HOW TO TUNE YOUR CAR'S HANDLING

A Driver's Guide

Ross Bentley

SPEED SECRETS

Important Stuff

You know that motorsport of any kind is dangerous. Therefore, I provide my advice for you to use in the way you choose. I can't be held responsible for anything that might happen as a result. You're a grown-up - you're responsible for yourself – and by reading on, you are accepting that responsibility.

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Having said that, I love helping drivers perform better – I enjoy sharing what I've been fortunate to learn through experience, study, and observation. With that in mind, please help me get this eBook in the hands of more drivers. Please recommend to others that they download their own copy. It's free! All anyone has to do is download it themselves (i.e., don't send them your copy). Thank you.

Have fun!

Ross Bentley

SPEED SECRETS

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INTRODUCTION

The goal of this eBook is to provide you with relatively simple principles and guidelines for tuning your car's handling in order to improve its performance.

As I'm sure you're already aware, the number of adjustments you can make to your car is huge, and therefore it's easy to "get lost" when tuning or not have a clue as to where to start. But if you think logically, understand what it is you really want from your car, have a good grasp of the key principles, and then follow the guidelines provided here, you will make more improvements than not. And just like making improvements to your driving technique, if you can make more of the right ones than the wrong ones, you're heading in the right direction. So, it's likely that not every adjustment you make will result in an improvement, although you will learn from everything you do. At least, you should, if you think about why you got the result you did.

But here's the thing: If you're looking for me to tell you what pressures to run on the rear tires or the camber angle on the front of your *"Excalibur GT4-Plus EXE, equipped with 13.5-inch Bigbo brake calipers and Stoppit HP13 pads, 800 lbs/in Acme front springs, a 14mm rear anti-roll bar, all powered by a 634-horsepower triple-turbo DOHC engine"*… well, I can't! No one can. See, there is no magic formula. If there was, then I'd just list all the correct settings for your wonder-car, every other version of it, and all other cars in existence, and we'd be done (and I'd be very rich!).

My point here (other than to jokingly illustrate some of the emails I receive) is to say that it's the process, along with the principles and guidelines that I share in this eBook, that will lead you to finding the best setup for your car.

I've written this eBook for drivers, and not race car engineers who tune the handling of cars for a living. Therefore, I've tried my best to keep it as simple and practical as possible, with only a little theory behind what I recommend – only as much as I feel is necessary.

You should know that the most difficult part of writing any book is not creating the content to put in it. No, it's deciding what not to put in it. In writing this eBook, I could have gone much deeper into practically every area that I cover. But that would not have met my ultimate goal of making this a useable guide, so I aimed to find the right balance between the details you need to understand why I'm recommending what I do, and "just the facts" you need to get the job done.

One of the things I like about eBooks is that they're easy to update, unlike printed books. So, if there is something specific you think I should change, add, or delete in future versions of this eBook, please let me know. The other great thing about

eBooks is I can provide links to other resources more easily than in a printed book, and I've done that here.

I'll mention this more than once in this eBook, so get ready… *there are exceptions to every rule*. In fact, that's why I'm using the term "guidelines" when it comes to the advice I provide. To me, guidelines work more often than they don't. Sure, they may not work one hundred percent of the time, but they work more than fifty-one percent of the time.

As a general overview, here's how I've laid out this eBook:

- General tuning principles
- Understanding what your car is doing
- Tuning guidelines
- Driving – how you sense what your car is doing, and common errors to avoid
- Glossary of terms

If I use a term or phrase that you don't understand, take a quick look in the glossary – hopefully I've defined it for you. But if not, I strongly recommend you understand it before moving on, and there is this thing called the internet and Google that will probably clarify it for you.

With the idea of learning in mind, I strongly urge you to dig deeper into vehicle dynamics, suspension geometry and alignment, and car tuning by reading a number of books (also refer to the Resources section at the end of this eBook):

- Tune to Win
- Prepare to Win
- Engineer to Win
- Carrol Smith's Engineer in Your Pocket
- Race Car Engineering and Mechanics
- Inside Racing Technology
- Ultimate Speed Secrets
- Shocks for Drivers

I would be remiss if I didn't point out that a majority of what I've learned about car setup and tuning the handling of a car comes from my friend Jeff Braun. Yes, I've learned a lot from trial and error (driving and coaching drivers), tuning cars myself, and from all the engineers I've worked with over the past five decades in the sport. But no one has taught me as much as Jeff has. There's no doubt that he's one of the best race car engineers in the world, but what makes him extra

special is his ability to explain what he's talking about. He makes the complicated uncomplicated. I'm attempting to follow his example in this eBook. Thanks Jeff!

Finally, before we get started, keep this in mind: In most cases, there is more in the driver than there is in the car in terms of performance improvement. In other words, before you dive headlong into making all sorts of changes to your car's setup to improve its handling, make sure you're driving it properly. In fact, there's a lot to be gained by learning to adapt your driving to manage any kind of handling problem you're experiencing.

Also, be sure you're driving consistently before you begin tuning your car's handling. If not, and you make a change to your car's setup, how do you know whether the change helped or hurt if your driving is inconsistent?

Having said that, tuning your car's handling can be a fun, rewarding experience. It's certainly a great learning experience. So, let's go!

SETUP TUNING PRINCIPLES

Before we move into the nitty-gritty of what adjustments you should make to tune for the handling problem(s) your car has, there are a few key principles that you should keep in mind.

1. ***Take notes.*** It's easy to forget what you did, and what caused or led to an improvement if you don't take notes of your changes. Do it on paper or digitally, using a trick "setup sheet" or random notes (but make sure you can find what you wrote down). Log every single one. Don't rely on your memory.
2. ***Make one change at a time.*** If you make two or more changes at one time, how do you know which one helped? Stick to one change at a time.
3. ***Make big enough changes that you're sure to feel them.*** If you make a very small adjustment and can't feel the change, you haven't learned anything.
4. ***Work with what you have.*** If the only tool you own is a tire pressure gauge, then the only tuning you should do is adjusting tire pressures. If you have the tools to adjust shock absorber settings and suspension alignment, then you can do more.
5. ***Adjust what is easiest to get a direction from.*** Often, you need a direction, something to tell you which way to head with all the adjustments you can make. For example, if you think that softening the front of your car will help, then make the easiest adjustment (that would likely be an anti-roll bar adjustment before changing springs).
6. ***Work on the end of the car that needs improvement - then the opposite if you can't fix it.*** If you want more rear grip, for example, do everything you can to improve that end of the car. If all else fails, you may have to reduce grip at the front of the car to make the car's balance better, making it easier to drive.
7. ***Balance is more important than overall grip.*** In most cases, you will drive faster in a car that is well-balanced than you will in a car that has more grip at one end than the other.
8. ***Do A-B-A tests.*** After you've made a few changes, it's smart to go back to your original setup to check whether the changes have really helped or hurt. It's possible that your driving improved, or the track conditions got worse, masking the effects of the setup changes.
9. ***Do sweeps.*** Especially if your car is new to you, you need to learn what the various changes do, and the best way to do that is work your way through each variable (tire pressures, anti-roll bars, springs, shocks, toe-in/out, ride

heights, and so on) from one end of its adjustability to the other. For example, by driving your car with higher than normal tire pressures, then lower than normal pressure – from one end of the range to the other – you'll learn how the changes impact the feel of the car. Do this with as many of the variables as possible.

10. ***Avoid pre-conceived ideas.*** It's easy to fall into the trap of thinking that a change you made did what you expected, when it didn't. When you make a change to your car's setup, just drive it and debrief yourself honestly. If you didn't feel a change, make note of that – don't judge it. If the change did the opposite of what you expected, make note of it, and think about why.

11. ***Copying one adjustment from someone else rarely works.*** A car's optimum setup is a package. If you change your tire pressures to what a friend is running, don't be surprised if it doesn't give you the result you're looking for. Unless absolutely every other component and setting on your cars are identical, copying just one adjustment may actually make your car handle worse.

12. ***Learning what doesn't work is as important as what does.*** If you make a change and it didn't improve the car's handling, that's valuable information. Make note of it, and think about why it did what it did – you'll now be smarter.

13. ***Understand why.*** Making a change that helped your car handle better, but not understanding why it improved the handling is just about as bad as not making the improvement. If you understand why, you can more easily replicate it in the future.

Tuning your car's handling can be looked at as a science experiment: Try something, see what happens. Over time, as you experiment more and more, you'll begin to guess what is the right direction to go to get to your desired result. There are so many different adjustments and changes that you can make, that what you're often trying to do is simply find the right direction: should you soften or stiffen the springs, anti-roll bars, shocks; should you increase or reduce tire pressures; add or take out camber or toe? Once you find which direction makes an improvement, you can then begin to home in on the amount.

HANDLING DEBRIEF

You can't fix a problem until you've identified what the problem is. You can't tune your car's handling until you've gotten very clear on what your car is doing. And not just what it's doing, but also where it's doing it. And that's where the Handling Debrief process comes in, and why I'm starting with it before diving into advice about adjusting tires and suspension.

By going through this process before you start thinking about the various adjustments, you'll make far better decisions. In fact, you may find that figuring out what to change with your car's setup becomes easy once you've thought deeply about what your car is doing, and this Handling Debrief process will help you do that.

After each session on track, it's important to go through this process. Whether you have a highly-paid and experienced race engineer, or you're the engineer, mechanic, and driver, take the time to go through the process below. As you'll see, you ask yourself a series of questions to help you identify what your car is doing, where it's doing it, and what you're doing when it does it. This process identifies the problem. And the specific question, in the specific order is important.

I should state right now that every car has a problem. Sometimes, the handling problem is so minor that it's not worth doing anything about it. In fact, it's often more beneficial to focus on improving your driving than it is to make adjustments to your car. On the other hand, one way of looking at your driving is that it's your job to find the weak point in your car's handling. If you're driving at a pace where your car doesn't show a weakness, that's okay; it's not worth making adjustments to your car until your driving is stressing the limits of your car's handling, revealing its weakness(es). But, if your car doesn't show a weakness, that's a sign that you're not driving close enough to its limits for it to be noticeable.

