PCDC SETUP GUIDE

Concepts and Consequences for everyone

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Introduction

To many simracers, car setup is a black box. As a driver, they will steer, brake, and accelerate, and some mysterious thing called "physics engine" will translate that into car behavior.

Most will sooner or later realise that the setup of a car has a very large influence on behavior and performance, and will open a setup screen in their favorite game, only to be greeted by a lot of adjustments, with little explanation on what they do, exactly.

It is therefore understandable that many drivers won't be able and/or willing to dive deep into setups, especially given the plethora of options to get setups from other people. If your preferred simulation is iracing, there's the forums, or setup shops such as Craig's Setup Shop, VRS Driving School, Pure Driving School. If you prefer Project Cars, you can just grab a setup off the Time Trial leaderboards. The same applies to all simulators on the market.

Then why exactly should you care about setups, when you can just let others do the work? Why should you invest time into trying to understand the fundamentals of setups, when there's a metaphorical million setup flowcharts you can consult to solve an issue with your setup?

Frankly, for many people, there's no particularly good reason. Many drivers will improve their lap times more by investing what time they have into practicing with a downloaded setup.

But if you're interested in engineering, in optimising every aspect of performance, if you enjoy learning and want to develop a deeper understanding of the car while you're driving it, learning how to do setups can open up a whole new aspect of a hobby we love, providing a lot of depth and immense satisfaction when you get to drive a car that you managed to put in that oh so elusive sweet spot.

What should you expect from this guide?

This guide is aimed at people who have no to some experience with car setups. If you're an expert, there's probably nothing new for you here. However, a basic understanding of race cars is required. The goal of this guide is to provide people with a basic knowledge of how the different parts of a race car interact, and how they can be leveraged to change car behavior on the limit.

If you read this guide, and take some time to understand and apply the concepts, you shouldn't need to refer to this guide or any flowcharts in the future - you should have all the understanding you need to draw your own conclusions.

If you are looking for an "if-this-then-that" sort of guide, or are struggling with an issue that you can't solve by applying the information contained in this document, I recommend you take a look at setup flowcharts. One I think is good is https://www.paradigmshiftracing.com/uploads/4/8/2/6/48261497/setupflowchart2.jpg

Where should I start?

I recommend you give the entire guide a read before you do anything else. If you then want to start applying your knowledge, I'd generally propose the following order, so you don't need to learn everything at once:

1. Brake Bias
2. Tyre Pressure
3. Anti-Roll-Bars
4. Differentials: Ramp angles
5. Dampers
6. Camber and Caster
7. Springs and ride heights
8. Aerodynamics
9. Everything else

Brake Balance

Brake bias is arguably the simplest adjustment you can make to a race car's setup. In most cars, it's even something that can be adjusted while driving.

The brake bias is usually described as a percentage of total brake pressure that is sent to the front wheels. If you set the brake bias to 100, the car would brake only on the front wheels. On 0, only the rears will brake.

So what does that mean for setups?

With race cars, optimal grip is achieved when all four tyres are sliding ever so slightly. In principle, the same holds true for braking. However, this is often unachievable, as the rear of the car will usually become unstable quite a while before the wheels lock. Therefore while braking hard:

Front wheels lock and/or understeer -> decrease brake bias
Oversteer -> increase brake bias

Controlling weight transfer

In racecar engineering, we make a distinction between sprung and unsprung weight. Unsprung weight is everything that is directly connected to the track: Tyres, Rims, the wheel hubs and brakes, and any appendages such as brake ducts.

Everything else, including the chassis, engine, fuel tank, as well as your own butt, are considered sprung weight, because their connection to the track surface is through springs.

When setting up a racecar, controlling the unsprung weight is largely of little interest as its behavior is hard to change. The sprung weight however is of critical importance, as it influences the load distribution on the tyres of the car, and is usually the attachment point of downforce-generating surfaces and therefore important to accurately position.

The challenge for a race car suspension is therefore to keep the car level, maximise grip, and keep the car stable over bumps.

The following components connect the sprung to the unsprung weight:

- Springs
- Dampers/shocks
- Anti-roll Bars (ARBs)

ARBs are the easiest to understand, and we will therefore look at them first.

Anti-Roll Bars (ARBs)

Tune to solve issues when turning while coasting

Body roll is generally an undesirable trait for race cars. While it is not detrimental to overall grip, it makes the car behave badly when changing direction, as the unsprung weight will have started turning long before the body has rolled back. The body rolling back can create a large and sudden increase in load to the outside wheels, which, depending on the setup, will cause any combination of oversteer, understeer, and 4-wheel slides.

While limiting body roll can be achieved by running very stiff springs, this would be detrimental to overall vehicle behavior. Therefore ARBs were introduced as a measure to separate suspension compression/decompression from body roll. This makes it possible to set up a car with a soft suspension that handles bumps well and reacts well to weight transfer, whilst still limiting body roll

A soft ARB means the corresponding axle will generally have more grip, at the expense of increased body roll. If one axle A has a soft ARB and axle B a stiff one, the body will roll over axle A, thus unloading the inside tyre on axle B. This will cause axle A to have more grip than axle B

