended. The reason you hear this referred to as "pushing" is that the driver feels the rear of the car trying to push the car off of it's intended line.

Conversely, if the suspension is set up so that, during cornering more weight is shifted to the outside front tire than the outside rear tire, then the front tire will have more grip during cornering than the rear tire. So, the rear tire will lose traction before the front. This is referred to as ***oversteer*** or as the car being "loose". The effect is that the rear wheels steer a wider path than the front wheels, rotating the car more than the driver intended, forcing the car into a smaller radius turn.

Most passenger car suspensions are designed with a certain amount of understeer (including the 944) because it is much safer than oversteer. If the car understeers, the car makes a wider turn than intended, but the car remains stable. If the car oversteers, the car makes a smaller radius turn. This increases the cornering force on the outside wheels which brings the rear wheels even closer to the point of losing traction. This results in even more oversteer. If no correction is made, the situation will continue to become worse until the rear wheels lose grip completely, the car spins, and all control is lost.

Realize that the above discussion assumes a constant velocity during cornering. Even in a car with a completely neutral suspension setup, you can induce oversteer or understeer via acceleration or braking during cornering. And, the effects of acceleration are different depending on whether the car has FWD or RWD.

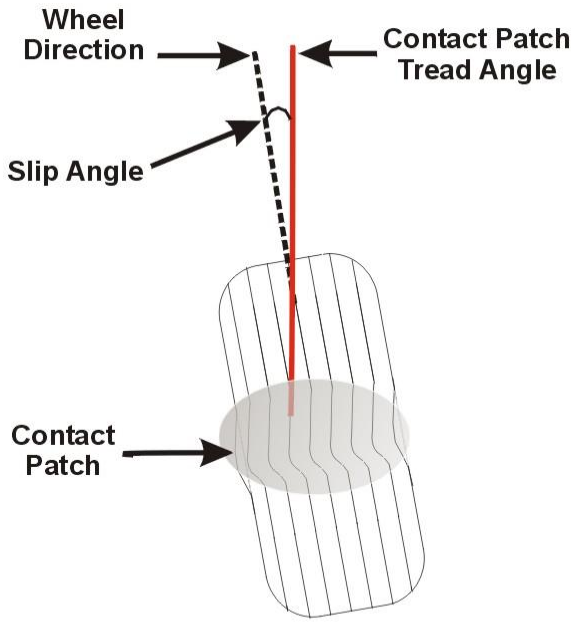
Ideal Setup?

So, the big question you might ask right now is "What is the ideal suspension response - oversteer, understeer, or neutral?" The answer - all three. During straight line acceleration, a slight amount of understeer is desirable because it makes the car very stable, requiring few driver corrections to keep the car moving in a straight line. At the turn in point, you again want a slight understeer to keep the car stable while the brakes are being let off and cornering forces are building up. Through the apex, neutral steering is desirable as the car's cornering traction is at is maximum and it allows the car to drift through the corner should you come in a bit too hot (instead of having the front or rear lose traction in the middle of the turn). And finally, at the turn-out a slight amount of oversteer is desirable to allow the car to take a tighter path through the turn-out.

Slip Angle and Suspension Dynamics

Now we're going talk about oversteer and understeer using a new term called slip angle. The concept of slip angle is a little more complex. However, understanding slip angles is essential to understanding how acceleration and braking affect steering.

When you're driving along in a straight line the car, wheels, and tires (including the tread on the tires) are all moving in the same direction. However, when you make a turn, the treads on the tire which are in contact with the ground (contact patch) resist the turning action due to friction between the tire and the ground. Due to the elasticity of the tires, the tread will distort creating an angular difference between the treads in the contact patch and the direction the wheel is turned. This angular difference is referred to as slip angle.



