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Suspension Tuning

Suspension Tuning is a critical part of getting the ultimate performance package, it is even possible to have a more competitive car then a rival with superior upgrades by having a well-balanced set up, which maximizes the available grip levels. It all comes done to extracting the best from what components you have and making sure they are well set up for the road or track conditions.

With upgraded suspension components, you have the potential for increase cornering capacities, by fine during the overall suspension balance and even help to eliminate weaknesses in the car chassis or handling characteristics. Suspension tuning can be used to change the way the car behave on different track and road conditions, playing to your car´s strength to gain a competitive edge.

We can reduce understeer and oversteer characteristics with the adjustments of anti-roll bar (sway bars), bump and rebound, ride height, spring rates, corner and static weights. The combinations are extreme and the more adjust-ability you have with suspension upgrades, the more the need to get the suspension tuning correct.

The suspension´s main role is to keep the tires in contact with the road surface for as long as possible and to optimize the contact patch of the tire. We can increase acceleration, braking and cornering forces by manipulating suspension adjustments. Suspension tuning even has an impact on the aerodynamics nature of the car under down force loads. We can increase down force levels with suspension tuning with the adjustments of ride height and spring rates for example.

One key area that you will need to know to maximize suspension tuning, is a good overall picture of your car´s current performance limitations and desired adjustment requirements. When trying to find the right suspension tuning settings it is important to consider a few things about your car and the track conditions you want to drive on.

Suspension Tuning Goals

Here is a list of things you need to identify before you can adjust the suspension to aid in achieving improved suspension tuning objectives:

- The car´s power to weight ratio.
- Engine characteristics, including maximum BHP and torque levels.
- Drive line configuration.
- Current handling balance.
- Weight distribution.
- Aerodynamic downforce levels.
- Tire width and characteristics.
- Track conditions, road smoothness, road camber changes, elevation, weather conditions, corner speeds, straight top speed, braking zones, apex curbing and even if the track is used regularly or if it is a special event. Or if you want a generalized fast road set-up.

All of the above points, will give you an ideal of what the objectives of the suspension tuning needs to achieve. The old saying “horses for courses” comes to mind. The suspension tuning for a F1 car if emulated for a lowed powered formula Ford, will not be effective, each car has its own needs from a performance point of view from the suspension. Ultimately we want the tires to remain in contact with the road at all times, with the greatest configurations to ensure maximum grip and loading.

1.0 Anti-Roll Bar (Sway Bar) Tuning

Anti-Roll (Sway Bars) as discussed in the Suspension Upgrades page, can provide adjustable settings in the suspension set up. Especially useful in dialing out oversteer, or understeer handling characteristics and getting a better balanced car. They have the same effects as changing the spring rates, but the focus of control is only used in lateral cornering forces.

The reason this is so useful for suspension tuning, is that you can make adjustment to front and rear anti-roll bars independently without affecting other suspension settings. Stiffer settings will reduce body roll, while softer settings will increase body roll. The relationship between the front and rear settings (roll coupling), will also have a direct effect on the handling of the car. Like most suspension adjustments, it is best to take small incremental adjustments rather than going to one extreme to the other.

It is critical that the right anti-roll bar is also selected to complement the other suspension components. I would suggest seeking profession advice on the overall suspension set up, as a whole and not just individual upgrades, when considering suspension adjustments.

It is generally accepted that it is better to reduce the anti-roll bar settings, rather than increase them to get a better balanced car. Softer settings will make weight transfer more gradual, with less abrupt loading of the tires, bending into corners rather than darting into them. Great care needs to be taken with too soft a setting as well, if the car has a low center of gravity, a soft setting could result in the car bottoming out. Which results in loss of traction, grip, and even car control in the extremes. Also camber settings ranges could be affected with a soft setting, where the tire exceeds the optimum set up.

