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A Basic Guide to Dialing-In Your Car

By

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Introduction

I have written this document to help the avid autocrosser dial-in their car for maximum handling. I have driven many cars over the last 9 years autocrossing. I have talked with all sorts of people at the national level, as well as read countless books on the subject of preparing a car for handling. This is a small compilation of this knowledge. The information below is to be used as a tool. Nothing more. I am not preaching "this is the way it is." In fact every car is unique in its handling characteristics (even the same model and model year). Manufacturers often change the suspension equipment that a car has based upon what other accessories it has. For example, if you look at a 1994 Camaro Z28 you will see that GM has 6-7 different sets of front and rear springs for that car, all of varying rates. The springs that go on the car depend on whether it's a V6, if it has T-Tops, power windows, A/C, etc. So just because someone else set ***their*** car up a certain way does not mean it is optimal for you. Setting up a car also involves a certain amount of personal preference. For example, you might set up your car to understeer a little to make it a little easier to drive. While the car in this configuration corners at 97% of what it could if you set it up optimally, you are more consistent driving it and will do better in competition. This will help you in the long run because at a national level Solo II, you only get 3 runs, being more confortable in what the car will do is a big plus to have on your side. Confidence in the car's capabilities is of prime importance. So lets get right into it.

So you set out to a test and tune. What do you bring? The first thing is a logbook or pad of paper. The key concept here is that you will adjust your car and ***WRITE*** down what the car did as a result of your adjustment. You will do this all day long. You ask: if I optimally tune the car, why do I need to touch it after? The answer is that conditions do change. They vary with surface (concrete, asphalt, age), temperature, moisture, barometric pressure among others. If you write down in your logbook what the car did once you adjusted something during the test and tune, then you can make that adjustment in a situation at an actual competition event at a different site and be confident that the car will do what you adjusted it to do. I want to show you how to make calculated adjustments, not blind guesses. The rest of the things you want to bring are: tire pyrometer (if you have one), tire gauge, lots of tires, tools for adjusting alignment (if applicable), factory service manual, different size sway bars, anything and everything you got that you can adjust your cars suspension with. Near the end of this document are some notable things you can focus upon for specific cars, such as rear-wheel drive, front wheel drive, etc. Note that this discussion does apply to all cars, but SP, P, and Mod cars have many more variables that can be changed in their suspension. We will mainly concentrate on Stock class cars. If anyone would like any help, techniques etc., please don't hesitate to ask me. I would be more than willing to take a drive and offer my opinions.

Tires, Shocks, Springs, and Swaybars

Lets talk a little about the role of the above things on your car's handling. Tires are obvious to everyone. Realize, the only thing connecting your car to the ground is your tires. This contact patch on most cars is only about 24 square inches per wheel (or smaller). That's not a lot of tire to motivate around a normal 3000 lb production car. So take a moment and look at the manufacturers design rim width for the tire you have. This number is published by Kumho, Hoosier, and just about any performance race tire.

Having a tire that is too wide on a narrow rim can be just as bad as having too narrow a tire on a wide rim. Sometimes it pays to get a set of each of two close sizes (say a 275/45/16 and a 245/45/16 on an 8 inch rim) and compare the handling of both sizes. Note that you may have to adjust the suspension to optimize the handling for each set of different sizes. It is not simply valid to run on each and let the clock say which is faster.

I will discuss springs and swaybars together. Springs and swaybars work in tandem with each other during a cars transition and steady state handling (see Appendix A). Both affect body roll of the car as well as weight transfer. A stiffer bar can often be put on a car to keep body roll in check, especially if the springs are soft. Conversely, stiff springs can be used to control body roll and smaller sway bars used with them. Which is better and why do you want to control body roll? I prefer having stiff springs and a smaller sway bar than the reverse. This is because a swaybar effectively makes the suspension on that end of the car dependent (instead of independent). This means, in order to control body roll, a sway bar will tend to lift the inside wheel in a corner, making what happens on one side of the car dependent on the other. By using springs to control most of the roll, you keep the suspension more independent from side to side. The reason you want to control roll is that body roll is a significant factor in weight transfer. While you do want to have some weight transfer (this is because a tire grips better laterally with more vertical load), at the same time too much weight transfer decreases vertical load on the inside tire, making the outside tire do more work to keep your car turned. Cars that roll little are best. But there is such a thing as too stiff. If the car is too stiff it will skip over bumps and deformities in the pavement as well as possibly load the tire under cornering too fast, causing the tire to break away and slide. Ideally you will need to change these rates by trial and error and by keeping accurate logs of the results, you can find the optimal setup for your car.