Wheel Turning Left

When more weight is transferred to a particular tire, the slip angle increases because the tread in the contact patch area develops a higher resistance to turning (due to the increase in friction between the contact patch and the ground). So, when the slip angle of the rear tires is greater than the front tires you have oversteer. Likewise, when the slip angle of the front tires is greater than the rear you have understeer. And finally, when the slip angles are the same, you have neutral steer. So you ask, "where is all this leading?" Bear with me and hopefully it will all become a bit clearer shortly.

Steering Response Under Acceleration

As I mentioned before, acceleration and braking have an effect on steering dynamics. If we consider a neutral steering car that is cornering and we accelerate the car, tractive force from the engine is applied to the drive wheels. Tractive force is the force applied by the engine necessary to overcome the force of gravity and cause the car to move. This force is ultimately felt between the tire and the ground which causes the tread on the contact patch (already distorted from turning) to distort even more, thus increasing the slip angle for the drive wheels. As we stated, if the car had neutral steering before acceleration was applied, it will cause oversteer in a RWD car (increased slip angle in the rear tires) and understeer in a FWD car (increased slip angle in the front tires). Is it starting to make sense?

Steering Response Under Braking

During braking, there is a weight shift from the rear of the car toward the front of the car. This applies more weight to the front tires increasing the front tire slip angle and inducing oversteer. In this particular case, it's very easy to put the rear of the car into a spin if you enter a corner carrying too much speed, panic, and get on the brakes. The effect is similar if you're on the throttle in a fast corner

and suddenly lift (take your foot off the gas). 911s are particularly bad about spinning out the rear if you lift in a turn due to the high concentration of weight behind the rear wheels. At my first PCA Driver Education event, the only two cars I saw get in trouble were 911s drivers who lifted in a corner. BTW, the driver's were DE instructors.

Handling Corrections

Now that we've discussed what oversteer and understeer are and what causes each, let's take a look at what can be done to correct oversteer or understeer conditions.

Understeer Corrections	
Front Suspension	**Rear Suspension**
Softer front springs	Stiffer rear springs
Thinner or no front sway bar	Rear sway bar or a thicker one
Raise front tire pressure	Lower rear tire pressure
Softer front shocks	Stiffer rear shocks
More negative front camber	More positive rear camber
Remove weight from the front	Add weight to the rear
More down force in the front	Less down force in the rear
Wider tires in the front	Narrower tires in the rear
More positive caster.	Limited slip rear differential or stiffer rear diff
Oversteer Corrections	
Front Suspension	**Rear Suspension**
Stiffer front springs	Softer rear springs
Front sway bar or a thicker one	Thinner or no rear sway bar

Lower front tire pressure	Higher rear tire pressure
More positive front camber	More negative rear camber
Add weight to the front	Remove weight from the rear
Less down force in the front	More down force in the rear
Narrower tires in the front	Wider Tires in the rear
Stiffer front shocks	Softer rear shocks

944 Suspension and Handling Setups

Now that we've discussed the basics of handling in general, let's take a look at specific setups for the 944.

There are a number of different ways to approach suspension setup. There are no hard and fast rules about combinations of springs, sway bars, and torsion bars. To find the right combination for what you want to do with the car, it may involve a lot of trial and error. Bottom line is it's all about establishing and maintaining a relative balance between the front and rear suspension such that there's not too much understeer nor too much oversteer. Ideally, you want the steering to be as neutral as possible.

For 944s, and almost all street cars in general, the car is going to have some amount of understeer from the factory. The reason is that when a car oversteers, your normal "street driver" tend to get into trouble more frequently with a car that oversteers as they tend to overcorrect in panic situations on the street. Therefore, understeer is considered safer. Driver's who spend a lot of time on the track tend to want a car that is neutral or has a slight oversteer and they get a better feel for how the car is handling under those conditions and hence can maintain better control over the car when driving it at it's limits.

To gain some perspective on making changes to the 944 suspension, it's valuable to first look at several stock suspension setup and discuss their performance characteristics under different conditions. The information in this table was obtained from a suspension article in Excellence magazine written by Jim Pasha. However, it has been modified to include torsion bar spring rate information and 968 M030 information.