The answers to the following questions will provide more guidance as to what to do with your car than anything else. Again, whether you're working with an engineer or by yourself, the process of asking the right questions, then answering them as thoroughly as you can, will get you at least ninety percent of the way towards finding the right adjustment to make your car faster. Skipping this step is a recipe for disaster, as you're more likely to make the wrong adjustments, ultimately making your car slower.

I very strongly suggest that you have a track map sitting in front of you while you go through this debrief process, and that you make simple notes on it. You can find free track maps specifically designed for notation by going to SpeedSecrets.com/Trackmaps.

QUICK DEBRIEF

If you don't have much time between on-track sessions, use the Quick Debrief, asking yourself just two questions:

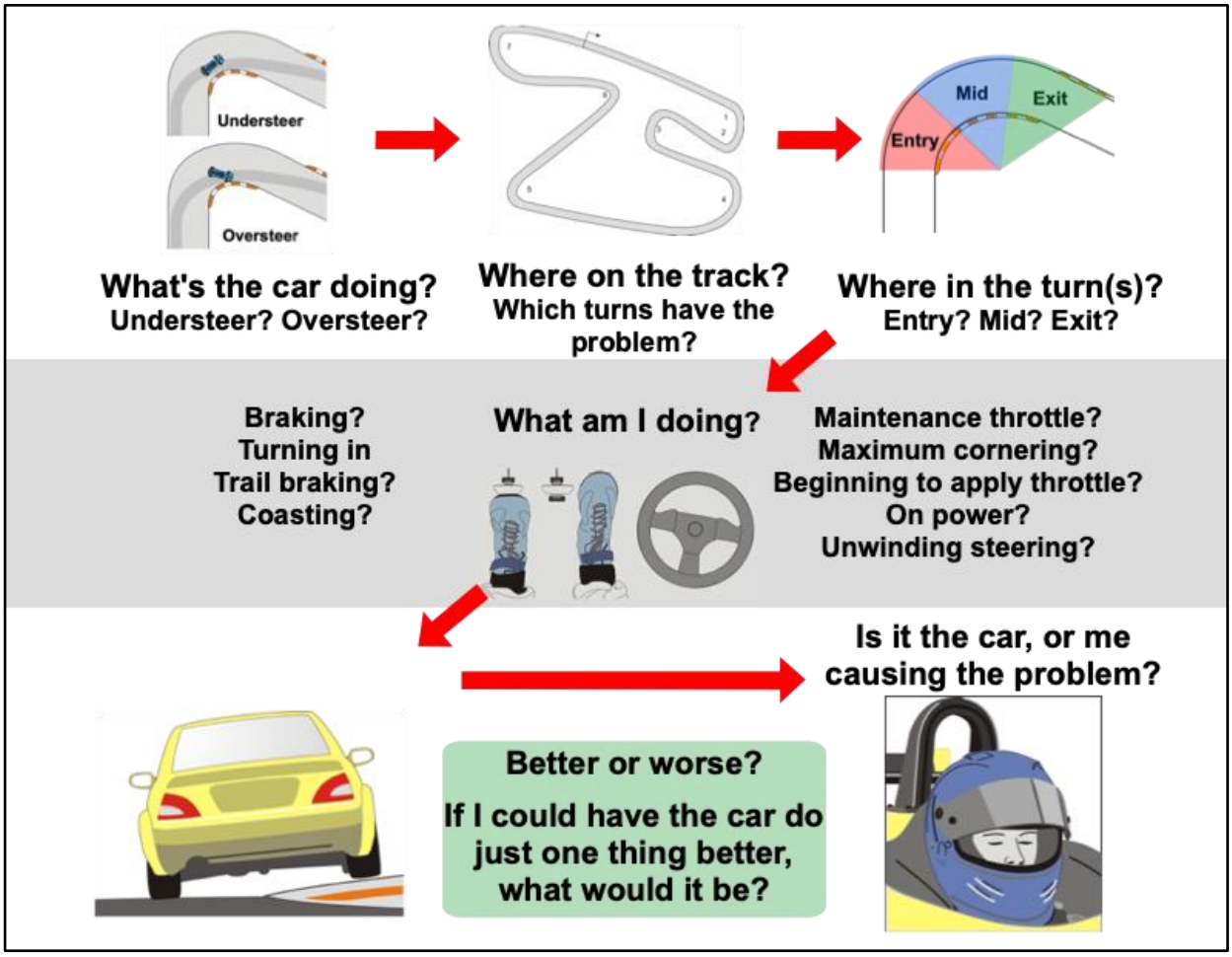
1. Better or worse? Was the car's handling better or worse than before the change?
2. If I could have the car do just one thing better, what would it be?

It's this second question that you should keep in mind at all times when driving. It is the ultimate question, and if you only ever ask yourself that one, you'll make good progress in tuning your car's handling.

DETAILED DEBRIEF

If you have the time (and this doesn't take a lot of time), sit down with your track map and ask yourself the following questions:

1. What is the car doing? Understeering or oversteering? Slow to respond?
2. Where is the car doing it? Which corner(s)?
3. Where in the corner(s)? Entry, mid or exit?
4. What am I doing when the car does this?
    - Braking?
    - Turning in?
    - Trail braking?
    - Coasting?
    - Maintenance throttle?
    - Maximum cornering?
    - Beginning to apply throttle?
    - On power?
    - Unwinding the steering?
5. How bad is it on a scale of 1 to 5 (1 = slight; 5 = serious)?
6. Is it the car or me? Am I inducing the handling problem, or is it the car?



Write down the answers to these questions, and make notations on your track map of the locations of each handling weakness.

The part of this process that most drivers ignore, and is a real key to figuring out what you should change, is number 4 above: What am I doing when the car does this? The adjustment you should make for, let's say, an oversteering car in the mid-corner phase can be very different if you're just releasing the brakes rather than beginning to apply the throttle.

Keep in mind that there are two modes for a driver:

1. Test driver, where your goal is to drive as consistently as possible and only sense and report what the car is doing.
2. Driver, where your goal is to adapt your driving to any handling problem your car has.

If your car has a handling issue, and you adapt to it, it's not possible to accurately sense and report what it's doing. Consistently driving the same way is what you're looking for when you're tuning your car's handling. Of course, if your goal is to drive as fast as possible, then you're going to have to adapt to how your car is handling, since you can't make any changes to your car while on track – other than adapting your driving. Know when you're in "test driver" mode, and when you're not.

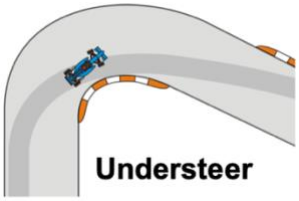
TUNING YOUR CAR'S HANDLING

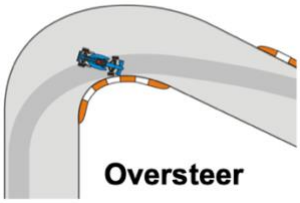
Now that you've identified what your car is doing, where it's doing it, and what you're doing when it does – and you have the key principles in mind - it's time to begin making adjustments to get it do what you want.

Tuning your car's handling comes down to two things:

1. What you want
2. Where you want it

As an example, reducing the amount of understeer your car has only really helps if it's reduced where you need it. If the understeer is not hurting your lap times in a fast corner, but it is exiting a tight hairpin, focus on making it better where you want it to – in that hairpin corner.





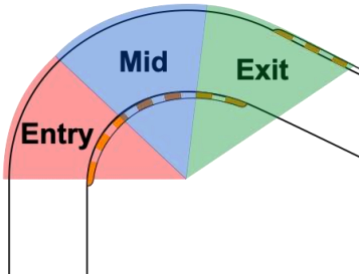
In terms of the "what you want," it comes down to four things:

1. "I want more front grip" (you have Understeer)
2. "I want more rear grip" (you have Oversteer)
3. "I want the car to feel more responsive when I turn the steering wheel"
4. "I want more overall grip"

Notice that the first two items are related to the balance of the car; then you have how quickly the car changes direction (transitions), and finally the overall grip level. As you go about tuning your car's handling, this is the best way to look at your priorities: balance, responsiveness, and grip.

The "where" you want the car to do something different comes down to:

- A specific corner or corners
- Brake zone
- Turn-in
- Brake release
- Mid-corner
- Off-throttle
- Maintenance throttle
- On power



- Corner exit

GENERAL TUNING GUIDELINES

Typically, the main tuning "tools" you have are:

- Tire pressures
- Anti-roll bars
- Springs
- Shocks
- Ride height
- Camber
- Toe

Beyond this, some cars may allow you to tune caster, anti-dive, and anti-squat, as well as aerodynamics. But those adjustments and/or modifications are beyond the scope of this eBook.

For most drivers, tuning the car's handling comes down to three main areas:

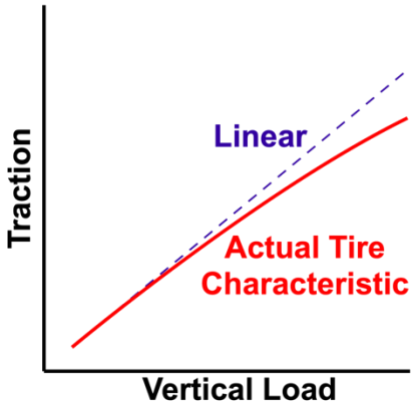
1. Roll stiffness front-to-rear relationship
2. Tires
3. Suspension geometry & alignment

You may think that we should begin with tires (Principle #4: Adjust what is easiest to get a direction from), and that's not a bad way to approach it. After all, adjusting tire pressures is about the easiest thing you can do to tune your car's handling. But I want to start from the perspective of understanding vehicle dynamics. So, even though you may end up adjusting tire pressures initially, you should be thinking about why you're doing that, in addition to thinking about your car's roll stiffness front-to-rear relationship.

VEHICLE DYNAMICS PRINCIPLES

Before we can begin to think about how to tune your car's handling, there are a few vehicle dynamics principles you must be super-clear on, otherwise you'll always be confused. This is far from a complete review of vehicle dynamics, but it is the basics that you need to know before beginning to tune your car.