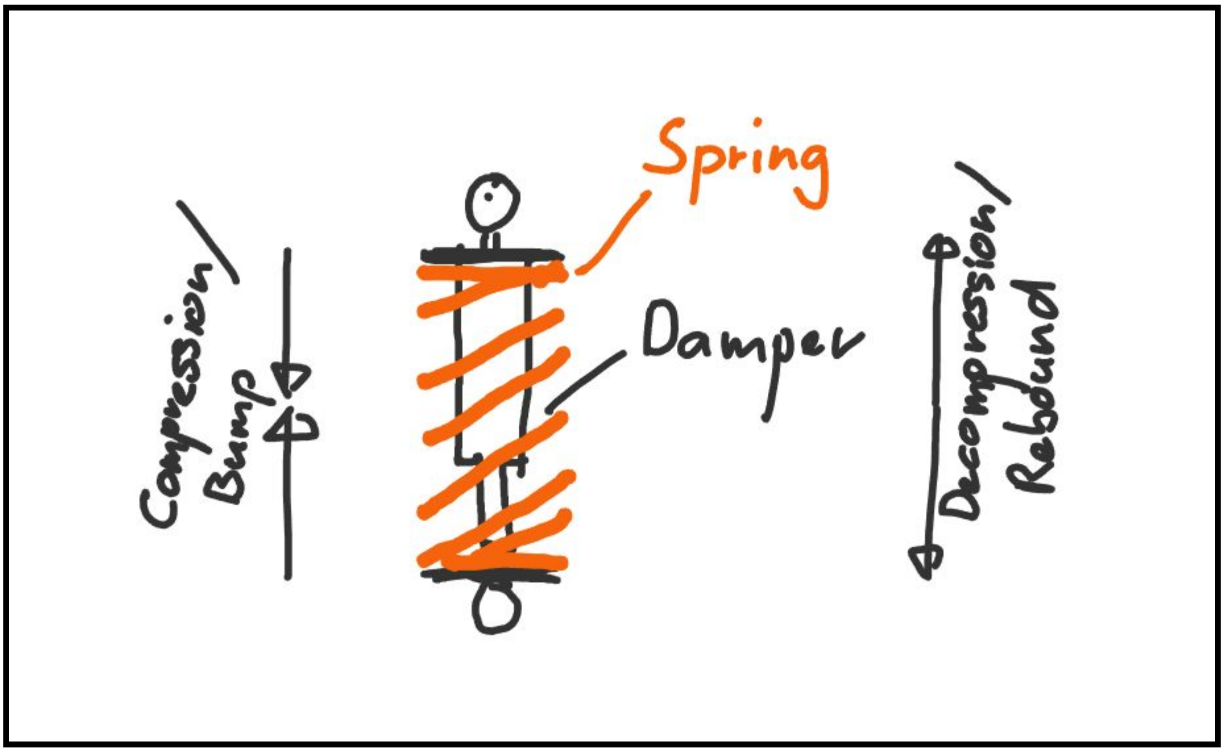
So what does this mean for setups?

You should in general run ARBs as soft as you can while still maintaining the necessary stability on direction change and while accounting for stability of the aerodynamic platform. The aerodynamic performance of high-downforce cars will benefit from stiffer ARBs.

Use different ARB stiffness on front + back to rebalance the car:
Soft front + stiff rear = more oversteer
Stiff front + soft rear = more understeer

Springs + Dampers

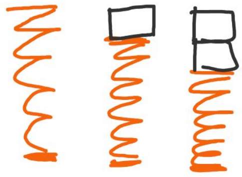
Tune to solve weight-transfer related issues during braking or acceleration



The main load bearing component of the suspension is the spring + damper assembly. In many race cars, it consists of a damper assembly surrounded by a spring.

Springs

Tune to solve harsh weight-transfer related issues during braking or acceleration and to maintain aerodynamic stability



Springs are components with a certain length and linear resistance. Double the weight = double the compression and so on.

This is important to understand because different situations in a racecar will mean different loads on the four springs. During acceleration, for example, the load on the rear increases, and the suspension compresses. The opposite is the case at the front, with the suspension extending. The same principle applies to cornering, but as explained earlier, this can be mitigated by ARBs.

So what does this mean for setups?

There's unfortunately no definitive answer to this, but a few things should influence your decision:

- Soft springs = more mechanical grip.
  And:
  - Soft springs = more weight transfer. This generally means more oversteer while braking and more power understeer.
  - Soft springs = more suspension compression/decompression. If ride heights are low and/or you are running a lot of downforce, this could cause the car to bottom out or hit the bump stops. Both of which are generally undesirable.

While this seems to imply that you should run your springs as soft as you're comfortable with, there's one big caveat: Aerodynamics.

In any car where overall performance is strongly influenced by aerodynamics, controlling ride heights can be of critical importance. That can make stiffer spring setups more viable:

- Stiff springs = less mechanical grip.
  And:
  - Stiff springs = less chassis movement and more consistent aerodynamic performance
  - Stiff springs = more responsiveness, as the chassis moves less in general
  - Stiff springs = less weight transfer and therefore more entry understeer and exit oversteer

To a certain extent, behavior of the car can also be influenced by changing front and back springs independently from each other. Under braking, the front springs are more important to overall car behavior, under acceleration, it's the rear springs.

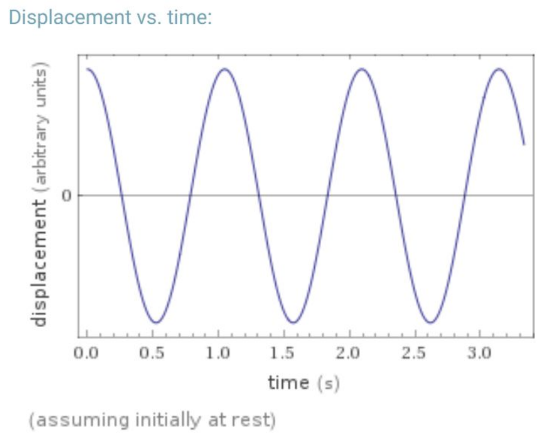
You could therefore run harder springs in the front to reduce weight transfer and oversteer on the brakes, while running softer springs in the rear in order to reduce power oversteer, or the other way round.