Having too stiff a setting could result in poor handling in tight corners, with the inside wheel lifting off the ground. If either of the two wheels linked on the axle are on different road surfaces (one wheel on track, other on the side of the track), having a stiff set up will result in imbalances being transmitted through the anti-roll bar to the other driven wheel, on the opposite side.

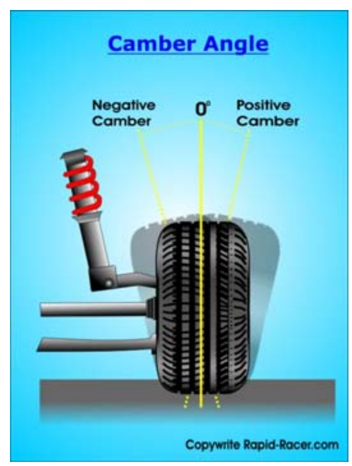
Anti-Roll/ Sway Bar Adjustment Effects on Handling.

Let’s have a look at the way we can adjust understeer and oversteer handling characteristics with the adjustment of anti-roll bars, also what effect the actual settings will have on the car if the stiffness is set too high.

Problem-	Solution-
Understeer.	Reduce front or increase rear anti-Roll/sway bar settings.
Oversteer.	Increase front or reduce rear anti-roll/sway bar settings.
Anti-Roll/Sway Bar Setting-	**Effect-**
Too Much Anti-Roll/Sway Bar: General.	Lack of feel with sudden response. Prone to slide or skate rather than taking a set. Darting over one wheel or diagonal bumps.
Too Much Anti-Roll/Sway Bar: Front.	Increased oversteer tendencies.
Too Much Anti-Roll Bar/Sway: Rear.	Increased corner exit oversteer, hard to put power down with excessive sliding.

2.0 Camber Angle

The Camber angle settings of the suspension can come in three different variations (vertically viewed from the front of the car), positive, neutral, and negative camber. It is normally represented in degrees. The camber angle, is used to adjust the tires footprint and position in relation to the road, during the suspensions´ dynamic movements in operation.



While it is true that a car's suspension will most likely pass through the various degrees of all of them in the normal operation of the vehicle (depending on set up and design). Having a good base in the beginning will be vital in having a competitive package for a given goal.

With any suspension adjustments and tuning, the best rewards will be achieved with a good baseline and small incremental changes for optimum results. Any camber angle adjustment will be positive up to a certain degree, until the settings have a negative impact on handling characteristics.

Negative Camber: increases the cornering grip of the tire during cornering, helping to maximize grip and providing better traction.

Neutral Camber: best suited for maximum acceleration and braking, this set up makes sure a flat contact patch is retained on flat road surfaces. The inside wheels may lift on the inner contact edge of the tire duration extreme cornering.

Positive Camber: used more for off road applications, especially with agricultural vehicles as this setting helps the wheels to turn with lighter steering effort required. The outside wheel under extreme cornering loads will benefit, but camber levels are normally linked (might be a consideration for oval tracks).

While double wishbone suspension is normally designed for camber angle adjustment, McPherson suspension might require after-market suspension mounts with various slots for adjustments in order to adjust the camber setting. Different suspension set ups and configuration also merit different camber generation depending on bump, rebound and roll forces.

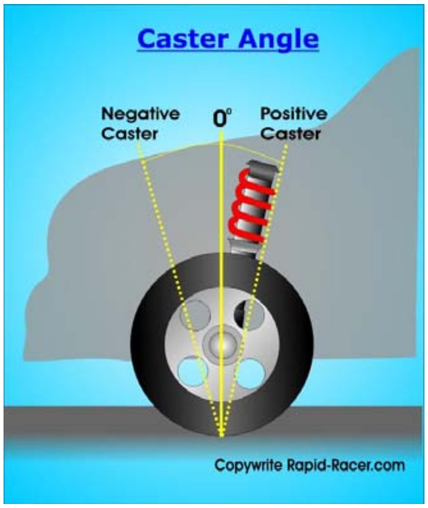
Camber Overview

Let’s have a look at the effect of different negative and positive camber settings on vehicle handling and tire performance.