Year/Model	F/Spring	F/Sway Bar	R/Torsion Bar	Torsion Bar Spring Rate	R/Sway Bar
1976-1977 924	140 lb	21mm	22mm	97 lb	18mm
(note: Sway bars were optional these years, standard models had none)					
1978 924	140 lb	22mm	22mm	97 lb	14mm (opt)
1979 924	140 lb	23mm	22mm 23.5 w r sway bar	97 lb 126 lb	14mm (opt)
1980 924/Turbo	140 lb	21mm	22mm 23.5 w r sway bar	97 lb 126 lb	14mm (opt)
1981 924/Turbo	140 lb 160 lb w M471 opt	21mm 23mm w M471 opt	23.5mm	126 lb	14mm (opt)
1982-1985 924 all (from Sept 1981)	140 lb	20mm 21.5 opt	23.5mm	126 lb	14mm (opt)
1982-1984 944	160 lb	20mm 21.5 opt	23.5mm	126 lb	14mm (opt)
1985-1986 944/924S	2946N	20mm	23.5mm	126 lb	14mm (opt)
(M030 opt)	2698N	21.5 solid or 23x3.5 tubular bar			
1987-1989 944/924S	2946N	21.5mm	23.5mm	126 lb	18mm (opt)
(M030 opt)	3050N	25.5x4 tubular bar			
1987-1988 944S	3535N	21.5mm	23.5mm	126 lb	18mm
(M030 opt)	3286N	23mm tubular	25.5mm 25.5 tubular	175 lb 149 lb	20mm (opt)
1985-1991 944T	3286N	22.5mm	23.5mm	126 lb	18mm
(M030 opt)	3250N	24mm tubular	25.5mm	175 lb	18mm
1987 and later (M030 opt)		25.5mm tubular	26.8mm tubular	175 lb	16mm
1989-1991 944S2	3250N	26.8mm tubular	24mm	137 lb	16mm
(M030 opt)	3120N	25.5mm			16mm
968	3250N	26.8mm tubular	24mm	137 lb	16mm
(M030)		30mm tubular			19mm (3-way adjustable)

To help you choose an appropriate torsion bar based on the front spring rate you choose, below is a table which lists torsion bar spring rate based on torsion bar diameter. Realize that this is based on solid torsion bars. For hollow torsion bars, the spring rate is based on the outside diameter of the torsion bar and the diameter of the hollow area inside the bar. For these bars, you'll have to get the spring rate from the manufacturer.

Torsion Bar Rates	
Diameter	**Spring Rate (lbs./in)**
22.0	97
22.5	106
23.0	116
23.5	126
24.0	137
24.5	149
25.0	161
25.5	175
26.0	189
27.0	220
28.0	254
29.0	292
30.0	335
31.0	382
32.0	434
33.0	490

Notice that some of the rates for the front springs in the first table are given in lbf and some are given in Newtons (N). For the rates given in lbs., it's for an uncompressed spring. For the rates given in Newtons, it's for springs compressed to their normal operating height. As the compressed height may vary from vehicle-to-vehicle comparing the spring rates above are useful only to the point of comparing one vehicle to another. So, without some fixed point of reference how do we know what kinds of changes to make to our suspension?

Basically, changing to higher spring rates for the front springs, torsion bars, and sway bars can benefit all vehicles in the 924/944/968 model line. The main benefit of changing to higher spring rates is reducing body roll during cornering. By reducing body roll, the tires maintain contact with the road longer. Other benefits are reduced squat during acceleration and reduced dive during hard braking.

Regardless of the spring rates listed above (in lbs. or Newtons), the maximum spring rate for any 924/944/968 suspension is approximately 175 lbs. So, we need to pick a spring that is something greater than 175 lbs. if we want to improve handling. So, exactly how much do we increase the spring rate? Generally, spring rates from 200 to 220 lbs. provide a good performance improvement cars that are primarily street driven. For street cars that see some track time, spring rates from 250-275 lbs. are an excellent choice. I have seen some cars where 400 lb. springs are used on street/track cars. In my opinion, 400 lb. springs are entirely too stiff for a street driven car. They provide much too harsh a ride on the street. More importantly, as streets are generally much less smooth and hence much less forgiving than a track, they can in fact be dangerous on the street. To give you some idea of the stiffness of a 400 lb. spring, 944 Turbo Cup cars used 375-410 lb. progressive rate springs.