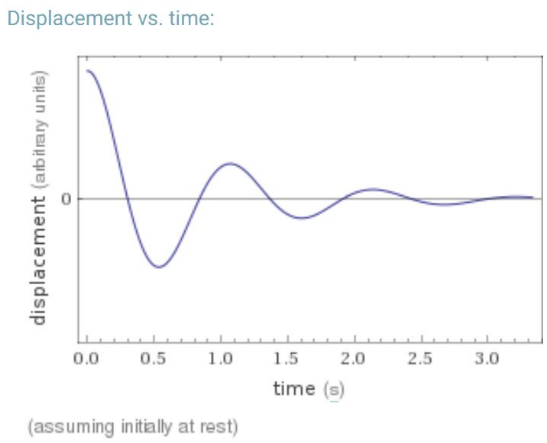
Dampers

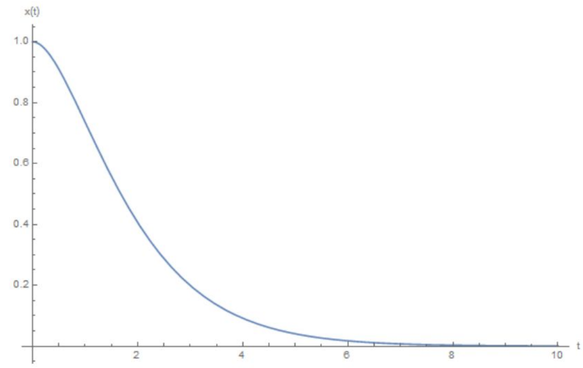
Tune to solve weight-transfer related issues during braking or acceleration

We have discussed springs at length now, but why do we need dampers and what do they do?
If you've ever played with a spring, you'll know that if you compress and then release it, it will continue oscillating (nearly) indefinitely. The same would be the case in cars with no dampers. It is simple to understand that this would be an undesirable trait for the suspension of a car. Hence, car suspensions employ dampers that, well, dampen the oscillation of the suspension spring.
There are four damping states a spring can be in, illustrated by the following graphics, which depict the oscillation of an ideal spring over time. From left to right, top to bottom:

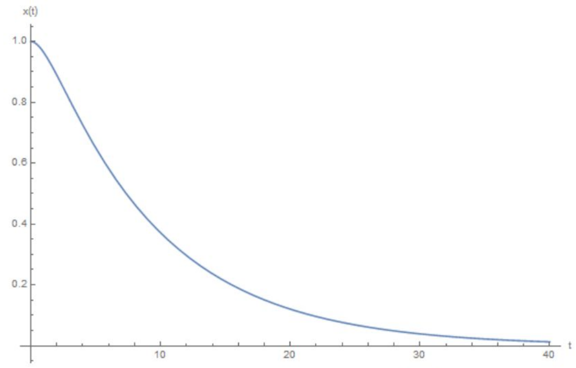
- Undamped
- Underdamped
- Critically damped
- Overdamped







Time evolution of the amplitude of a critically damped harmonic oscillator.



An overdamped harmonic oscillator approaching equilibrium slowly.

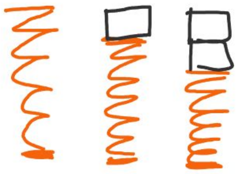
An undamped spring will continue oscillating at the same amplitude (maximum compression distance) forever. An underdamped spring will oscillate with exponentially decreasing amplitude. A critically damped spring does not oscillate - if compressed, it will move back to its resting position without going over it. An overdamped spring will, once compressed, never return to its resting position without external interference.

All of this matters for car setup because in general, strongly over- or underdamped springs will yield bad results and might make the car behave weirdly.
Underdamped springs will result in the car oscillating shortly after heavy changes in weight distribution, causing instability and unpredictable behavior. Overdamped springs are harder to spot, and will usually result in suspension setups that feel too stiff and unresponsive.

Dampers control the speed of weight transfer, springs how much weight is transferred.

You might be rightfully asking yourself why we shouldn't just calculate critical damping rate and setup the dampers accordingly for all springs. The answer to that question is that fortunately (or unfortunately, if you hate fiddling with car setups), dampers are an excellent tool to control the speed at which weight transfer occurs.

The main takeaway from this paragraph should be:



Spring compression is linearly proportional to applied force

Dampers = how quickly
Springs = how much
} weight transfer occurs

or:

Dampers = during weight transfer
Springs = weight transfer completed

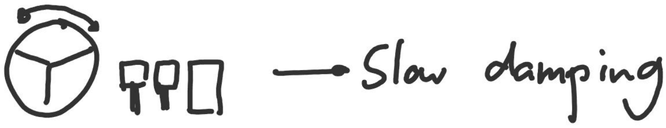
Damper setups in race cars

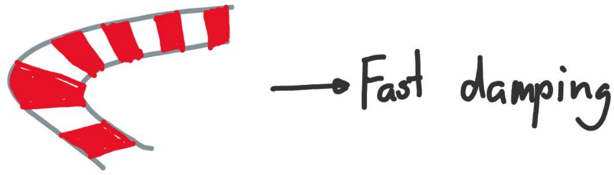
Modern race car suspensions include sophisticated hydraulic dampers which can apply different damping depending on the current load of the suspension. The four different damping modes of modern dampers are:

- Slow compression damping:
  Applies when the suspension is compressed relatively slowly, as is the case during weight transfer onto the corresponding wheel
- Slow rebound damping:
  Applies when the compression is decompressing relatively slowly, as is the case during weight transfer away from the corresponding wheel
- Fast compression damping:
  Applies when the suspension is being compressed quickly, as is the case when going over bumps
- Fast rebound damping:
  Applies when the suspension is being decompressed quickly, as is the case when the wheel is bouncing back after going over bumps

Many modern dampers also allow the transition point at which the damper switches from slow to fast damping to be changed. We will not be covering this in detail, but it's worth playing around with if you are having trouble separating the car behavior over bumps with the behavior of the car under driver inputs (weight transfer).