Problem:	Possible Causes:
Too Much Negative Camber.	Increased inside tire wear. Increased heat on inside of tire. Reduced front braking capacity. Reduced rear acceleration capacity.
Too Much Positive Camber: Front.	Increased understeer after turn in on cornering.
Too Much Positive Camber: Rear.	Increased outside tire wear. Increased heat on outside of tire. If extreme could cause turn in response instability. Increased corner exit oversteer.

3.0 Caster Angle

The Caster angle is the ability of the front suspension system to self-center under cornering loads. Too much caster and the front of the car will understeer more (positive caster), too little and you will get oversteer handling characteristics (negative caster).



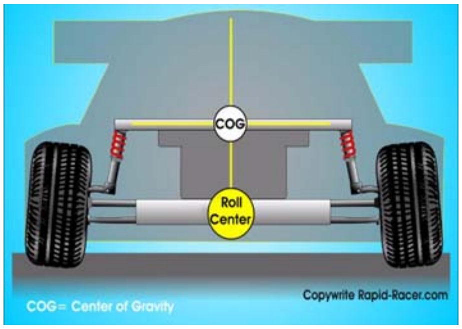
Improper adjustment will result in steering inputs required both into and out of a corners, resulting in a car which is difficult to keep on a straight line. A large positive camber setting (wheel facing forward of axis) is good for high speed stability but can make it more difficult for turning the steering, excessive amounts of caster angle will increase tire wear rates.

Caster Angle Overview

Problem:	Possible Causes:
Too Much Wheel Castor: Front.	Excessive steering effort required. Too much self-return action. Transmittal of road shocks to steering wheel.
Too Little Wheel Castor: Front.	Car sensitive to steering effort. Lack of steering feel. Self-return action and feedback reduced.
Uneven Wheel Castor: Front.	Bias steering response on one side. Car prone to swerve on higher castor setting side, on a straight line.

4.0 Center of Gravity and Roll Center

The center of gravity (CG) can be seen as the balancing point of the car, if you hung a car from a cable above the ground it would be balanced perfectly. It can be hung from any dimension and would remain balanced, it can be viewed as the center point of where the majority of the mass of the car is located and is a 3-D location across different the different axis's of the car´s body, longitudinal, traversal and laterally.



It is critical to understand that all acceleration, braking and lateral g-forces go through this point and the whole suspension system is set up and designed around this point.

Although in reality we have little adjustments of the center of gravity (unless we design a racecar ourselves), understanding its importance and effects is import on fine tuning suspension set ups. Your drive line configuration and vehicle weight distribution are also import factors in this equation.

Generally speaking we want to have a car with a center of gravity as low to the ground as possible, this helps reduce weight transfer loads acting on the roll centers of the suspension system. Less weight transfer downloads on the tires, through high suspension loads, will result in better tire performance. This is because as the load increases on tires, their ability of efficiently converting the vertical download decreases (coefficient of friction). The longer the wheelbase and wider the track of the car, in relation to the center of gravity, the less the weight transfer loads. Smaller tracked and higher CG cars can even roll over in extreme situations.

The center of gravity also affects the cars dynamic roll centers, as it acts as a lever on this point. The roll center is a point at which the suspension is designed to rotate around, this point changes fore and aft with acceleration and braking forces, also horizontally with left and right lateral forces in the opposite direction. The further the roll center is away from the center of gravity, the more roll or weight transfer happens, getting a balanced suspension set up which handles predictably past the limit is the ideal set up. Otherwise extreme handling could result, high speed understeer or oversteer tendencies.