1. When the car leans over in a corner, this is called "roll." It's caused by the lateral g-loads.
2. When the car rolls during cornering, weight (load) is transferred from the tires on the inside of the corner to the outside tires, pushing down harder on the outside tire, and unloading the inside tire.
3. The more weight transfer, the less overall grip; conversely, the less weight transfer, the more grip. For more insight into this principle, I highly recommend you watch the Why Smooth is Fast video here.



4. The front and rear of the car can have different "roll stiffnesses." This difference – the front-to-rear roll stiffness relationship or distribution (technically called LLTD, for Lateral Load Transfer Distribution) – is a large contributor to either understeer or oversteer.

ROLL STIFFNESS TUNING

With these principles in mind, how do we tune the car's handling by adjusting the front-to-rear roll stiffness relationship?

Generally, soften the end of the car that needs more grip. That can be done with:

- Anti-roll bars
- Springs
- Shocks/dampers

When the terms "soften" and "stiffen" are used, we're talking about changing the ability of the anti-roll bars, springs, and shocks to move. For example, a softer spring means one that is easier to compress; a softer anti-roll bar twists more easily; a softer shock setting allows them to compress or extend more easily.

Therefore…

If your car is oversteering ("I need more rear grip"):

- Soften the rear anti-roll bar
- Soften the rear springs
- Soften the compression and/or rebound on the rear shocks

If your car is understeering ("I need more front grip"):

- Soften the front anti-roll bar

- Soften the front springs
- Soften the compression and/or rebound on the front shocks

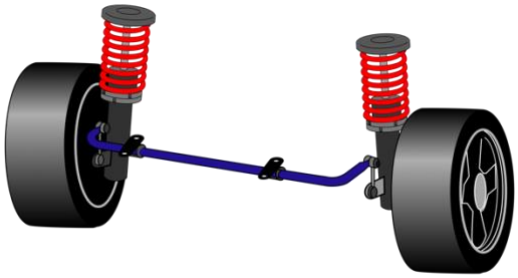
When I say soften the springs, anti-roll bar, or shocks, this is an "and/or" situation. You may do just one, or some combination. But keep in mind Setup Tuning Principle #2, *Make one change at a time*.

Alternatively, you could stiffen the opposite end of the car that needs more grip. For example, if your car oversteers – you need more rear grip – you could stiffen the front springs, anti-roll bar, and/or shocks. This ties into the Setup Tuning Principle #6, *Work on the end of the car that needs improvement - then the opposite if you can't fix it.* Ideally, you'd improve the rear grip by softening it, but if that doesn't work or you can't go any softer (i.e., you have the softest springs in the rear), then try stiffening the front. In either scenario, you're changing the roll stiffness distribution, and that's going to change which end of the car generates more grip.

There are always exceptions to the rules, and sometimes you need to do the opposite of what is logical. There are times when you need to stiffen the end of the car to generate more grip there. Why? Because instead of the lack of grip caused by too much weight transfer, the reason is that end of the car is rolling too much from not enough support (springs, bar and/or shocks too soft). In this case, stiffening that end of the car would help.

If you can sense the reason for the lack of grip from one of end of the car, that will help you decide whether to soften or stiffen it. For example, if you feel the front tires are sliding across the surface of the track, that's likely due to the front springs, bar and/or shocks being too stiff; softening them would generate more front grip. But if the front of the car feels as though it's "falling over," or the chassis is rolling over too much in the front, stiffening that end of the car could generate more grip.

Anti-Roll Bar



Typically, the anti-roll bars are solid or hollow steel bar/tubes that are attached to both sides of the car's suspension, and when the car begins to roll from the lateral g-loads, it twists. The number of locations and how the anti-roll bar connects to the rest of the suspension is as large as the number of different cars in the world, so it's impossible to describe the details here. But most anti-roll bars are adjustable in some way. For example, by:

- Changing the position of where the link at the end of the bar connects, thereby changing the leverage on it.
- Changing the entire bar to one that is either larger/thicker or smaller/thinner, thereby increasing or decreasing the ability of the bar to twist.

By changing either the size/thickness of the tube/bar, or the leverage on it, you're increasing or decreasing its stiffness (ability to twist).

Some cars have front and rear bars, and some only have them on the front. To maximize the softness of a bar, you could even disconnect it, which is a common thing to do to the rear bar when driving in the rain (to maximize the amount of rear grip on the slippery track).

Springs

Choosing the optimum spring rate is one of the most important setup factors you'll deal with. Most cars have coil springs, although some may have leaf-type (essentially, one or more metal blades that flex with the suspension movement) on the rear. One other option is a torsion bar, which is a simple metal bar that twists when the suspension moves.

Generally, finding the optimum is a compromise between having a soft enough spring to allow the suspension to handle the undulations in the track surface, while being stiff enough to keep the car from bottoming out when hitting a bump, as well as making the car respond quick enough. There are many more factors involved, such as your driving style or preference, the amount of aerodynamic downforce you are running, the weight of the car, the shape and condition of the track surface, and so on. Perhaps most important, though, is the balance front to rear.

A good strategy to start with is to use the softest spring possible on the rear - to help the rear tires achieve maximum traction under acceleration – and then balance the handling with the front springs to achieve balanced handling (neither understeering or oversteering – neutral).

Shocks

Tuning shock absorbers is a topic all in itself, and they should have a book or eBook devoted to just them. Oh wait, I've done that already! See my Shocks for Drivers by clicking here.

You can use the shock absorbers to alter the transient handling characteristics - how responsive the car is to your inputs. If the springs and anti-roll bars determine the amount of body roll and the distribution front to rear, then how quickly that body roll occurs is determined mostly by the shock absorber rates. It's important to keep in mind that shocks impact your car's handling mostly in transient situations, as well as how well the suspension soaks up the bumps and

undulations on the track surface. But once the car has taken a set in a corner (is in a steady state), they don't impact the handling that much (a little, but not a lot).

Some shocks are not adjustable at all, so the only way you could tune your car's handling, then, would be to install completely different ones. Other shocks are adjustable in one direction, but not the other; then there are some shocks that have four or even more different types of adjustments.

What do these adjustments do? First, think of a shock absorber that is being compressed. In tuning terms, this is referred to as "compression" or "bump." Now, imagine that same shock being extended. In this case, that's called "rebound." So, you may have only compression adjustments, or both compression and rebound adjustments available to you to help tune your car's handling.

Something else to keep in mind is the speed that the shock is either being compressed or extended. Most of what we are concerned with while tuning the car's handling is considered "low speed." That's because the speed that the shaft and piston moving inside the shock is relatively slow, and this is when the car is rolling due to load transfer in cornering. "High speed" compression or rebound is what happens when the suspension is moving quickly to soak up bumps in the track.

Note that when referring to low- and high-speed shock rates or adjustments, this has nothing to do with the speed that your car is traveling. It's all about the speed that the shock shaft is moving. You can imagine that when you hit a bump on the track surface, the shock shaft moves fast; when you turn into a corner and the car begins to roll, the shock shaft is moving relatively slowly.

Here are some general rules about shock tuning (again, see Shocks for Drivers eBook for more information and detail):

- Adjust the low shock shaft speed (Low Speed Adjustors) to tune the handling, feel, and grip of the car; and high shock shaft speed (High Speed Adjustors) to control the car over track bumps. Low-Speed damping affects the "feel" of the car when braking, turning, and accelerating. High-Speed damping affects the car's grip when travelling over bumps in the track surface.
- To improve the ride quality over bumps, adjust the High-Speed characteristics. This is done primarily with the High-Speed Compression, but reducing the High-Speed Rebound can also help (to a point). In fact, too much High-Speed Rebound can make the car feel very harsh over low amplitude/low frequency bumps; too little and the car will continue to oscillate for too long after the bump.
- Low-Speed adjustments control the handling of the car – the transient

response and the rate of roll, dive, and squat. Usually, an increase in Low-Speed damping will make the car feel more responsive, without affecting the ride quality too much. Often, that will also make the tires work harder, and raise their temperatures.

- Low-Speed adjustments are a good way of controlling the feel at corner entry (the initial turn-in), and when putting the power down (accelerating out of a corner). To improve the initial turn-in responsiveness, increase the Low-Speed Compression and/or Rebound at the front – primarily the Rebound. This makes the car feel stiffer when turning into the corners, giving you the responsiveness you're looking for. To make the car put the power down better, reduce the Low-Speed Compression at the rear, making it softer, and increasing its grip level.
- When adjusting the oversteer/understeer balance, try to determine if the imbalance is caused by the car being too stiff (not enough roll, feeling like a go-kart), or if the car rolls too much (feels like an old Buick!).
- If the car is understeering too much, and it feels too stiff, reduce the front Low-Speed Compression and/or increase the rear Low-Speed Rebound. This will allow the front of the car to roll a little more – much like putting softer front springs in the car or softening the front anti-roll bar. If the understeer feels as though it is caused by too much roll – it feels like an old Buick, the front end falling over – then increase the front Low-Speed Compression and/or reduce the rear Low-Speed Rebound. This helps support the front of the car, reducing the amount of roll.
- If you have an oversteering car that feels too stiff, reduce the rear Low-Speed Compression and/or increase the front Low-Speed Rebound. This has a similar effect as softening the rear springs or anti-roll bar. If the oversteer feels as though it is caused by too much roll, increase the rear Low-Speed Compression and/or increase the front Low-Speed Rebound.
- To reduce chassis roll, and hopefully increase the grip, increase the Low-Speed Compression at the end of the car that needs the improvement.
- Finally, shocks are just one part of the overall package. If you change to much stiffer springs, for example, you will have to change the shocks to match, and vice versa. Stiffer springs typically require less compression and more rebound, and softer springs require more compression and less rebound. Either too much or too little shock control for the springs will mean the car's performance will suffer.

Decision Time

Given the options of softening or stiffening the springs, anti-roll bar, or shocks, which should you choose? First, go with Setup Tuning Principle #5, *Adjust what*

is easiest to get a direction from. If it's difficult to change springs, but easy to adjust the anti-roll bar, go with the bar.