The main takeaway from this discussion should be:





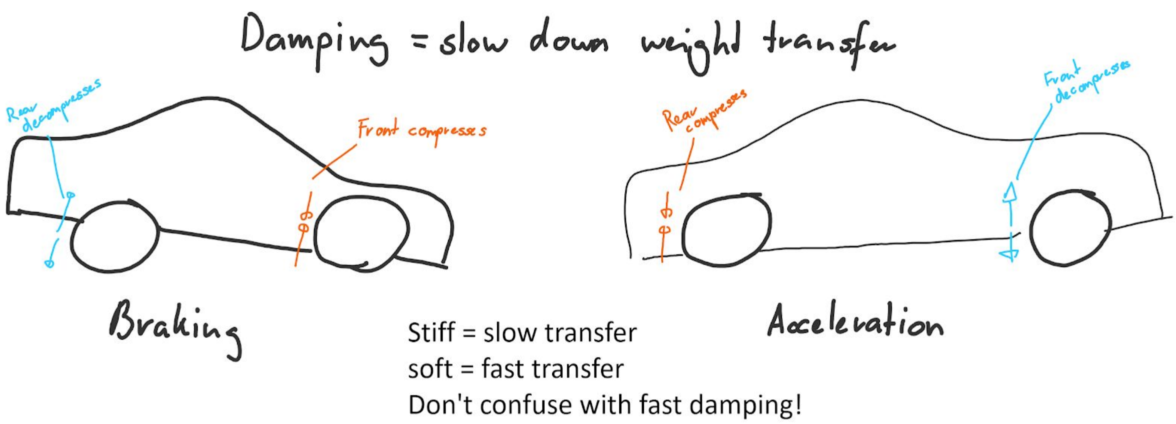
So what does this mean for setups?

While braking, softer front slow compression damping and softer rear slow rebound damping will increase the speed at which weight is transferred, thus shifting the balance towards oversteer. The opposite is true for stiffer front slow compression and rear slow rebound.

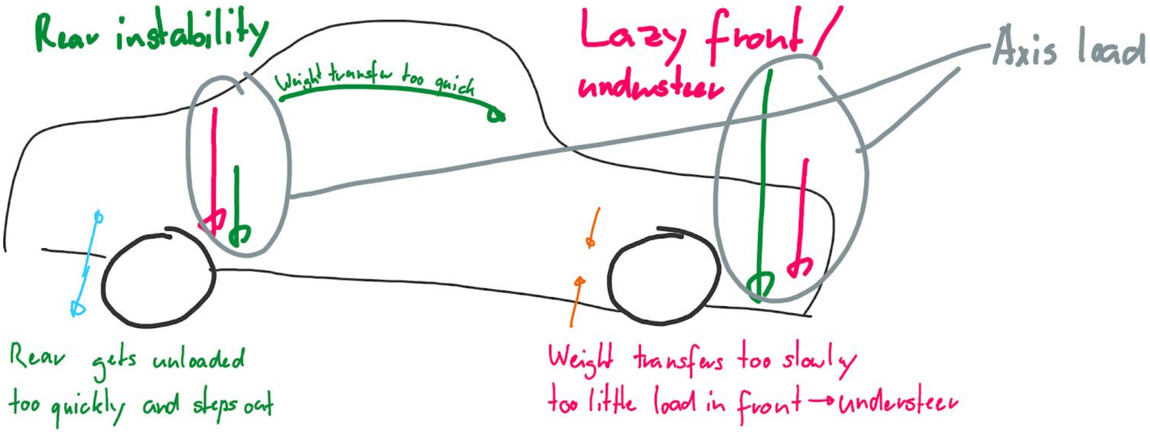
While accelerating, softer rear slow compression damping and softer front slow rebound damping will increase the rate at which weight is transferred, thus shifting the balance towards understeer. The opposite is true for stiffer rear slow compression and front slow rebound.

For fast damping, stiffer means less grip. Soft damping can mean less loss of grip, but might not stop the suspension from hitting the bump stop, which can create a great loss of grip.

Use this knowledge to balance the car over bumps. Most people prefer their car to understeer slightly over bumps, as that will keep the car stable. If that is not the case in your current setup, try stiffening the front fast dampers and softening the rear fast dampers.



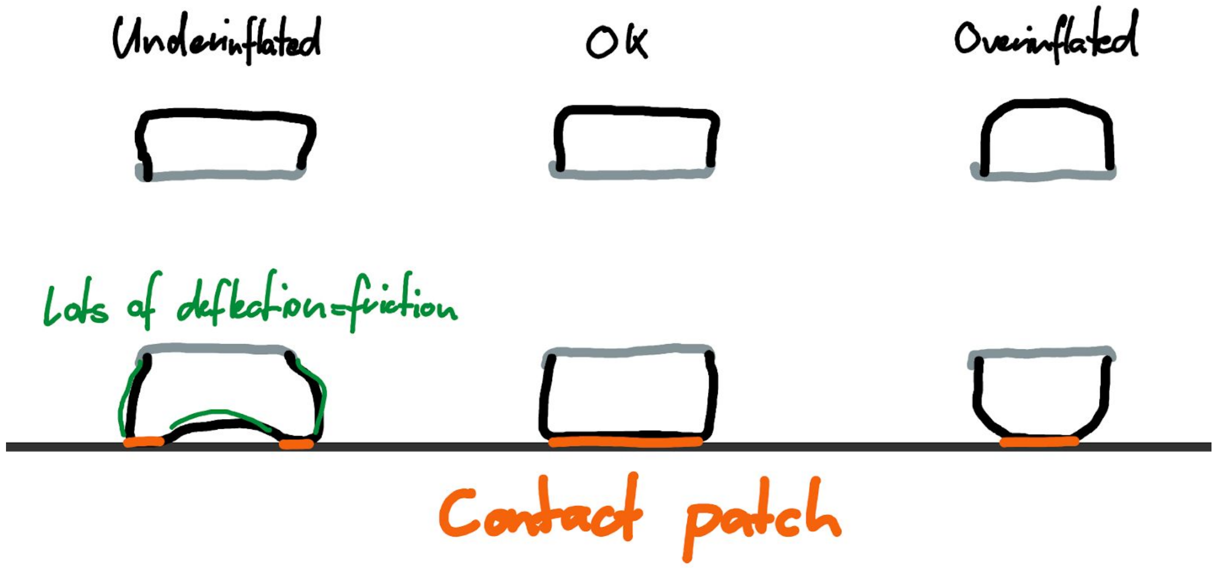
Damping issues under braking:



Maximising the Tyre contact patch

However well you are able to control weight transfer, if you transfer that weight onto tyres that are not optimising the way they interact with the track, you're giving away performance.