Roll centers can be different, both at the front and rear of the car, as the independent suspension components operate separately during different loading phases. It is important to reduce weight transfer through roll centers, because overloading an outside tire under extreme cornering for example, will demand more from the component then is available and reduce its traction and grip capacities (exceeding tires traction cycle). This is determined by the suspension geometry, including length upper and lower arms, track width, chassis pick up points, tire contact patch and other chassis settings.

Roll Center Overview

Problem:	Possible Causes:
Too High Front Roll Center and Too Low Rear Setting.	Increased rear load transfer resulting in increased oversteer. Nonlinear chassis roll and load transfer. Roll axis out of parallel with mass centroid axis.
Too Low Front Roll Center and Too High Rear Setting.	Increased front load transfer resulting in increased understeer. Nonlinear chassis roll and load transfer. Roll axis out of parallel with mass centroid axis.

	Possible three wheeled motoring on corner exit.

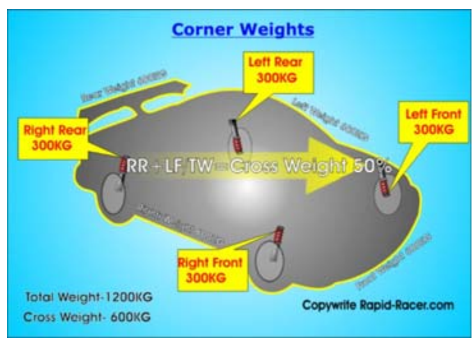
Mass Centroid Axis:
Mass centroid axis (MCA) is related to the CG (center of gravity) in some respects, if we had a side profile of a car and sliced it into sections (transversely), each section would have its own CG or centroid. When we link all the individual CG point, we can plot the mass centroid axis.

This gives us an indication of how the vehicle mass is distributed and will have an impact on CG, roll rates and general suspension setting to a certain degree. Mass centroid axis is different than the CG in that different section of the vehicle will have the mass located at different locations.

A lot of people will argue that all that is important is CG, but this is untrue. CG in a car with counter weight issues will still remain on the center line of the vehicle, but if we have more weight say on the front right and rear left corners. Taking just CG into the equation will leave us at a disadvantage. Corner weighting is a good example of this, where front to back weight could be equal, but not each wheel on the same axle.

This is why it is import to have the MCA on both axles as close as possible and ideally running through the CG point front, front to the back of the vehicle. Uneven weight distribution will affect acceleration, braking and cornering forces (or a combination), we need to have a balanced set up to maximize tire efficiency.

5.0 Corner Weights and Weight Distribution



Once a car is in motion, the vehicles static weight will move around in a dynamic nature to all four wheels through either one or a combination of acceleration, braking and cornering forces. It interacts through the unsprung weight proportion (as this is what is actually sprung) and the center of gravity, roll centers of the suspension system. All these forces are ultimately transmitted through various suspension components and either resisted or controlled, in an aid to download on the tire´s contact patches.

This is why static weight is so important to get right in the first place. As discussed in the static weight page, if we do find out we have a less than perfect weight distribution, it is possible to make suspension tuning adjustments to counter act these in balances. Sometimes the static weight might change due to off track diversion, will sequential damage or misalignments to the car.

If we are not designing a racecar from the drawing board with advantageous weight distribution in the first place, what can we do?

We can use corner weighting to adjust a single spring perch and either make it shorter or longer (adjusting ride height). This changes the car´s static weight distribution. Normally it is better to set minimum ride height settings, which will stop the car bottoming out. This way any adjustment to corner will be increasing height and not compromise the suspension system too much from bottoming out.

Static Weight:
If we take a static car which is fully loaded with all fuels, oils and driver on board, ideally we want equal corner weights distributed equally across the car (50% left, 50% right and at the front and rear of the car).

While the overall car designs drive line layout will play a fundamental importance in the total fore and aft static weights, it is possible to still make some changes to increase this ideal balance harmony (normally through moving components like batteries, fuel cells etc.).

It is always best to get your static weight measurements in the first instants before making any radical suspension changes. This can be calculated with digital scales designed for the job, and will best be done when new suspension components are fitted to the car.