Second, think about where on the track you want the change. Springs and bars tend to influence the grip level most of the way through a corner, whereas shocks mostly impact the car in transition. So, if your car is understeering or oversteering in the middle of a long corner where it's "taken a set" and the weight transfer is relatively steady, look to the springs and anti-roll bars to provide more grip. But if it's in the transition as you turn into a corner, or as you're unwinding the steering wheel and applying throttle exiting a corner, then the shocks are going to play a big role. This is why your initial Handling Debrief is so critical, as it helps you determine not just what you want your car to do better, but where (and what you're doing when you want it to do something better).

And remember that you're looking for a direction. For example, if your car is understeering mid-corner before you begin to apply the throttle (by using the debrief process, you've identified where the understeer is happening, and in this case it's not a transitional thing, so it's less likely to be helped with just the shocks), your first reaction would likely be to soften the front of the car. But, should you soften the springs or anti-roll bar? Again, start with the easiest to adjust? The anti-roll bar is often easier to adjust than changing springs, so start there. If the understeer is reduced, but now the car is a bit "lazy" in the way it turns into the corners, and it feels "roll-y," then you've found the right direction – softer in the front. But now you could put the anti-roll back to the stiffer setting, and make the more difficult change: softer springs.

Tuning your car is a process. Just like improving one's driving, there's always more, and often it's a cyclical process.

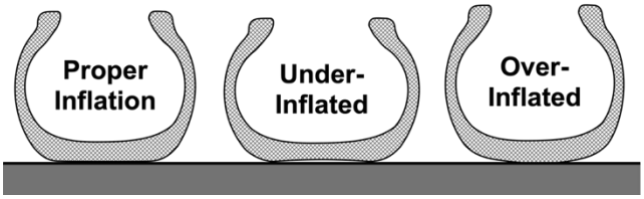
You may find that when you make one change, that it helps solve the initial problem you were trying to fix, but it's made the car worse somewhere else. First, think about what else you could do to have the same effect of the positive change you made, but without the negative effects it caused. Then, weigh up the trade-offs. If it improves the car in one part of the track, but hurts it somewhere else, which is most important? Perhaps the improvement is not worth it, as it hurts more than it helps, overall. Or maybe you can more easily live with the downsides, since you can change your driving technique to deal with it, or it's on a part of the track that is less important.

TIRE TUNING

What about tire pressures? How can you use them to tune your car's handling, especially since they're the easiest to adjust (see Setup Tuning Principles #4 *Work with what you have*; and #5, *Adjust what is easiest to get a direction from*).

When tuning tire pressures, think about two things:

1. Tire tread surface
2. Tire spring rate



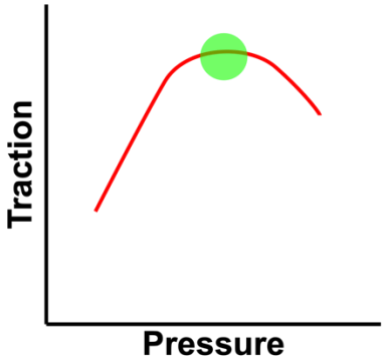
A tire generates its most grip when the tread surface is flat across the track surface - when all of the tire is working to grip the track. If the center of the tire tread is crowned up due to too much air pressure, only part of the tread surface will be on the track. The opposite of this is also true if the tire pressure is too low.

So, the first thing to keep in mind when tuning tire pressures is whether you're keeping the maximum amount of tread surface on the track.

Air pressure also affects the amount the tire sidewalls flex. If they flex too much, the tread surface will deflect too much, and again you won't have the maximum amount of tread surface on the track. In this case, the tires will roll over so much that you'll wear on the very top edge of the sidewall, and that's not what they're designed to do! Also, if the sidewalls of the tires flex too much, the car will feel mushy when you initially turn into a corner (if you've ever driven a car equipped with snow tires on a dry road, you know that mushy, non-responsive feeling). Air pressure affects how responsive your car feels.

Air pressure also affects the tire spring rate. Yes, tires are another spring within the suspension of your car, and the same guidelines you used for tuning the roll stiffness relationship come into play. However, this is usually less important than keeping the tread surface on the track, and the sidewall stiffness.

Tire Pressure



With that in mind, here's the thing: Tires have an ideal window or range for their pressures; too much pressure and you lose grip, too little and you lose grip; just right is…well, just right for maximizing grip. That range could be a couple of psi (pounds per square inch of pressure), or as small as half a psi or so. So, if your tires are at the top of that range, and you raise the pressures, you'll lose grip. Conversely, if you lower the pressures a psi or two, you may gain grip. Your take-away from that experience would likely be that lowering tire pressures will always result in more grip, but that's not the case. If your tires are at the very bottom of that pressure range, and you lower them, you'll lose grip.

That leads to the obvious question, "How do I find that ideal range?"

Like everything else, do a sweep, and fine-tune from there:

1. Start with pressures that are recommended for your tire for track driving (check out Tire Rack's website, ask whomever you purchased the tires from, and/or talk with other drivers running the same tire on the same type of car that you're driving).
2. If you can't get a recommendation from a trusted source, find the pressures that your car manufacturer provided (owner's manual or on the driver's inner door frame), and raise them by 5 psi. Why? Because the side loads you'll be putting on the tires are far greater than those the manufacturer based their recommendations on, and you need that extra pressure to support the tire sidewalls so they don't flex so much that the tread surface is pulled off the track. Call these pressures, or the recommended ones, your "baseline."
3. Drive your car with these baseline pressures until you're consistent with your driving and you know that you'll be able to sense changes in tire pressures.
4. Raise all four tire pressures by 4 psi, and drive your car again. Make note of how it felt – the overall grip level (more or less?), as well as the responsiveness to changes in direction.
5. Lower all four tire pressures to 4 psi below your baseline (a total of 8 psi less from the previous step), and drive it again, while making note of how it felt. Is overall grip and responsiveness better or worse?
6. You should now have a direction. You will know whether more or less pressure than baseline is likely to help you get the tires into their ideal range. Set your pressures to whatever you felt provided the most overall grip and responsiveness: baseline, plus-4 psi, or minus-4 psi. This is your new baseline.
7. Go through steps 4, 5 and 6 again, but this time making only 2 psi changes. Then again, but making only 1 psi changes.
8. If you liked the feel of your car's handling with more pressure, or less pressure, but you sensed that your car had less overall grip (it was more responsive, but lacked overall grip), that provides a direction, too. Raise or lower the pressures by 2 psi, and test it again, looking for a direction.
9. Carry on with this process, making smaller and smaller adjustments until you feel that you've found the ideal range for overall grip and responsiveness. Then, depending on track conditions and ambient temperature, you can make fine adjustments to dial it in for individual track conditions.

Notice that you should start off with large changes, and gradually work down to finer adjustments as you home in on the ideal target pressures.

Through this process you'll get a feel for whether raising or lowering the pressures will usually help or hurt, and this is critical information, since you can use it to tune the balance of your car. For example, if your car is understeering

and you want more front grip, you should have a good idea whether raising or lowering the pressures will help. Sure, you won't be right every time, but the goal with following the steps above is that you'll "guess" right more often than not.

Also, by following this process, you'll learn just how small an adjustment you can sense. You may find that with your tires and car, that you can notice a 2-psi change, but not 1 psi. That's important to know, as some drivers spend a lot of time fiddling with 1 (or even 0.5) psi changes when, in reality, they can't feel the difference.

If you're unable to go through this process, my recommendation is to start with these very general guidelines:

- To improve grip on one end of the car, increase tire pressure on that end's pair of tires.
- To improve overall grip on both ends of the car, increase tire pressures.
- To improve the responsiveness of your car's handling, increase the tire pressures.

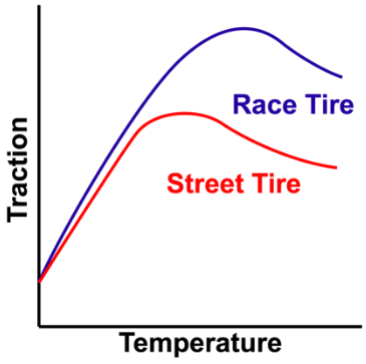
Am I suggesting that raising the pressures will always increase grip? No. These guidelines work every time, except when they don't! Again, if the tires are already on the verge of being over-pressured (at the top of the ideal range), increasing the pressure will only hurt the grip levels. Most often, when the tires are over-pressured, the problem is you're no longer keeping the tread surface on the track.

But if you have to make a fairly wild guess, start by increasing the pressures. You can always reduce them if you don't gain grip!

Keep in mind that your driving will have a big effect on the ideal tire pressure range. If you drive your car closer to the limit than you have in the past, your pressures will likely need to change. So what you think are the perfect tire pressures today may not be in six months or a year from now when you're driving your car harder.

Tire Temperature

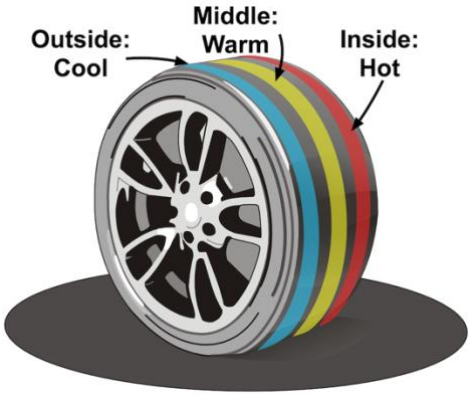
Just like tires provide the most grip with the ideal pressures, they also work best in an ideal temperature range. The temperature I'm talking about is across the tread, including the carcass of the tire and the surface of the tread where it comes in contact with the track.



Tire grip initially rises with an increase in temperature, until it reaches its ideal range, and then tapers off with higher temperatures. As a driver, you have likely experienced this: cold tires don't have the same level

of grip as hot ones do, and if you over-drive the tires (sliding the car too much), they overheat and begin to lose grip. It's this ideal temperature range we'd like our tires to operate in. But not all tires have the same ideal temperature range. A slick race tire will typically operate and produce maximum grip at a higher temperature than one designed for average road use, with ultra-high-performance street tires somewhere in the middle.

Measuring tire temperatures with a probe or infrared tool can be helpful, and yet can also be misleading if not done properly. Mostly what you want with tire temperatures is to get readings across the tread surface, from the inside, the middle, and outside. In a perfect world, if you could measure the temperatures in the middle of a long corner, readings would be the same across the full width of the tire tread surface, meaning that the full width of the tire is in contact with the track and doing its job of providing traction. The challenge is that unless you're able to take these tire temps while you're driving through corners, you don't have perfectly accurate information.