Tyre Pressures



Optimal tyre pressures can vary wildly between cars, tyre construction, and compound. While a GTE or GT3 tyre might run at its optimum at about 1.8 bar, a modern F1 tyre might be closer to 1.3 bar.

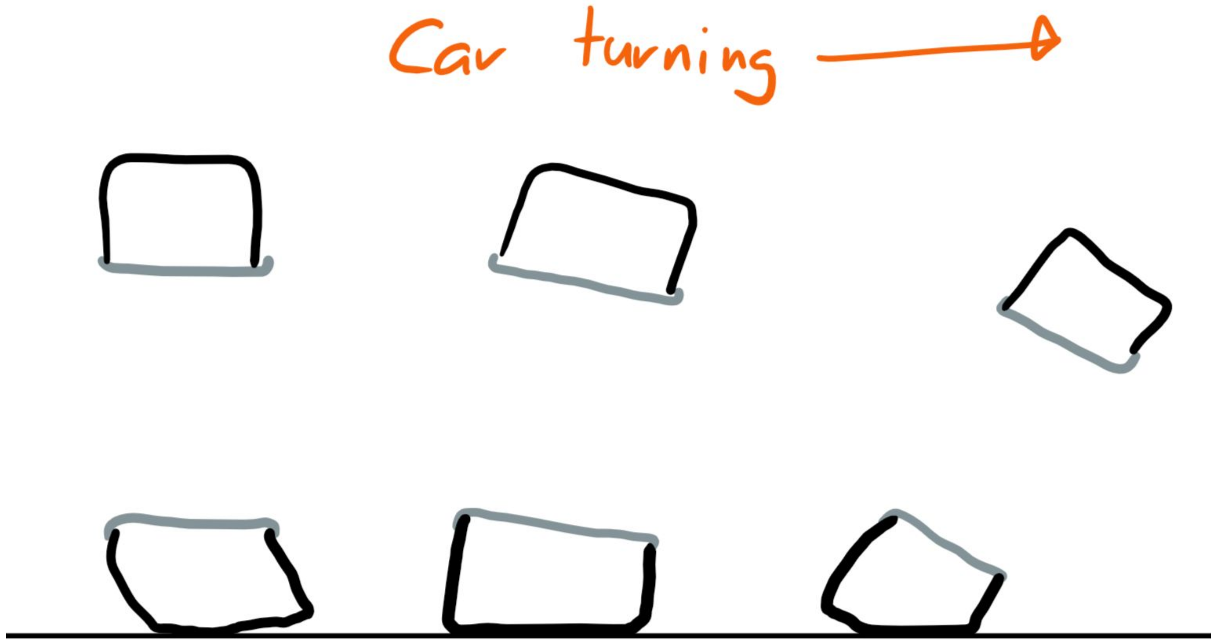
What is the same for all tyres is that the air pressure in them helps them maintain their optimal shape and control deflection. Looking at the picture above, you can see that an underinflated tyre is unable to support the load put on it by the car, and will deflect a lot. This causes the sidewall of the tyre to partly fold under and the center of the tyre contact patch to become unloaded.

The combination of this causes bad grip, a mushy feeling through the steering, and increased friction on a straight line.

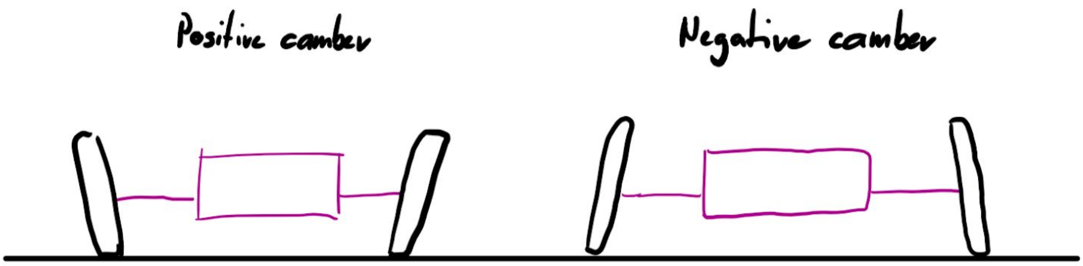
A well-inflated tyre will maintain an even load across the contact patch, with the tyre pressure supporting the sidewall in keeping the tyre in sits appropriate shape.

An overinflated tyre will cause the tyre to balloon, reducing the width of the contact patch and/or decreasing the load at its edges

Camber



When a car turns, its tyres experience lateral force. The contact patch being the part where this force applies causes the tyre to deform. If the tyre is oriented perpendicular to the road, this will cause the contact patch to reduce in size, and the load distribution to become uneven, resulting in a loss of grip. Race cars therefore run their wheels slightly inclined - the top of the wheels closer to each other than the bottom - to combat this effect. We call this inclination negative camber



Adding camber generally increases grip while cornering, but decreases grip in a straight line, and can increase tyre wear on the inside shoulder. As the front tyres are responsible for rotating the car and are therefore dealing with the majority of lateral force, the vast majority of race cars require more negative camber at the front than at the rear.