<u>Drive line and Static Weight</u>
- Front Wheel Drive (FF) = more weight over the front of the vehicle, normally 60:40 split.
- Front Engine, Rear Wheel Drive (RF) = tend to be very balanced with 50:50 split possible.
- Mid-Engine, Rear Wheel Drive (MR) = more weight normally over the rear of the vehicle, 40:60 split.

As soon as the car is in motion, the car's weight will act through the center of gravity and affect the suspension's roll center. During acceleration, braking and cornering loads, this is when any uneven static load rates will transmit themselves into understeer or oversteer handling characteristics.

Bear in mind the following rules:
- If we increase the FL (front left) and FR (front right) spring perch (adjustment ring), then only ride height increases.
- If we increase RL and RR spring perches, then only the ride height increases.
- If we either increase the FL and RL or FR and RR (one side of the car), we only increase the ride height.

Uneven Weights:

If we placed a car on the scales and we could see that the front left (FL) and front right (FR) had a difference of 25 lb./kg between them, this will affect the way the tires behave under download forces acting through them. Acceleration, braking and cornering (or a combination), will be slightly unbiased and will result in less than optimum performance for the tire with more weight.

Under Braking the corner with the more weight will be prone to lock up quicker, with cornering loads it will lose traction quicker and side, causing some understeer, also there will be slighter better cornering capacity on one side. With acceleration, the corner with the more weight on, will unload the diagonal rear tire more, which could cause oversteer tendencies.

Any tire which is overworked will reach its peak performance quicker, overloading it and raising the temperature and it will also wear out quicker. Corner weighting strive to counteract act these imbalances if not already dealt with in the design stage. The actual drive line layout, tires and unsprung mass, will contribute to the overall effect to these unbalanced corner weighting issues.

Single Raised Spring Perch:
If we do have an imbalance in the corner weights, we will have to try and even this out, this is done by adjusting a spring perch. If we were to raise a single spring, this has an effect on all the other corner weights.

If we raised the front left corner up, this would have a direct effect on the diagonal rear right corner weight, as it would lower the ride height. The rear right corner would resist the downward force applied to it and additional weight would be transferred to that corner. As the front left and rear right corners are now under more tension (as they are linked from a weight distribution point of view), the front left would also increase its corner weight.

Now that both front left and rear right are carrying more static corner weight and there has not been an increase in unsprung mass. It is logically to assume that the transferred corner weight has come of the front right and rear left corners. As a result they will also increase in ride height, due to the reduction in corner weight acting upon them.

If you have a perfectly balanced car, than you will want to retain this configuration as it has been engineered into the specifications on the drawing board. Production cars are not perfectively balanced in most cases, from a performance point of view and we can use corner weighting to maximize static weight distribution levels. Sometimes we even have cases of previously balanced cars, running off the track or for other reason becoming cross weight unbalanced. This is where corner weighting can help us out.

Multiple Diagonal Spring Adjustments:
This is where it gets a little more complicated, what if we had the perfect ride heights, but our corner weights were out. We know from adjusting a single spring perch, that it will have an effect on all the other corners, so what can we do?

By adjusting all four corner weights in the same diagonally direction, up or down, we can change static corner weights without affecting ride heights. Effective we are counteracting each diagonal corner while still affecting corner weights.

It is important to know that different vehicle drive line configurations will affect the front and rear ratio´s differently, this is one of the reason to make precise documentation of any adjustments make while corner weighting. Have fun with your corner weighting to achieve the perfectively balance car.