Finally, a note about strut type vs double A-arm (or double wishbone) front suspensions. In strut type suspensions, the load bearing part of the suspension also serves as the shock damper. In a double A-arm, the load bearing unit is separate from the shock. The strut suspension is less sophisticated (and was created to save carmakers money). The important thing here is that strut cars lose camber when the body rolls. So if you turn into a corner and the body rolls 1 degree, the outside wheel will gain 1 degree of positive camber (or rolling over of the tires). If your suspension has –1 degree of camber dialed in at rest (and assuming that camber does not change with suspension movement), the net effect will be a wheel that is perpendicular to the ground and optimizing that contact patch. On an A-arm suspension, 1 degree of body roll does not translate into 1 degree of positive camber (maybe only .6). These suspension types gain camber as they are compressed and the net effect is that less static camber is required to make the tire square to the ground.

Lets move on to shocks. Shocks are the 2nd thing most important in a suspension, next to the tires. Tuning them correctly is almost as important as the kind of shocks you have. There are two types of shocks. The first is the twin-tube low pressure shock. This shock (standard Konis are twin tubes), as its name suggests, uses an inner and outer tube. The inner tube has a piston and chamber filled with oil, while the outer tube has low pressure gas (usually nitrogen) in it. The nitrogen compresses as the shock compresses to allow movement of the hydraulic oil. The second type of shock is a monotube shock. This shock has only one tube but usually with two pistons. One connected to the shock shaft, and the other piston serving as the gas/oil boundary. As the shock is compressed, the main piston moves oil against the 2nd piston which compresses the nitrogen chamber. In both types of shocks, washers stacked upon one another are used to control the oil flow through the pistons, thereby varying the amount of damping force the shock is putting out. Monotube shocks (Koni 28/30 series, Penske, JRZ, Ohlin, Bilstein) are almost exclusively used in professional racing. This is because the monotube shock has advantages. These include a larger diameter piston (thereby being more sensitive to small suspension displacements), better heat dissipation (the inner tube/gas interface on the twin-tube shock is not a great heat conductor), and very little cavitation (when air gets mixed in with oil, causing foaming or aeration). Shocks and springs work together to form a control system for the wheel of the car. Together, they are what keep your tires on the road in an optimal manner instead of bouncing around (see Appendix A). Shocks have to be tuned to the springs that are used with them. Shocks, ideally, have resistive force only when the shock shaft is in motion (ie, only during a transient maneuver). For this reason, do not use your shocks to tune your car's steady state handling characteristics (skidpad, mentioned later). Most aftermarket shocks are tuned to the spring rates that came with the car. For example, Bilstein shocks are made with this in mind. What you don't want to do is get shocks that are too stiff for the springs or springs that are too stiff for the shocks. When the shock overpowers the spring (a little overpowering can be used to make the car do things it normally can't, we will see this later), weight is transferred extremely fast, and in the long run could lead to premature wear of your springs. Similarly, if the springs are too stiff for the shock, they will prematurely wear the shocks out. Most people today get some type of adjustable shock. For most stock class applications, the damping range of these adjustable shocks are within a good range and can be adjusted to match the stock spring rates. Once you get into street prepared and above, off the shelf shocks may not have the range of adjustability to dampen the springs.