By the time you slow down, drive into pit lane, and back into the paddock, your tires have cooled down. And the inside edge of the tread will have cooled down less than the rest of the surface, since it's being run on while driving straight (remember that your car will have some amount of negative camber, meaning that the inner part of the tread surface is more in contact with the track when driving straight; the outer part of the tread is not being used as much while driving relatively slowly into the paddock, and therefore will cool down more than the inner part). A typical temperature spread from the inner part of the tread to the outer part can be 20 to 30 degrees (Fahrenheit) for a setup that is providing good traction. If the tire temps are equal across the surface by the time you've slowed down and stopped, it's most likely you do not have enough negative camber in your suspension; much more than 30 degrees and you may have too much negative camber.

If you don't measure the tire temps almost immediately after slowing down and coming into the pits, the information you're getting can be inaccurate and misleading. Ideally, you should drive your cool-down lap as close to maximum speed as possible, and come into pit lane and have the tire temps taken as quickly as possible.

As a general guideline, if the tires on one end of your car are running hotter than the other tires, that means those tires have a higher slip angle. Therefore, for example, if the front tires average hotter temperatures than the rear tires do, that

means your car is understeering; the opposite temperature spread - the rear tires hotter than the fronts - would indicate oversteer.

So, tire temperatures can be a useful bit of information for tuning, as they can tell you or confirm your sense of whether the car is either understeering or oversteering; they can also be used to home in on the ideal camber and toe angles. But how and when you take the temperatures is critical; wait too long before measuring them and you're going to get information that could very well lead you in the wrong direction.

I can tell you that more than a few of the very top race car engineers in the world do not put too much emphasis on the spread of tire temperatures across the tread, for the very reasons I mentioned above. Instead, they spend more time simply looking at the tread surface, and "reading" them. If you take time after every session to study the tread surface, and compare what you see with what you felt while driving the car, over time you'll learn more about what works and what doesn't work by just reading your tires. You can take this a step further by taking a quick photo with your smartphone, and then add a few short notes about how the handling and grip levels felt. Eventually, you'll have a valuable library of what tires should look like when your car is handling well.

A quick note on getting your tires up to temperature. Quick, back-and-forth swerving of the steering does very little to build heat in the tires. Long, hard acceleration and braking does much more. Why? First, when you build heat from the inside of the tire, that's more effective. So, when you brake hard and long, heat builds in the brakes, and that temperature transfers into the hubs, then into the wheel, and finally into the air inside the tires. When you quickly swerve back and forth, only the very surface of the tires are sliding (slightly) on the surface of the track. That, then, requires more time to build heat throughout the tire, and that's what matters most.

Temperatures versus Pressures

Never forget that temperature affects pressure: with increased temperature comes increased pressure. Therefore, when you're adjusting tire pressures to find that ideal window, you're looking for the pressures when the tires are hot. For example, if the recommended pressures for your car and tires are 36 psi, that's a hot pressure. That means that you need to figure out how much the pressures will increase from when you initially set them when cold.

It's not unusual for tire pressures to increase by 5 to 10 psi from the cold settings. Since all you really care about is the pressures when your tires are hot, you have to figure out where to set them when cold that will ultimately end up where you want them on track. That means that if you're at the track on a cold day, you may have to start with cold pressures a little higher than if you're at the track on a very hot, summer day, and vice versa.

A big factor in how much your tire pressures increase on track is how hard you're driving your car. If you're consistently driving at the limit, then the tires are being loaded more, and the pressures will rise more; if you're driving well under the limit, they will not increase as much.

Another factor that determines how much the pressures increase on track is the amount of humidity in the air inside your tires. Since water (the humidity in the air) expands more than air, the pressures can increase dramatically if there's a lot of moisture in the air that has been put in your tires. For that reason, it's best to use some type of air dryer on the air compressor that you use to fill your tires. If you have to fill your tires with air from a local gas station, be prepared for your tire pressures to increase more when they get hot on track. If you use air from different sources from day-to-day, or event-to-event, be prepared for the pressure increase to vary, making it difficult to dial in your ideal pressures.

Again, your goal should be to find the ideal tire pressure range when hot, when you're driving at your limit.

SUSPENSION GEOMETRY/ALIGNMENT TUNING

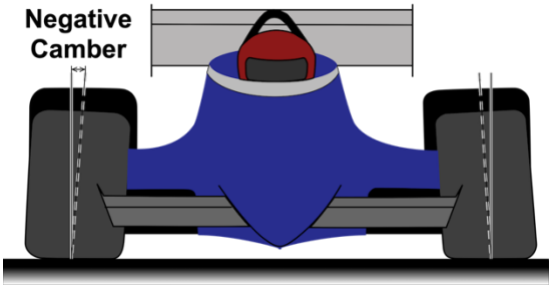
Obviously, there are a multitude of adjustments that can be made to a car's suspension, with its geometry and alignment. But for most drivers, the three main adjustments you can make reasonably easily are:

- Ride height
- Camber
- Toe

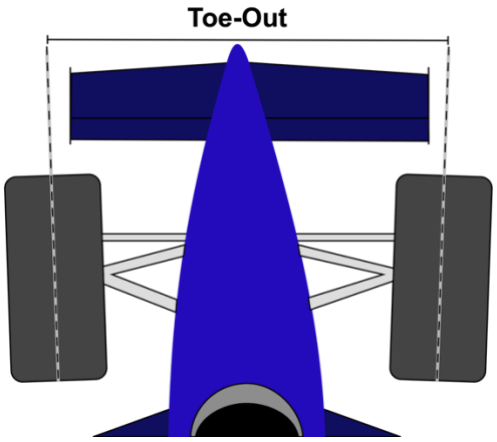
Guidelines for suspension tuning:

- Lower most often generates more grip. Therefore, if you want more front grip, lower the front of the car; lowering the rear will generate more rear grip. The exception to this guideline is when you get so low that the chassis begins to bottom out, or the suspension geometry gets so far from the original designed ride height that the camber and toe begin to work outside their ideal range. There are aerodynamic considerations, too, but we won't go into that, here. But, your car's rake – the difference between the front and rear ride height (positive rake is when the nose of the car is lower than the rear; negative rake is the opposite) – can be a powerful tuning tool.

- More negative camber (the top of the tire leaned into towards the center of the car) increases grip… until it doesn't. Keeping in mind what I said earlier about the goal of keeping the tread surface flat on the track, you would think that you'd want the tire standing straight up and down with no camber whatsoever. But since the tires on the outside of a corner lean outward due to chassis roll, beginning with negative camber will mean that they're straight up and down - and the tread is fully on the track - when cornering hard. Increasing the negative camber will generate more grip until the tire is leaning too much, to the point where the tread surface is not flat on the track in the middle of the corners. Like tire pressures and temperatures, your tires have an ideal camber range, and it's your goal to zero in on the middle of that range. And different levels of track grip, and even ambient temperature, can make a difference to where that ideal camber setting is.



- If your car has independent rear suspension, then the toe can be adjusted. In practically every situation, you want some amount of toe-in on the rear, as toe-out will make the car very unstable. Unless you're very knowledgeable, stick to factory specs for rear toe.
- Adjusting front toe is an effective tuning tool. Too much toe-out and the car will feel unstable when driving in a straight line, as each tire will be trying to pull the car to one side or the other. However, toe-out will help improve the car's initial turn-in capabilities (because the tire on the inside when entering a corner is already pointing into the turn, it makes the initial turn-in more responsive). So, if you want your car to have more turn-in response, increase the toe-out. If your car is set with toe-in, decrease the amount of toe-in, or even go to toe-out. If you really want to understand the impact of toe, do a sweep, where you test your car from one end of the spectrum of toe-in to toe-out. In doing so, you'll learn more about slip angles and where your tires generate the most grip. Note that tire temperatures can help you tune the toe, as well. If the inside of the tread surface is much hotter than the outside, it may be that you have too much toe-out, and that inside edge is scrubbing while driving in a straight line. Also, keep in mind that more toe (either in or out) will increase



tire temperatures due to the scrub while driving on the straightaways, and that temperature increase will show up more on the inside part of the tread surface. So, if you want your front tires to run hotter, more toe is an option; the opposite is also true.

To begin, always start with the stock, factory alignment if driving a production-based car, or the recommended settings if driving a purpose-built race car. Not only does this give you a good, solid baseline to begin with, but it's not going to make the car undriveable. Start there, and make incremental changes, while always keeping track of the changes in your notes.

BALANCE, RESPONSIVENESS & GRIP

Many drivers relate handling to responsiveness, and that's why they think stiffer springs and/or anti-roll bars and shocks result in better handling. If the car responds quickly to your steering inputs, it gives you confidence. And confidence is usually faster than overall grip. But balance is just as important – maybe more so – than responsiveness. So, it's important to separate your thinking - initially - between responsiveness, balance, and overall grip.

When we talk about balance, we're talking about the relationship of oversteer to understeer. If the car understeers too much, that's not balanced; same with too much oversteer. Having said that, there is a time and place where you may want a touch of understeer or oversteer. For example, most drivers are faster with a bit of understeer in fast corners (since it gives you confidence that it won't snap sideways), and a little oversteer in slow corners (since it helps you change direction, or rotate the car).

Similarly, there is a time and place for a very responsive car, such as in Esses or a chicane, where you need to change quickly from one direction to another. But entering a high-speed sweeping turn, you don't need the car to be as responsive. There, you likely want to "bend" the car into the corner.

This leads us to a few more general guidelines:

- Stiffer anti-roll bars, springs, and shock settings will result in a more responsive car. You turn the steering wheel and the car will respond. It feels crisp on turn-in.
- Softer anti-roll bars, springs, and shock settings will result in more grip. Yes, the car will roll (lean) more in corners, but it will be generating more overall grip.
- A touch of understeer in fast corners is good; a little oversteer in slow corners is also good.

To complicate things even more, you could have a car with stiff springs up front, and soft on the rear, relative to each other. This might make the car feel

responsive when you turn in to the corners, but it will likely be unbalanced. In this case, it's likely to understeer shortly after turning into the corner.