Example Suspension Setups

Sport Suspension

A good sport suspension setup for a car that is primarily driven on the street might include 220 lb. front springs, 27 mm torsion bar, 30 mm front sway bar, and 19 mm rear sway bar. Personally, I like a car that has very neutral steering characteristics. If you prefer to maintain the understeering characteristics of the stock 944, you might prefer a 26 mm torsion bar to the 27 mm. If you prefer a car that oversteers, you might choose a 28 mm torsion bar. Just realize that a car that oversteers is much more sensitive to steering corrections and can you into trouble during a panic maneuver. With regards to the sway bars, I really like the 968 M030 sway bars. The reason I like them is that the 19 mm rear bars are 3-way adjustable which give you another option when it comes to changing the steering characteristics.

High Performance Street/Track Suspension

A good high performance suspension for a car that it used on the street and track might include 260 lb. springs, a 28 mm torsion bar, 30 mm front sway bar, and 19 mm rear sway bar. Again, if you want more understeer, you might choose a 27 mm torsion bar. And, if you want some oversteer, you might choose a 29 mm torsion bar. As I've already cautioned you about oversteer we won't repeat that again.

Full Race Suspension

While I've seen this suspension setup used on the street, I don't recommend it. A good combination for the track might include 400 lb. front springs, 31 mm torsion bar, 30 mm front sway bar, and 19 mm rear sway bar.

Additional Suspension Notes and Suggestions

When you decide to change the suspension of a 944 and you make the decision to change the torsion bars, you have to realize that changing a torsion bar yourself is not necessarily a job for the novice mechanic. It's not that the job is all that difficult. It is very tedious because the torsion bars must be properly indexed to achieve the proper ride height. Indexing the torsion bars may involve a lot of trial and error to get the proper ride height which includes driving the car at a given torsion bar index for a day or so to allow the suspension to settle. For that reason, it may be more practical to go to a suspension setup that uses coil over shocks in the rear and remove the torsion bars completely.

It is also becoming more common to see suspensions that use a combination of torsion bars and coil over shocks in the rear to achieve an overall rear spring rate that will balance whatever springs you use in the front. By doing that, you can leave the rear torsion bars alone and simply choose a coil over shock to match your new spring rate in the front. However, if you choose to do away with the torsion bars or use a torsion bar/coil over combination, you must select a coil over shock that has adjustable spring perches so that you can adjust the ride height. The primary disadvantage of going to a coil over setup in the rear is that it's much more expensive than simply changing the rear torsion bar.

Up to this point, we really haven't discussed shocks or struts at all. The factory shocks and struts are adequate for street use. However, I like an adjustable sport shock/strut setup, even for street use. Personally, I prefer Koni Sport shocks/struts because that's what I've become accustomed to over the years. However, Bilstein makes good sport shocks/struts as well. For use on the track, a full coil over setup (front and rear) is the only way to go in my opinion.

Closing Comments

Realize that, due to the large number of variables that can affect a car's handling, no two cars are going to respond exactly the same to the same change in suspension components. Likewise, no two drivers will have the exact same feel for the same suspension. The idea is to get to a suspension setup that is right for you. What's right for you may not be right for me. The suggested setups above should get you close to a fairly neutral handling setup. However, it may not get your car exactly where you want your handling to be. From there you should be able to "tweak" the suspension feel to get to "your" suspension setup by making minor changes in weight distribution, shock stiffness (assuming you go with adjustable shocks/struts), camber, caster, and tire pressure.

Hope this article gives you some idea as to what direction to head with your suspension modifications.

Drive it like you stole it!