The Skid Pad

A skid pad is used to measure steady-state cornering ability. You can measure the lateral acceleration (given in Gs) of the car at maximum cornering speeds. It will also tell if your car understeers or oversteers and will allow you to adjust these characteristics. A skid pad will not help you with high-speed stability or acceleration or braking. Your maximum Gs will also not be affected by your shocks (shocks, ideally, only affect your suspension when the suspension is moving). A skid pad is nothing more than driving around in a marked circle of a certain radius. For the test and tune, we will be using a skidpad that has a 100-ft. radius. By measuring the time it takes to make one lap of the circle, the lateral acceleration can be computed. To make this calculation, we will need the radius of the circle and the time for one lap at maximum speed. The formula then for lateral acceleration is:

$$\text{lateral acceleration in G's} = 1.22 \times \frac{\text{Circle radius (in feet)}}{(\text{lap time in seconds})^2}$$

To get an accurate value for lateral acceleration, the centerline of the car should be at the radius of the track circle. So, for the test and tune with a 100-ft. radius skidpad, the circle radius you should use is 100 ft plus half of the track width of your car in feet. In skid pad testing, tire temperature and pressures can be a big factor. Remember the rubber temperature will change tire grip, so you must run all comparative tests at roughly the same temperature.

For the test and tune, we will work it like this. A person gets the go ahead from the course worker. You then make one warm-up lap, and the timer will start after this first lap so that your 2nd lap will actually be timed. This gives you a chance to come up to steady state speed and warm the tires a little. The course worker will have your lap time and you can convert it to lateral Gs. Now that you have your lateral Gs, how do you tune the car? Well, the things that affect steady state handling are alignment, springs, swaybars, tires, and tire pressures. Other things like relative ride height from front to back and other factors are not covered here. The key here is make a few runs to get a baseline lateral acceleration. Once you have done this, change tire pressures. Go out and do some more laps. Note how the pressure change affected your lateral acceleration. This is where your logbook comes into play. WRITE EVERYTHING DOWN! This way you can systematically tune the car for the best results. Is the car understeering or oversteering at the limit? Did your tire pressure change affect that at all? If you have a tire pyrometer, measuring the tire temperatures as soon as you come off the skid pad, you can get a relative idea of how hard the tires are working. If the rear tire temps are 20 degrees on average than the fronts, it probably means your car is understeering a little. Similarly, if you measure the tire temperature on the inner, middle and outer part of a tire, you can see what part of the tire is doing all the work. Ideally, you will want the tire temps across the tread to be about the same, but realistically, this may not be possible, especially on a stock class car. So now after a few iterations, you have the tire pressures dialed in and you know that if you increase or decrease tire pressures (front and back) the car will do certain things (ie, understeer more or oversteer more). You can use this knowledge at an event with a different surface/conditions to fine tune the car.

Lets look at sway bars. They will affect your car's steady state handling. Generally, a bigger sway bar at one end of the car will make the car roll less at that end of the car. This may be a good thing or a bad thing. The key is to test. If your car leans a lot, then getting rid of some body roll will let tires on both sides of the car share in the cornering work. If you have too stiff of a bar, you will not load the outside tire enough but will load it too quickly, the result will be decreased handling at that end of the car. For the rear wheeled cars, too stiff of a bar in back can cause oversteer, as well as hindering your car's ability to put power down (because a sway bar, while limiting roll, tends to lift or unweight the inside wheel.). Now the question comes up: why does my car have better lateral acceleration going clockwise than counterclockwise (or the reverse). The answer to that is, more than likely, sway bar preload. Your car was put together symmetrically. Now you put a driver in the car that weighs 165+ lbs on the left side of the car, this will affect your car's suspension. What this does to the swaybar is cause it to pre-load. What this means is that the roll resistance will be greater when the car is turning left than right. Rest assured, there is a way to help correct this. To get rid of the pre-load, you can insert shims or washers in the middle section of a swaybar endlink at the passenger front side of the car to in effect lengthen the middle part of the link. This will help equalize the preload. How do you know how much to lengthen that center endlink part? The best way is trial and error. Add some length, then go to the skid pad and test lateral acceleration in both directions. Keep tuning until the lat. accel. is about the same for both directions. Another way to check preload is to weigh your car on a scale with corner weights. Weigh the car with driver with the front swaybar disconnected, note the difference in front left and right corner weights. Then reattach the endlinks and compare the weights again. If there is a difference, then you have a preload. You can then adjust the endlink height and keep weighing until the effect of the swaybar preload is minimized.