Whenever you're tuning the handling of your car, think in terms of balance, responsiveness, and overall grip. I'd recommend you focus your tuning in that order.

Having driven thousands of cars on numerous tracks, I'll choose a balanced car first, over one that is responsive or has more overall grip. Of course, I'd rather have it all - more grip in a responsive, balanced car. But if I had to choose one over the other, balance wins most often. Why? Because I can make the car do what I want, and drive with confidence, increasing my chances of making up for the lack of grip.

But if I had to choose between balance and responsiveness? That depends on the extent of each one, but I usually go with balance first (for the same reason - it's easier for me to work with a balanced car). Having said that, if the car is very unresponsive, that makes it difficult to make the car do what I want (which, most often, is change direction quickly).

Again, as a driver, balance and responsiveness are most often more important than overall grip (Setup Tuning Principle #7, *Balance is more important than overall grip*).

There are exceptions, but if the car gives you confidence that you can sense what it's doing, you'll drive faster than when driving a car that has more grip - but scares you because it has a lot of understeer or oversteer! Ultimately, it's all about your ability to feel what the car is doing.

There are two main things you need to consider when thinking about feel:

1. Is the car communicating what it's doing, and can you sense it?
2. How responsive is it to your inputs?

Going back to the Vehicle Dynamics Principles, a softer car will usually generate more overall grip since it doesn't transfer as much weight from the inside to the outside tires (keeping the load on each tire more equal). With that in mind, you would think that a softly-sprung car would always be better. In many cases, that's true – especially on a low grip surface, such as slippery pavement, in the rain, or to the extreme, when racing on ice. This is why the general guideline for tuning your car for driving in the rain is to soften the springs, anti-roll bars, and shocks.

However, if you've ever driven a very softly-sprung car (again, think of an old Buick), you know its handling is not responsive. When you turn the steering into a corner, it takes a while to respond. And if you have a section of track where you quickly go from a right turn to a left turn and back to the right again (tight Esses, for example), you won't like it. To make a car more responsive, the general

guideline is to stiffen the springs, anti-roll bars, and shocks. Yes, the opposite from what could generate grip.

Keep in mind that a track can go from a relatively high-grip surface in the cool of the morning to a low-grip one in the middle of a hot afternoon. In that case, you might soften the car to adapt to the changing conditions. But, if the track gains grip due to additional rubber put down on the surface, or cooler ambient temperatures (but not cold) and cloud cover, a stiffer setup may gain grip.

Ultimately, your goal is to find the ideal compromise between overall grip, responsiveness, and balance. There is no magic formula telling you how much grip you should sacrifice for responsiveness, and vice versa. This is where driver preference really comes into play, and why two drivers may prefer a very different setup on the same car. What matters most is what provides you with the most confidence to drive the car as close to the limit as you want.

THE TUNING-DRIVER LOOP

Whether you're adjusting the anti-roll bars, springs, shocks, tire pressures, or suspension alignment, think of it was a funnel. Begin with big changes, and work your way down until you're fine-tuning with small changes. If your car has a drastic handling problem, there's no point in making a one psi tire pressure change, or one click stiffer on the shocks' compression settings. No, make a big change, and that is more likely to be with tire pressures, anti-roll bars or springs, or maybe ride height. Again, look to get a direction from a large change, and then begin making smaller and smaller changes as you determine the handling you're looking for.

As I said earlier, tuning is an ongoing process, and part of the reason that's true is that your driving will change over time. As you make the car's handling better, you'll drive with more confidence, meaning you'll drive faster, which will expose the next weakness in your car's handling (and there will always be a weakness). It's a never-ending loop from car to driver to car to driver…and so on.

REVIEW

Let me recap the guidelines for tuning the handling of your car:

1. Think in terms of balance, responsiveness, and overall grip, in that order.
2. To reduce oversteer:
    - Soften the rear anti-roll bar
    - Soften the rear springs
    - Soften the compression and/or rebound on the rear shocks

3. To reduce understeer:
    - Soften the front anti-roll bar
    - Soften the front springs
    - Soften the compression and/or rebound on the front shocks
4. If the handling problem is in steady-state conditions, focus on tire pressures, anti-roll bars, springs, and alignment adjustments. If the problem is in transitions, then tune the shocks, as well.
5. To make the car more responsive, stiffen the anti-roll bars, springs, and shock settings.
6. To make more grip, soften the anti-roll bars, springs, and shock settings.
7. A touch of understeer in fast corners is good; a little oversteer in slow corners is also good.
8. Soften the anti-roll bars, springs, and/or shocks when driving on a low-grip track surface; stiffen them on high-grip surfaces.

SENSING THE CAR

Just as you can tune the handling of your car, you can also tune your own ability to sense what the car is doing. And when you really think about it, that's more than half the battle when trying to make your car faster. I've written extensively about this topic (in my *Ultimate Speed Secrets* book, as well as in multiple issues of *Speed Secrets Weekly*), as well as put on lengthy webinars (see Reading Your Car webinar here) about how we, as drivers, sense the limits of our cars – and how we can get better at it. So, rather than repeating myself here, I'm going to just give you a basic bullet-pointed overview of what we sense, and how you can improve your ability to sense it.

What Are You Sensing?

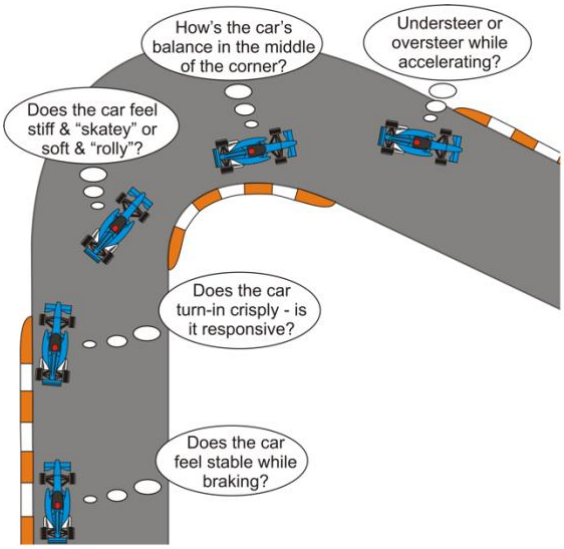
- Yaw (Body Slip Angle, Rotation)
- G-loads
- Weight (Load) transfer
- Steering effort/vibrations (steering is output & input device)
- Visual picture
- Tire/wind/engine sound

Improving Sensing (Learned skills)

- Personal sense of balance
- Exercises:
    - Centering
    - Sports/training (cycling, balance board/ball, etc.)
- Deliberate Practice sensing the car
    - Street practice
    - Light hands
    - Sensory Input Sessions
    - G-load sessions
    - Setup sweeps
    - Skid pad
    - Test the limits – steering, braking, accelerating
    - Make car show its weakness

- Handling Debrief Process

Drivers are not born with a special gene that gives them an ability to sense a car's handling better than another driver. No, this is mostly a developed skill. Okay, it's possible that some drivers have better senses of balance than others, but even that is a skill that can be improved. Developing your ability to sense the limits of the tires and how the car is handling should be approached like any skill – in a deliberate and intentional way. Rather than simply going on track and chasing a lap time, set aside sessions to solely focus on what you can feel, in a very detailed manner, and at a deep level. Take time after each session to use the Handling Debrief process, and write down on a track map what you felt. Most importantly, while doing this, close your eyes and mentally replay what you and your car were doing on track.

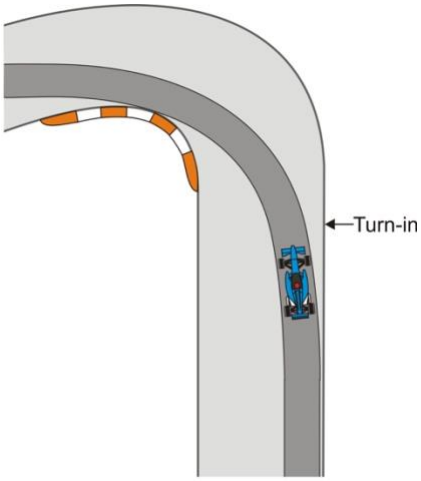


A strong psychological factor that will help develop your sensing abilities is called "priming." If, prior to driving on track, I tell you that when you come in at the end of the session, I'm going to ask you to describe how the car initially turns into Turn 3, your ability to recall that information improves dramatically. In this example, I've primed your brain. But you can do the same on your own. Prior to going on track, look at the Handling Debrief process, and know that you're going to ask yourself each of those questions, for each corner on the track. Your ability to sense what your car is doing, and recall it, will improve by priming your mind before driving.

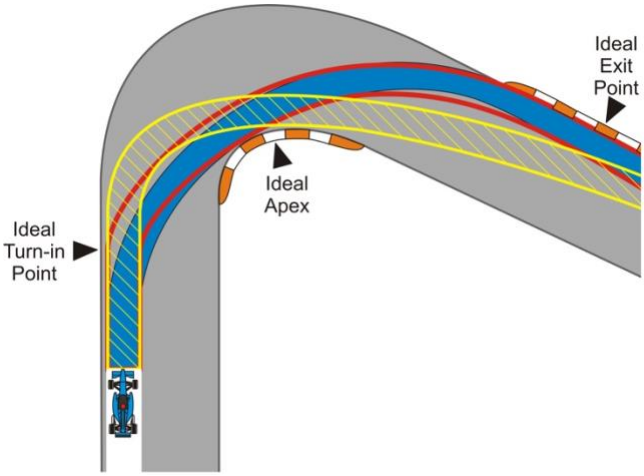
COMMON DRIVING ERRORS LEADING TO HANDLING PROBLEMS

Is it possible that your driving technique is causing a handling problem? Yes. Therefore, I provide the following, simply to help you become more aware of possible driving errors you're making that can lead to handling problems. By asking yourself whether you're making these mistakes, you'll be better at identifying the real issue.