If a tyre is run at too much negative camber, the outside shoulder of the tyre will not be loaded optimally during cornering, resulting in a loss of grip in all phases of cornering.

Camber and ARBs

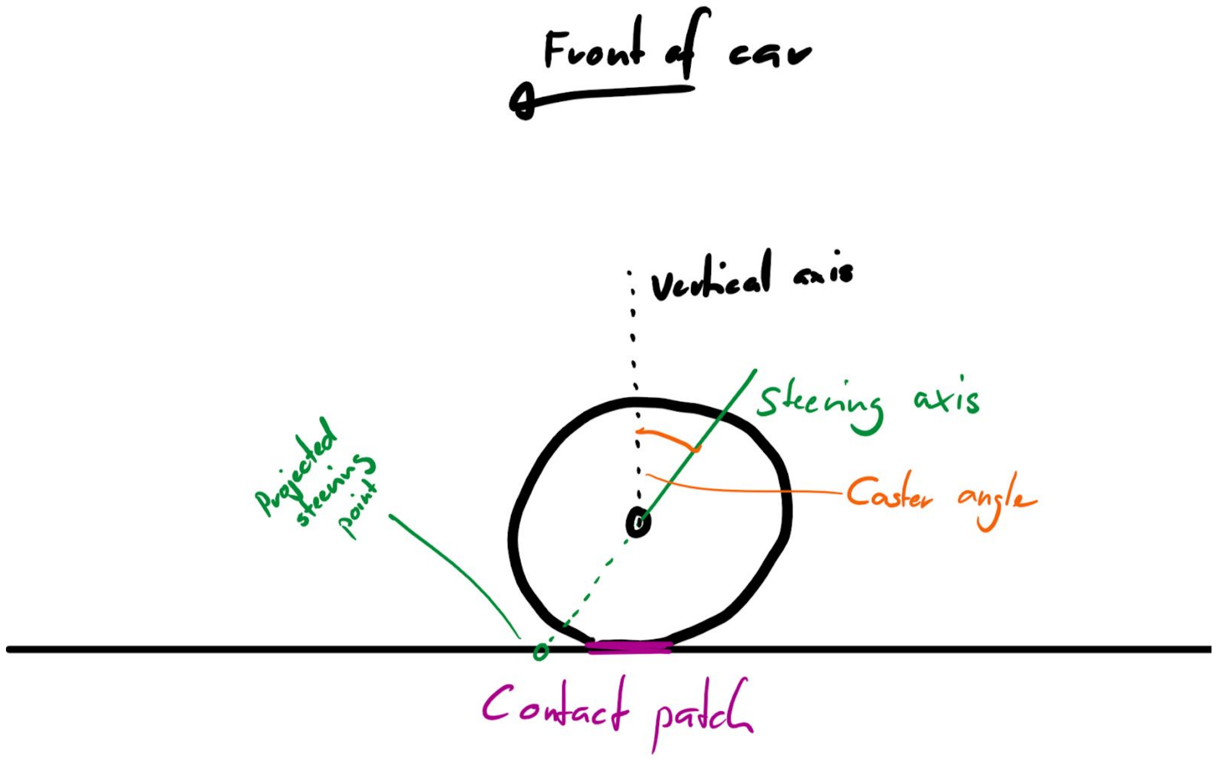
If a car chassis rolls, so do the wheels. This means that the outside wheel will lose negative camber while cornering, while the inside tyre gains negative camber. Setups with soft suspension and ARBs will require more negative camber in general.

So what does this mean for setups?

Small camber adjustments can be used to balance the car between straight-line grip and cornering. If the car is grippy in straight lines but struggles in corners, adding a bit of negative camber to the axle losing grip can help

Caster

Caster describes the angle between the vertical axis of a wheel and the steering axis.



Positive caster angle projects the steering point in front of the contact patch of the front tyres. This has two interesting characteristics:

- The steering gets a self-centering force
- As the steering wheel is turned, the wheel *gains* camber

The second of those points is the really interesting one. Adding camber while turning means the front tyres can run relatively little camber while braking hard, thus maximising

deceleration. While turning, especially during tight corners, the added camber can increase rotation of the car.
The downsides to added caster are that the steering gets heavier and less responsive.

So what does this mean for setups?

Run as much caster as you are comfortable with. If the car oversteers with increasing steering lock, consider decreasing it.