Transient Handling and Tuning

To tune your car for transient handling we will do a lot of trial/error testing but this time with the shocks and alignment. A car's transient handling (as instantaneous Gs) can be much more than a car's static handling. The ideal tool for testing the transitional characteristics is the slolam. For the test and tune, a several cone slolam may be set up (if room permits) or you will have to use the practice course to fine tune these characteristics. Let's tune the shocks. As a start, set the shocks to full soft on compression and rebound. First lets concentrate on compression. The compression adjustment on a shock controls the unsprung weight of the car. Unsprung weight is weight that is not held up by the springs. This includes wheels, tires, disc rotors, control arms. So you do not need a lot of damping in compression because the weight you are controlling (maybe 75-100 lbs) is pretty small compared to the sprung weight which could be several hundred pounds per corner (see Appendix A on shock valving). It is better to be slightly too soft in compression than too stiff. Too stiff, and the car will understeer at high slip angles over small seams in the road. Do a few runs and note how the car does when you turn over a bump or seam in the pavement. Then keep stiffening the front and rear compression one click until you notice the car start to skip over these pavement seams. Then back off the compression one or two clicks. Another way to know if you have enough compression for the rear is that it does not oscillate over bumps (driving straight down the road).

Now lets turn to the rebound adjustment. This is the tricky one. This adjustment will make the most difference to your car's transient handling characteristics. On stock class cars, there are not a lot of modifications allowed. We will, therefore, use the shocks to compensate for things we cannot modify or make the car do something it normally can't. The rebound of shocks control weight transfer from left to right (and right to left) of the car as well as front/back weight transfer. When you make a change in the front shock damping, you will also affect how the rear is affected as well. That is why it is most important to make small adjustments in rebound, note what the car does, and write it down. For autocrossing, which is a lower speed event than time trials or road racing, we want the car to transition as fast as possible to get turned quick so that we can be ready for the next maneuver which will immediately follow. By following this line of approach, start with full soft rebound front and rear. Take a couple of laps on the practice course, note how the car understeers or oversteers in the slolam and transitional maneuvers. Now, increase the rebound and repeat. Keep going until you notice the front of the car, instead of responding quicker and quicker, starts to understeer at the input of the wheel. This is the point where you have so much rebound that you are severely limiting roll and making the weight transfer from left to right so fast, the tire is giving away before it has a chance to grip. Back off a little in the front rebound. Now our shocks are in the ballpark.

Once you have your shocks in the ballpark, now its time to play. Play with the rebound settings in small increments from these ballpark settings and note the changes in the handling characteristics, write it down. Keep doing this until you are comfortable with what the car does and your improvement in time levels off. This is your optimal setting at this particular site with the conditions that exist. Now that you have written everything down, maybe test yourself. If, for example, you know that if you soften the front rebound, the car starts to oversteer, try it. Verify it on course. Now you know if you go to another event, and the car is pushing in an entry to a corner, softening the front rebound should help the car handle better. And the fact that you know what will happen will make you confident in the car's ability to deliver for you. Some notes on front wheel cars versus rear wheel cars. Front wheel cars are unique in that they tend to have a lot of weight up front as well as have to use the front tires for acceleration as well as cornering. The rear of the car is "just along for the ride." For such a car it may be advantageous to run a very stiff front rebound and to increase the rear tire pressures so that the rear rotates very easily when the wheel is turned. Rear wheel drive cars are harder in this respect in that too stiff rebound in the rear can cause the shock to exceedingly unweight the inside rear tire in a corner, allowing that wheel to slip and not be able to put power down. Similarly, if the front rebound is too soft on a RWD car, the car will lean excessively in a turn causing significant weight transfer at the rear of the car to the outside rear tire, also causing non-optimal power putting down capability. The key is to test, test, and test. Then write down your findings so that you can reference them later. Let the clock be your guide to tuning.