- "Crabbing" - easing away from the edge of the track before turning into a corner (reduces radius of corner, often causing understeer)
- Turning in early (reduces radius of corner, often causing understeer)
- Turning in late (increased steering angle, often causing understeer; abrupt turn-in can also cause oversteer)
- "Pinching" – not unwinding the steering when exiting a corner (often leads to oversteer in a rear-wheel-drive car due to the steering angle not being reduced while accelerating; or understeer in the front-wheel-drive)
- Early and/or abrupt brake release (often leads to understeer due to unweighting the front tires while turning in)
- Early throttle application (often leads to understeer due to unweighting front tires before beginning to unwind the steering)
- Aggressive throttle application (often leads to power oversteer, or possibly understeer from unloading the front tires)
- Mid-corner steering increase (usually to force car to missed apex, leading to understeer or oversteer)
- Overreaction to understeer (often causing oversteer when front tires grip up and the car turns dramatically)



Crabbing into a corner, moving the car away from the edge of the track before the Turn-in point.



Early turn in (blue); late turn in (yellow); abrupt turn in (red outline).

GLOSSARY

Ackerman: The inside wheel of a vehicle driving through a corner travels on a tighter radius than the outside wheel. Therefore, the inside front wheel must be turned more sharply to avoid it scrubbing. The geometry of the front suspension is designed to achieve this, and this is called Ackerman steering.

Anti-dive: When you apply the brakes, the front end of the car dives. The suspension geometry can be designed in such a way as to resist, or reduce this tendency. Generally, this is something designed into the car and requires - or even allows - little or no adjustment, except on purpose-built race cars.

Anti-Roll Bar: An anti-roll bar (sometimes wrongly referred to as a sway bar) is used to resist the vehicle's tendency to lean (roll) during cornering. The anti-roll bar, usually a steel tube or solid bar, is used to alter the front or rear roll resistance, therefore affecting the car's handling characteristics. Some cars have adjustment controls in the cockpit, so that you can make changes as the track conditions, fuel load, and tire wear change throughout a race. Adjusting the anti-roll bars is often the easiest and quickest change you can make to the suspension setup.

Anti-squat: When a car accelerates, the rear "squats" down. As with Anti-dive, the suspension geometry can be designed to limit this. And again, very little adjustment is required or available on most cars.

Balanced: When a car is neither accelerating, decelerating, or cornering, it's balanced. Why? Because the weight of the car is distributed equally over all four tires. Well, as equal as its static weight distribution. Any time you brake, turn the steering wheel, or apply the throttle, the car will not be perfectly balanced due to this weight or load change (see "weight transfer").

Blow through the tire: This is a phrase that drivers use to describe how the car feels when it begins to lose traction and either understeers or oversteers. A tire will grip the track surface for only so long, and then, if the load or lateral cornering expectations are increased, it eventually lets go and slides. This can feel as though the load of the car has "blown through the tire."

Bottoming, bottoming out: When either the bottom of a car's chassis contacts the track surface, or the suspension reaches the end of its travel and some component contacts the chassis, it has "bottomed."

Brake bias: An important factor in braking is how the brake bias is set and/or adjusted. Braking forces are not equally shared by all four wheels. Due to the forward weight transfer under braking, and therefore more front tire traction, more of the braking is handled by the front brakes. So, the brake forces will be biased

towards the front. This is why practically all vehicles have larger brakes on the front wheels than on the rear.

Ideally, you want to adjust the brake bias so that the front wheels will lock-up (or activate ABS) just slightly before the rears. This is a more stable condition, as it gives you more warning of a skid. You will feel it in the steering immediately if the front tires begin to skid. Plus, if the rear tires lock-up first, the car will tend to skid sideways.

However, different conditions will require a different ratio, or bias, of front versus rear braking forces. In the rain, because there is less forward weight transfer to the front (because traction limits are lower, heavy braking is not possible without locking-up), you want to adjust the brake bias more to the rear (if it's adjustable). Some cars also change dramatically as the fuel load diminishes during a race. This is where a driver-actuated brake bias adjuster is beneficial.

Bump steer: Bump steer should be avoided. This is when the front or rear wheels begin to either toe-in or toe-out during the vertical suspension movements caused by a bump or from body roll (sometimes called "roll steer"). Although it has been used to help "band-aid" a handling problem, generally bump steer makes a vehicle very unstable, particularly on the rear wheels. The goal is to have no bump steer whatsoever.

Camber: Camber angle is the inclination of the wheels, looking from the front or rear of the car. A wheel inclined inward at the top is said to have "negative camber"; a wheel inclined outward at the top has "positive camber." The angle is measured in degrees.

Caster: Caster angle provides the self-centering effect of the steering (the tendency for the car to steer straight ahead without holding the steering wheel). The front wheels on a shopping cart have lots of caster. It is the inclination angle of the kingpin, or upright, looking from the side. Positive caster is when the top of the kingpin/upright is inclined to the rear. Negative caster is never used.

The more positive caster, the more the steering will self-center - which, generally, is a desirable effect. However, the more positive caster, the more effort it takes to turn the steering against this caster. There has to be a compromise between easy self-centering and heavy steering.

Caster also affects the camber when the steering is turned. The more positive caster, the more negative camber on the outside tire during cornering. This must be kept in mind when adjusting for the optimum camber setting. Perhaps, instead of dialing in more static camber, you may be better off adjusting in more caster (if you have this option). Remember, this will result in more negative camber on the outside tire during cornering.

Contact patch: As you drive down the track, there is only a small part on each tire that is in contact with the track surface at any one moment in time. If you look

at your tires while your car is sitting still, it's easy to see that the amount of your tire touching the road is relatively small. It's this part of the tire that is referred to as the "contact patch."

Obviously, if you have a wider tire, it will have a larger contact patch. But if you were to push down on your tire harder, putting more weight on it, its contact patch would grow larger, too (think of pushing a balloon against a table surface – the more you push on it, the larger the area of the balloon touching the table). And, generally, the larger the contact patch, the more grip or traction the tire has with the track surface.

Corner Weight: If you place your car on four separate scales (each tire on its own scale), they will give you the corner weights of the vehicle. From there, you can determine the front-to-rear and left-to-right weight distribution, as well as total vehicle weight.

Usually, for a road course, the left-to-right corner weights should be the same; with practically any mid-engine car the rear corner weights will be higher than the front; front-engined, and especially front-wheel-drive cars usually have more weight on the front tires. For oval tracks, often the setup will be biased to one side or corner.

Adjusting corner weights is an important suspension tuning tool - one which is often overlooked by many inexperienced drivers/tuners.

Entry: If you divide a corner up into thirds, the corner entry is the first phase; it begins at the turn-in point.

Exit: This is the third and final phase of the corner, and includes the exit or track-out point.

Fall over: A phrase used to describe the car when it feels as though it has rolled too much, causing it to begin to understeer or oversteer. In a corner, the car may initially have grip, but then let go and start sliding. If you feel the car's chassis roll a lot, then the grip let go, it may be due to the car "falling over."

Flat slide: This is a phrase that describes a condition similar but very different from "falling over." In this case, the car doesn't feel as though it's rolling too much, but rather that the tires have let go and begun sliding across the surface of the track.

Free: Another term used for describing oversteer. If a car is oversteering too much, it can be described as being "free."

Friction Circle: The Friction Circle (sometimes referred to as Traction Circle) is a graphic way of showing the performance of any driver in any car. Basically, it is an X-Y axis graph produced by a data acquisition system of the g-forces during braking, cornering, and acceleration that the car experiences while being driven around a track.

A tire has relatively equal traction limits in each direction - braking, cornering, or acceleration. As an example, a car and tire combination is capable of braking at 1.0 g, cornering at 1.0 g, and accelerating at 1.0g before the tires begin to break away and start to slide. If you exceed the tires' traction limit, they will begin to slide - slowing you down, or, if not controlled, resulting in a spin. On the other hand, if you do not use all the tires' traction available, you will be slow.

These g-forces can be measured and graphed as you drive through the corner. If you use the proper driving technique, the graphed line will follow something similar to a circle - the Friction Circle - telling you that you are using the tire's full potential. Actually, it will not be a circle, but rather an ellipse, as the acceleration forces of a car can rarely ever match the braking and cornering forces, and therefore the bottom of the "circle" tends to be flat.

The Friction Circle demonstrates how a tire's traction limit can be used and shared. It shows that if you are using all of the tire's traction for braking, you can't expect to use any for cornering without easing off the brakes; if you are using all the traction for cornering, you can't use any for acceleration until you begin to "unwind" or "release" the steering (straightening the wheel); if you are using all the traction for acceleration, you can't still be cornering near the limit.

The Friction Circle really demonstrates the key to driving fast is balancing the pedal application with the steering angle.

Hooks around the front: This is a phrase used to describe when the car turns well in the corner, and then feels as though it suddenly gains grip at the front and loses grip at the rear, causing the car to oversteer – but the oversteer is coming from the "hooking around the front."

Loose: Another term used to describe oversteer. Oval racers most often use "loose" to describe a car that is oversteering.

Loose in, loose off: Again, this is how oval track racers talk about a handling characteristic, but it also applies to driving on a road course. Oval track racers tend to have more ways to describe a handling issue because they fine-tune their cars more than most road racers. "Loose off" refers to when the car oversteers when accelerating out of a corner (also see "throttle steer" and "power oversteer," as they may be related – but not necessarily). "Loose in" means the car begins to oversteer when entering a corner. Both terms are good because they not only describe what the car is doing (oversteering), but also where in the corner.

Maintenance throttle: You're applying just enough throttle to maintain speed – you're not increasing speed, or accelerating; nor are you decelerating. On a flat track surface, you won't be changing the position of the gas pedal, but when going up or down hills, you'll either be adding or decreasing the amount of throttle to maintain speed.

Mid-corner: This is the second phase of a corner, if you divided it up into thirds. Typically, the apex of the corner is in this phase, as is the part of the corner where you've ended your braking and transitioned to throttle.

Nervous in: You'll hear this term used to describe a car that oversteers entering a turn. As the driver turns in, the rear wants to step out, making the driver unsure of whether he's going to spin or not. No wonder the word "nervous" is used, right? If, just after turning in, the car immediately begins to oversteer, one could describe that as being "nervous in."