Corner Weight Adjustments, Where to Begin

Before we adjust the corner weights to get a perfectly balanced car, or as close as is possible under the design constraints, we need to check that the car is race ready and we have the following check list complete:

- Tires (tires) inflated to the desired pressures.
- Anti-roll bars (sway bars) are disconnected, as not to add to the springs loading force, which will skew the results.
- You have a method of recording the small adjustments, this is very important as it may take multiple changes to get the desired corner weights. It is easy to forget what you have already done on each corner.
- Ride height adjusted to minimum levels for suspension compliance if known.
- Full fluids in the car including fuel, coolant levels, gearbox oil, power steering etc.
- Driver is in position, or is calculated in the final results.
- Suspension settings including toe, camber, castor, damping etc.

Changing one spring perch will have the effect of changing the static loading and ride height on all four corners, so it is important to logically approach this. If we change the height of both the front, rear or sides, together, there will be no change in corner weights. Changing diagonal corner either up or down together, will change corner weights but not ride heights.

Setting up the Scales:

Once the car is ready to begin the process of corner weighting, lay the scales out in the corresponding location for each corner. Make sure that the scales are correctly set up as of the manufacturer’s instruction, all cables plugged in and allow time for them to warm up. Zero the scales to make sure that no weights in registering on any of the corners, also make sure the scales are on a flat surface.

Double check the scales do not need charging, and if possible get somebody else to stand on each scale to make sure you have the same readings and that one of corners is not correct. Paying attention to the scales zeroing back after each release of weight. We should all be ready to start to jack up the car and slide the scales into position. We need to now make sure the car is settled and it is best to bounce the front and back up and down and let the suspension settle.

Keeping records:

We are now ready to begin the spring perch adjustments to optimize corner weighting. It is best to follow the same procedure every time you check the corner weighting on the car. Any adjustments should be thoroughly recorded and the car should be bounced up and down again and let to settle to confirm weight readings. Record as much detail as possible about the whole suspension settings used, this way when lap times are recorded at the track, it can be easier to analyze how different adjustments have impacted pace. Having a chart to record spring turns to height increases can help to save time if you are planning on this process regularly.

Weight Distribution

Having a car will as near equal weight distribution as possible will have a number of advantages. This will increase cornering balance between understeer and oversteer characteristics, improved acceleration, and braking. The ultimate aim of weight distribution is to try and get a perfectly set up car, which is balanced during cornering in both directions and maximizes equal loads through the tires as much as possible. Unequal weight distribution, can result in a tire or set of tires being overworked, this can exceed the tires overall grip levels. Also we can increase heat temperatures and premature wear rates.

By adjusting the weight of the vehicle, we can start to work towards the very best set up possible, within design and configuration limitation of the car.

Weight Distribution and Drive lines

Depending on the drive line layout and the other components on the car, it can be difficult to achieve equal weights, as there are certain design limitations:

- Front wheel drive (FF) cars tend to have more weight over the front axles, with 60:40 front bias.
- Mid-engine rear wheel drive (MR) car normally have more weight over the rear axles, with 40:60 rear bias.
- Front engine wheel rear-drive (FR), can have an equal balance, with 50:50 even balance.
- All wheel drive (AWD) car´s weight distribution can vary depending on the engine location.

Different Vehicle Weights

While we can look at the vehicles overall mass as its total weight, we can further split this into two types of weight, sprung, and unsprung weight. Let’s explore them in more detail.

While we can look at the vehicles overall mass as its total weight, we can further split this into two types of mass, sprung, and unsprung weight. Let’s explore them in more detail.

Sprung Weight:

This is the proportion of total weight which is supported by the suspension springs, but not including the unsprung weight. This can include the following components:

- Chassis.
- Engine.
- Driver.
- Fuel Loads including tank.
- Gearbox.
- Exhaust system.
- Up to 50% of the suspension components, depending on mounting points on the chassis, inboard or outboard set ups and various other configuration settings.
- All other components not included in unsprung weight.

When any forces from motion occur during acceleration, braking and cornering, it is the sprung weight which moves through the center of gravity and suspension roll centers through the springs. This is how we get weight transfer, where the sprung mass is moving in the direction opposite to motion. The whole suspension system is designed to counteract and control this weight transfer and its impact on the tires. Spring rates need to be able to support the sprung mass of the vehicle and any down force generated, which will further add to the downloads.