Below is a table listing some general guidelines for tuning. This was taken from the book by Don Alexander. Other books you may want to read on the subject of car tuning is "How to Make Your Car Handle," by Fred Puhn. A good technical reference is the book "Race Car Vehicle Dynamics," by Milliken. Use these as a guide only! Trust your real world data more because it reflects how your car ***ACTUALLY*** responds to your suspension settings!!!!!!!!!!!

Effect of Suspension Changes

Before making changes to suspension components and settings, it is good to know how the changes will effect performance and ride. The following chart will help give you a general idea of the effect a specific change will make to handling and ride.

Spring Rate Changes	
Modification	**Effect on Suspension**
Increase front and rear rate	Ride harshness increases; tires may not follow bumps causing reduced traction. Roll resistance increases.
Increase front rate only	Front ride rate increases. Front roll resistance increases, increasing understeer or reducing oversteer.

Increase rear rate only	Rear ride rate increases. Rear roll resistance increases, increasing oversteer or reducing understeer.
Decrease front and rear rate	Ride harshness decreases; tires follow bumps more effectively, possibly improving traction. Roll resistance decreases.
Decrease front rate only	Front ride rate decreases. Front roll resistance decreases, decreasing understeer or increasing oversteer.
Decrease rear rate only	Rear ride rate decreases. Rear roll resistance decreases, decreasing oversteer or increasing understeer.
Antiroll Bar Changes	
Modification	**Effect on Suspension**
Increase front rate	Front roll resistance increases, increasing understeer or decreasing oversteer. May also reduce camber change, allowing better tire contact patch compliance with the road surface, reducing understeer.
Increase rear rate	Rear roll resistance increases, increasing oversteer or decreasing understeer. On independent rear suspensions, may also reduce camber change, allowing better contact patch compliance with road surface, reducing oversteer.
Decrease front rate	Front roll resistance decreases, decreasing understeer or increasing understeer. More body roll could reduce tire contact patch area, causing understeer.
Decrease rear rate	Rear roll resistance decreases, decreasing oversteer or increasing understeer. On independent rear suspensions, more body roll could reduce tire contact patch area, causing oversteer.
Shock Absorber Changes	
Modification	**Effect on Suspension**
Increase rebound and bump rates	Ride harshness increases.
Increase rebound rates only	On bumps, tires may leave track surface.
Increase bump rates only	Body roll resisted; outside tire loaded too quickly; car won't stabilize into a turn.

Decrease rebound and bump rates	Ride harshness decreases; car may float over bumps.
Decrease rebound rates only	On bumps, tires follow track surface more effectively; car may continue to oscillate after bumps.
Decrease bump rates only	Body rolls quickly; car is slower to respond to turn-in.