Neutral: This is the term used to describe a car that is neither understeering nor oversteering. If, when pushed slightly past the limit, the car slides the front and rear equally, it's considered to be "neutral" with its handling balance. This is what we're most often aiming for when tuning the car's handling.

Off-throttle: Essentially, you're coasting, as you're not applying any pressure to the gas pedal.

Oversteer: Oversteer is when the rear tires have less traction than the front tires do, and the car turns more than you intended – it has "over steered." The effect is having the rear slide out and make the car rotate or almost spin out. Yes, taken to an extreme, the car will spin around. The rear tires have a larger slip angle than the fronts do.

Plow: Another term used to describe understeer, since a car plows straight ahead when it's understeering.

Power oversteer: If the driver aggressively applies the throttle, causing the rear tires to break traction and get some wheelspin, this will reduce those tires' cornering abilities. This also leads to the rear of the car having a larger slip angle than the front, so the car oversteers. In this case, though, it's power-induced (actually, driver-induced!), so this is "power oversteer."

Note that you cannot produce power oversteer in a front-wheel-drive car; it may be possible in some all-wheel-drive cars, depending on how the power is divided between front and rear wheels.

Push: Like "plow," this is another term used to describe understeer. Oval track racers tend to use "push" most often.

Push center-off: This phrase is used to describe a car that understeers when accelerating out of a corner, essentially from the center of the corner to the exit. As it describes not only what the car is doing (understeering), but also where, it's very useful.

Rake: The difference between the front and rear ride heights. Positive rake is when the front is lower than the rear, so the car has a "nose-down" stance.

Ride Height: The ride height is the distance between the road surface and the lowest point on the car. Adjustment of the ride height - particularly the rake - is used to tune the handling.

The ride height is usually determined by running the car as low as possible without the chassis bottoming out on (or, at least, just barely touching) the road surface, or the suspension running out of travel. Usually, the lower the car is run, the better the aerodynamics; as well, the lower center of gravity is advantageous.

Roll: Think of roll as the amount of "lean" your car experiences when going around a corner. If you hear someone say their car has "too much roll," they're not suggesting it's going to roll right over and onto its roof. A car can roll fractions of a degree, and yet it's still rolling.

Roll Stiffness: Roll stiffness is the total amount of resistance to the car leaning or rolling provided by the springs and anti-roll bars. This is measured in pounds per inch of spring travel at the wheel and is a function of the spring rate and the anti-roll bar stiffness.

The distribution of the vehicle's roll stiffness between the front and rear suspension is called the roll stiffness distribution, and is expressed as a percentage, front to rear.

Generally, it's the roll stiffness distribution that we use to fine-tune the handling balance of the car, using the springs and anti-roll bars. Adjusting the front roll stiffness (with springs or anti-roll bars) in relation to the rear, and vice versa, is the most common method of altering the handling balance of the car.

Shock Rate: The purpose of a shock absorber is to slow down and control the oscillations of the spring as the suspension absorbs undulations in the roadway. Actually, a shock absorber is a damper - it dampens the movement of the springs. Especially in Europe, a shock absorber is called a damper for this reason.

Shocks work in both directions: compression is often called bump; extension is called rebound. A shock absorber, therefore, is rated by the rate of deflection at a given shaft speed, both in the compression and rebound direction. The car's springs are force sensitive, but the shocks are velocity sensitive.

For more information on shocks, see the Shocks for Drivers eBook.

Slip Angle: The difference between the direction the wheel is pointing and the direction the car is traveling. Due to the way tires deform and interact with the track surface, when there is a small difference – typically somewhere in the 4- to 10-degree range – between where the tire is pointing and the car is traveling, the tire will generate its maximum traction.

Spring Rate: The spring rate is the amount of force needed to compress a spring a given amount, and is usually measured in pounds per inch of deflection. The

diameter of the spring wire, the overall diameter of the spring, and the length or number of coils determines this rating, or resistance to being compressed.

Squat: When accelerating, weight (actually, load) transfers to the rear, causing the back of the car to "squat" down, and the front of the car to rise. How much the car squats depends on a number of factors, such as the acceleration abilities of the car, its suspension geometry (whether it has "anti-squat" designed into it), and spring and shock absorber settings.

Sweep: When beginning to dial in the setup of the car and learn how it responds to changes, do a "sweep" of various adjustments. For example, start by adjusting the front anti-bar to full stiff, then go drive the car; then adjust it to full soft, and drive it again. Thus, you've gone from one extreme to the opposite end of adjustability, doing a "sweep" from one end to the other. With each setting, make note of how the car feels and its handling balance. This will help you decide which direction you should go to get a good balance with the car. Ideally, you'd do this with the full range of adjustments with tire pressures, shocks, springs, anti-roll bars, and alignment options.

Take a set: As you turn into a corner, weight transfer occurs. Usually, just after the Turn-in point, the load is coming off the front tires as you release the brakes, and at the same time, the outside tires are being loaded more and more as weight transfers laterally from the cornering forces. If the corner is relatively tight and short, immediately after the weight transfer has occurred from corner entry, it changes as you progressively unwind (straighten) the steering and begin accelerating. At this point, the load is transferring more to the rear and beginning to balance out as the cornering forces are reduced.

But, if the corner is long enough, or you've done everything smoothly enough, there could be a point in the corner where all the load shifting is complete and the car is in a steady state of cornering. It's at this point where the car has "taken a set." In reality, there is rarely a time when there isn't some amount of weight transfer happening, but when it's at a minimum, the car has taken a set.

Once a car has taken a set, it's easier for you to sense the limit and manage it. When load is changing, it's a moving target that you're having to sense. If you're able to make the car take a set by deliberately balancing the weight, you'll be better able to drive the car at the limit.

Toe: Toe can be either "toe-in" or "toe-out." It's the angle of either the two front or two rear tires looking at them from above. Toe-in is when the front of the tires is closer together than the rear; toe-out is the opposite - the front of the tires is farther apart than the rear. Toe can always be adjusted at the front, but can only be adjusted at the rear on cars with independent rear suspension.

Toe plays an important role in the car's straight-line stability, as well as its transient handling characteristics - how quickly the car responds to the initial

turn-in to the corner. Generally, front wheel toe-in results in an initial understeer; toe-out results in an initial oversteer or makes the car more responsive to turn-in (but not always!).

Rear wheel toe-out, which would cause instability and an unpredictable oversteer, is rarely used on a road course.

Trail braking: This driving technique is where you ease your foot off the brake pedal while simultaneously turning into a corner. The term "trail" comes from this easing off of the pedal, as you're trailing your foot off. Any time you have some amount of brake pressure applied while turning into a corner is trail braking, whether that's for just a foot or so into the corner, or all the way to the apex.

TTO: Trailing Throttle Oversteer is initiated by the driver lifting off the throttle, causing weight to transfer forward, and reducing rear tire grip. This may be a deliberate and useful technique to help the car follow a tighter line around a corner, or an instinctual thing triggered by some level of fear. In the latter case, it's as if the emotional response makes the driver want to curl up in the fetal position, lifting the right foot off the throttle!

Understeer: Understeer is when the front tires have less traction than the rear tires do, and the car does not turn as much as it should – it pushes or plows on a larger radius than you'd like. In other words, it "under steers," not turning or steering as much as you intended. Technically, the front tires have a larger slip angle than the rear tires do (they're slipping more than the rear tires are).

Here's another way to think about it: the rear tires are driving your car straight ahead; the front tires are trying to change its direction; the rear tires "win" – they drive the car straighter than you'd like.

Unwind: The act of straightening the steering wheel as you exit a corner on a progressively larger radius. For most drivers, this begins as a deliberate act, but eventually becomes part of a subconscious movement, allowing the car to "run free."

Weight Transfer: When you apply the brakes, the car "nose dives" – the front of the car drops. That's because a percentage of the weight of your car has transferred forward, compressing the front suspension. It puts more load or weight on the front tires.

When you accelerate, weight transfers to the rear, causing the rear suspension to compress, and the back of your car to squat. Going around a corner, weight transfers to the outside, causing the suspension on the outside of the turn (the left side tires when going around a right-hand corner) to compress.

Every time you brake, corner, or accelerate, you cause weight to transfer. But keep in mind: the less weight transfer you cause, the more overall traction your car will have – as I explain in this video.

Wheel Rate: The wheel rate is the amount of force needed to move the wheel up and down a given amount, and is measured in pounds per inch of deflection. It is determined by the geometry of the suspension and spring mounting location, and the spring rate. Understand that even though you have the same spring rate on the front and rear suspension (or two different cars), the wheel rate may differ due to the amount of leverage a suspension system applies to the spring.

RESOURCES

I have a number of resources to help you dig further into the understanding of how to tune your car's handling:

- Reading Your Car webinar
- Data for Drivers webinar
- Shocks for Drivers eBook
- Ultimate Speed Secrets book

Also, check out these videos:

- How to Adapt to Handling Problems
- Oversteer: What Is It & How Do You Control It
- How to Control Understeer on the Race Track
- The Friction Circle & The 100% Tire Rule
- Make Your Car Show Its Weakness
- Why Smooth Is Fast

Learning more about your car's suspension and setup, and how to tune its handling, will make you a better driver, so I encourage you to use these resources.

In the end, though, you're driving the car, and you have more of an influence on your car's handling than any suspension adjustment. While you need your car to help you do your job of driving well, never forget that you can most often find more in your driving than you can in your car. Even bolting on a new set of tires will make you faster for only so long, whereas learning to improve your driving technique will never wear out.

There's always more….

BUT WAIT, THERE'S MORE…

That's all I have to share with you (for now), at least regarding tuning your car's handling – until I learn more and update this eBook. If you'd like to make suggestions for future updates, or you have questions, please email me at ross@speedsecrets.com.

I definitely have more to share on other topics, though, and they're all available at SpeedSecrets.com.

- Speed Secrets Podcast
- Ask Ross (weekly Q&A column)
- Free track maps
- Speed Secrets Weekly e-newsletter
- Car club presentations & group seminars, in-person & online
- Webinars
- Virtual Track Walk videos
- Speed Secrets Books
- eCourses
- Speed Secrets gear (t-shirts, hats)
- Online chalktalks
- And many other eBooks

Keep learning and having fun!

Ross

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