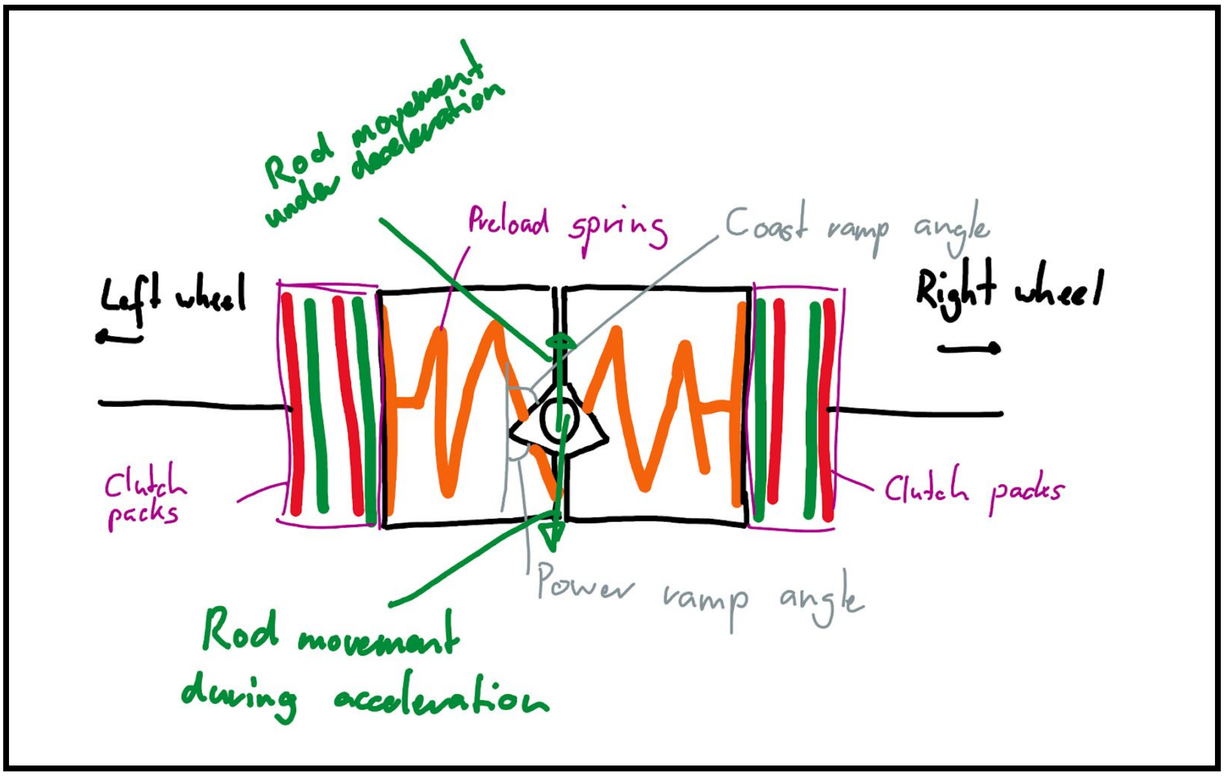
The Drivetrain

Differentials[1]

Tune if you need to control wheelspin, or if you notice undesirable balance changes between coasting and very slight throttle.

The basics of how Limited Slip Differentials (LSD) work are relatively simple.
In this example, we will be looking at a RWD car with a single LSD at the rear.

The goal of the differential is to control the torque difference and prevent the wheels from acting independently in certain situations. While allowing the wheels to rotate at different speeds is required for cornering, it is undesirable while braking and accelerating.

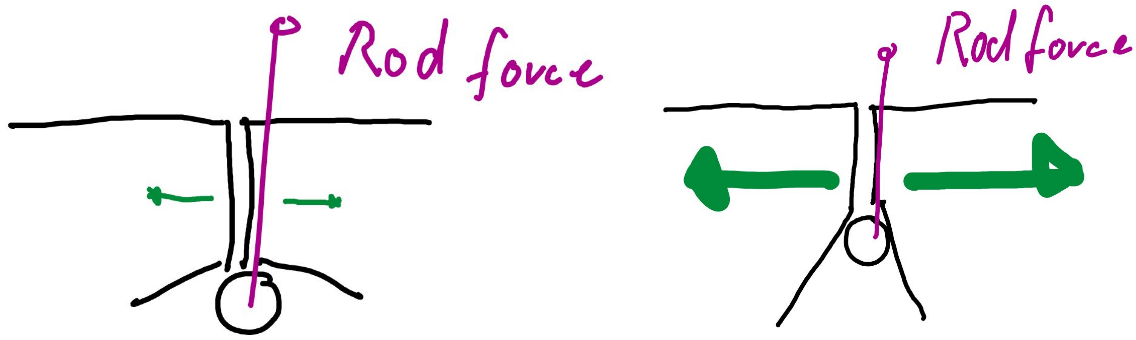


In our example, the rear differential connects both wheels of the driven rear axle and is connected to the drive shaft, passing engine torque to the wheels. Clutch packs connect the axles of both wheels by creating friction when pressure is applied to them. The rod in the middle is connected to gears that run on the inside of the pressure rings (black cylinders around the preload spring), and reacts to torque from the drivetrain. This movement of the rod controls the amount of pressure applied to the clutch packs in certain situations.

[1] https://www.youtube.com/watch?v=PEdnH7_7_yc is a great video that explains the basic workings of an LSD very well

As a first step, let's look at the differential while no torque is applied to the drivetrain, as is the case when the car is standing still and the engine is off or clutched. The rod rests in the pressure rings, not applying force on either side. Therefore the only force acting on the clutch packs is the force generated by the preload spring. In all reasonable setups, this would mean that the wheels are allowed to rotate relatively independently.

Let's look at the car under acceleration next. Looking at the illustration, the rod applies force in a downwards direction. This means that the pressure rings are pried apart, applying further pressure to the clutch packs.
The power ramp angle controls how much force is added to the clutch packs under acceleration. A 90° ramp angle would mean the rod would press against a perfectly perpendicular surface, creating 0 additional pressure to the clutch packs. A very low ramp angle would mean the rod can move downwards easily and cause the pressure rings to apply a lot of pressure to the clutch packs. To better visualize this, look at the image below, with a high ramp angle on the left, and a low ramp angle on the right. The low angle allows the upward motion to be translated into more force to the clutch packs, thus creating more locking



The same applies under braking, except the rod now of course moves in the other direction, and the coast or deceleration ramp angle decides additional pressure.

So what does this mean for setups?

While braking, increasing the amount of locking in the differential can help prevent lockups and instability issues in the rear axle. Too much locking will cause the car to feel less nimble during turn-in and cornering, and will often induce understeer mid-corner.

During acceleration, an open differential (or one that doesn't lock enough), can cause the inside wheel to spin, thus wasting engine torque, slowing down acceleration, and potentially inducing power understeer. A differential that locks too much can cause both wheels to suddenly break traction, which causes power oversteer.

While coasting, an open differential will allow the car to rotate more freely, while more lock will increase stability at the cost of reduced nimbleness.