APPENDIX A

Let’s first talk about one corner of the car. This is usually modeled as a spring, a damper (shock to those Neanderthals out there :^)), and a mass. The mass in this case is either the unsprung mass of the car (usually the wheel, brake, control arm, everything not supported by the spring) or the rest of the car (everything supported by the spring, like the body of the car). Generally, the bump (or compression) of a damper controls the unsprung weight of the car and rebound usually controls the sprung weight of the car. It is not unusual to need more rebound since the weight you are controlling is much heavier (eg. a 98 1LE camaro with a 1040 lb front left corner weight, only has about 100 lbs of that weight due to the wheel, lower control arm, brakes and steering knuckle). Stagger is the term defined to relate the force of rebound vs the force of compression. Mike O'Callaghan from Shoktek recommends staggers of 2-3:1 (ie, rebound forces are 3 times more than the compression for a given shock velocity). So, how much shock damping do we really need? Well first lets consider what a shock does. If you didn’t have a shock on your car, when you hit a bump, or turned the car, the spring would cause the suspension of the car to oscillate back and forth forever (well not really since in the real world there is friction). The main role of the shock is to dampen this oscillation (hence the term dampers) to keep the tires in contact with the pavement as much as possible. Now, back to our shockless system. If the system were put into oscillation by a force (like a bump pushing the wheel up) it would oscillate. This oscillation is termed the Undamped Natural Frequency. This is defined as the sqrt(K/m) where K is the spring rate and m is the mass(not the weight). Lets do an example: My camaro has a corner weight of 1040 lbs and a spring rate of 360 lbs/in (ie, it takes 360 lbs of force to compress the spring one inch). Normally we would like to know the damping frequency in cycles per second (Hertz). sooo...for example, the natural frequency for my car is calculated as follows: frequency = square root (360 lb/in /(1040 lbs/(32.2 x 12 in/sec^2))) =4.31 hertz. (The 32.2 x 12 is to convert from mass to weight and ft/sec^2 to inch/sec^2, acceleration due to gravity is 32.2 ft/s^2)) This means if my suspension had no shock and I compressed it 2 inches and let it go, it would uncompress 2 inches, overshoot 2 inches, come back 2 inches to the original position (before I compressed it) and then compress another 2 inches to the position where I compressed it. It would do this whole process 4.31 times per second (without any damping). Now, in the real world we have shocks (yay!). In most texts, a shock is modeled as a device that acts only with shock shaft velocity (ie, the shock force is a function of how fast the suspension is moving). In practice this is a complicated function vs shaft velocity, for simplicity we will assume this function to be linear with some value, call it C. The dimensions of C are lb/in/sec.. Therefore, a shock that has a C of 5 lb/in/sec would provide 5 x 6=30 lbs of force if the shock shaft were moving at a velocity of 6 inches per second (is that clear?). In damper dynamics we usually define a term called damping ratio. This number (denoted usually by the greek letter zeta) relates how the mass, shock, damper system reacts to a transient response (in our case a bump, or transient maneuver in autocross). Mathematically, this ratio is defined to be: damping ratio = C /(2 x (sqrt(K x M))) where C is the shock constant, K is the spring rate, and M is the mass as defined above in the example. When the damping ratio is equal to zero, C=0, or its as if there is no shock. If the damping ratio is less than 1, the system is said to be underdamped. What this means is if the suspension was compressed from point 0 to point -2 inches and let go, the suspension would go back to zero and overshoot to some point, say +1, and then back to say -.5 before resting back at the reference point 0. If the damping ratio is greater than one, the system is said to be overdamped. With this, if we compress the suspension to the -2 point and let go, the suspension would not overshoot at all and come to rest at 0. Once you decide on a damping ratio, you can see from the equations above, you can determine how much shock force is required. Now, suspension engineers are plagued with the process of determining what damping ratio to use in their suspension systems. For general passenger cars, manufacturers prefer smooth rides to ultimate performance, thus they tend to use damping ratios of around .2 If you look at empirical data compiled by GM and Chrysler (published in various source references), you will see tests where they measured road holding for a tire and a surface for several different damping ratios. Empirically they determined for optimal roadholding a damping ratio of .4 to .5 is desirable. Mike O from shocktek recommends a ratio of .4. Now, lets assume I want the maximum roadholding and don't care about ride too much. for my camaro example, using a damping ratio of say .45 and the above equations we get: .45 = C /(2(sqrt(360 lbs/in * 1040/(32.2*12))) then C= 28.02 lbs of force per inch per second. This is what I would like to have as the damping characteristic for my shock, ideally. Now all this above is over simplified and takes into account the one wheel acting independently. In the real world we get more than 1040 lbs of force at that corner on our camaro because of weight transfer from the rest of the car. This can complicate things since how the shock on one side of the car acts, will affect the amount of weight transfer to the other side of the car. Sounds complicated. Well it is. That's why most manufacturers do computer simulations of the suspensions that they design and see what the computer tells them will happen under certain situations. There are also many other variables. For example the tire acts as a spring and can affect overall spring rate. The wheel rate, which is the rate of compression of the wheel to the rate of compression at the spring (if the spring is inboard a lot, like a strut suspension on a mustang) this rate can be fairly high. That's why you cant compare a 1000 lb spring on a mustang and a 1000 lb spring on a camaro. The two cars have different wheel rates.