More Clutches or clutch packs = more locking in general, especially while braking and on power

More preload = more locking, especially while coasting

Lower ramp angle = more locking under braking / power respectively

Finding a good balance will enable you to get on power early and keep the car balance neutral while accelerating without inducing excessive wheel spin.

Engine Braking

Tune if you have issues under braking and have already tried dampers and diffs

In some cars, it is possible to set engine braking. Due to the confusing way this setting is sometimes scaled, we'll break it down into the underlying concept.

When revving an engine while it is clutched, once you go off-throttle, the revs will drop. This is caused by the internal friction of the engine.
This friction can cause issues while braking, as it adds to the braking force applied to the driven wheels. To reduce this friction, some cars support engine modes that automatically apply a bit of throttle while braking to offset this effect.

So what does this mean for setups?

If you are having rear instability issues that you can't fix with differentials and dampers, it might be worth a shot to fiddle with this setting. Try both extremes and look for improvements.

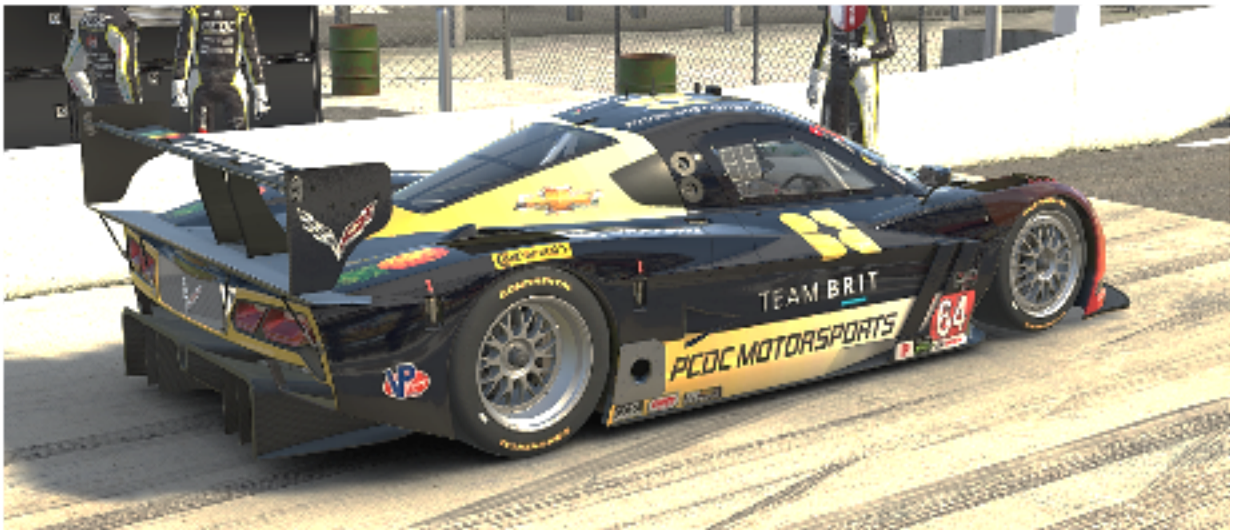
Aerodynamics

Tune for any issues mainly occurring at high speeds

Enzo Ferrari once famously uttered the words “Aerodynamics are for people who can't build engines.”
What Ferrari was not aware of is basically everything. Making a racecar that currently tops out at 252 kph go 288 kph requires either 30% more power, or just a 15% reduction of it’s drag coefficient. And while a car with no downforce can reach cornering levels of about 1G, aerodynamically optimised cars can easily reach 2-3 G.

It should therefore become apparent that when setting up cars that rely strongly on aerodynamics for performance, it is important to consider the needs of the aerodynamic platform when doing suspension setup.

As an example, we are going to look at the Corvette C7 Daytona Prototype



The C7 DP features a front splitter (black, below the radiator grill), a big flat floor with very low bodywork on its sides, a massive rear diffuser, and a big, but relatively shallow rear wing.

Contrary to popular belief, the most important aerodynamic surfaces of pretty much all aero-driven race cars are not the wings, but the things that you barely see: The complete floor assembly including the front splitter and rear diffuser.

The tricky thing about that is that in general, the closer to the ground an aerodynamic surface is, the more dependent on ride height it will be.
For most cars such as the DP, optimal downforce efficiency - that is, the ratio of downforce to drag - is achieved when the front splitter is sitting very near the ground, and the diffuser has a bit of distance from it. We call this height difference front to rear "rake".

When setting up a car for rake, it is important to note that ride height settings in the garage will not correspond to the ride heights being measured at speed - most cars will drop significantly closer to the ground as they gain speed. To fine-tune ride heights, the use of a telemetry system is unavoidable. In Project Cars for example, the in-game telemetry overlay can be used for rudimentary analysis, while on iRacing, ATLAS Express provides a way to do extremely detailed analysis.

A well-optimised floor aero setup will increase the downforce of the car substantially without sacrificing top speed.

So what does this mean for setups?

In many cars, the optimal ride heights will be unknown. Try getting the front of the car low, without it bottoming out, and experiment with different heights at the rear.

Once you have found the sweet spot, try finding a good balance at high speeds by dropping the rear down a bit if you get understeer, or raising the front a bit if you get oversteer.

If the car has wing settings available, check how they influence top speed and balance, and make a decision based on that. Remember though, that increasing or decreasing the wing angle will change the effective ride height at speed and you'll have to readjust.

Final Thoughts

I hope this guide helps you along the way of understanding race car setups. By now, it should become apparent to you why following setup flowcharts blindly can be an issue: Many of the different components have overlapping effects, and there's often more than one way to skin the cat. It's therefore important to remember that experience is king.

I hope this guide encourages you to start moving stuff around and learning the effects. Studying good setups from other people can also give good insights and a reasonable base to begin tweaking from. Start small, change one thing at a time, and don't get discouraged by setbacks - even small improvements can make a huge difference over a race distance.