Unsprung Weight:
Unsprung weight is not supported by the springs and has a direct impact on the bump during suspension travel. The less we have of unsprung weight, the easier it is to control bump and the tires contact with the ground. These components in the unsprung weight can include:

- Wheels
- Tires.
- Hubs and hub carriers.
- Brakes unless mounted inboard.
- Up to 50% of the following components depending on location and set up- suspension links, drive-shafts, springs and shocks.

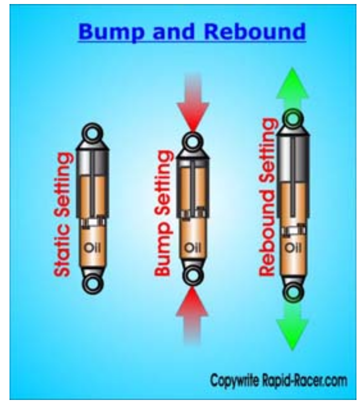
Unsprung suspension components acts through roll centers in an aid to maximize the tires contact patch with the ground. Also if we decrease the unsprung weight of the tires and wheels, we will see a slight increase in acceleration, braking and cornering forces. Just like light weight flywheels, reduced mass reduces power to act on inertia.

Jacking:
Jacking is a term normally associated with independent suspension systems. Effectively when a car goes round a corner and is subjected to lateral load transfer, the car "jacks" itself up.

Any suspension set up with its roll center above ground level with jack to a certain degree. Reaction forces of the tire which balance the centrifugal forces of the cornering, act through the roll centers of the suspension system. The tires contact patch in line with the above ground roll center, has an upward projection towards the car´s centerline. This is why the forces effectively lift up or "jack" unsprung mass through suspension components in cornering.

The lifting of the unsprung mass will raise the center of gravity, which will not help cornering abilities, also rebound will be generated by the laden tire which in turn has a negative effect on the tires camber, in the positive direction. Overall we want to reduce this effect as much as possible as it impacts cornering performance. We do this by keeping the roll centers as low as possible.

6.0 Damping: Bump and Rebound



Shocks work in conjunction with springs to form the basis for the car´s suspension system, they are sometimes incorrectly referred to as shock absorbers. If a car was only fitted with springs and not shocks, then any movement in the cars suspension in the vertical plane, would effectively keep bouncing up and down until the kinetic energy is displaced. Also every time a new bump or dip in the road was driven over, this would add to the already unstable suspension. This would make the car very difficult to drive from a performance point of view, as the geometry would be constantly changing.

Shocks effective help to dissipate any vertical movement in the suspension and keep the springs movements controlled, also they help the wheel keep full motion under different loads, while keeping the wheel in contact with the ground.

Adjustable Suspension:
It is possible to adjust the shocks to give different hydraulic resistance to fine tune the handling of the suspension for given conditions, the movement is broken down into bump (compression) and rebound (extension) motions. Shocks don't control load levels, but affect the speed of how fast the suspensions reacts to load changes and how fast the tire contact patch receives these loads.

Suspension Type	Adjustability
1-Way adjustable Suspension:	Rebound adjustable only.
2-Way adjustable Suspension:	Bump and rebound adjustable.
4-Way adjustable Suspension:	High and low speed bump setting, high and low speed rebound settings (high speed for bumps, low speed for corners and braking).

Damping Effect:
The overall damping effect has the following effects on the car handling behavior:

Damping Setting	Effect
Stiffer front damping (bump and rebound):	Increases grip at the rear of the car, increasing understeer characteristics.
Stiffer rear damping (bump and rebound):	Increases grip at the front of the car, increasing oversteer characteristics.

Bump:
During bump, the shocks and springs absorb the upward movement from cornering or road irregularities (the springs store some of the energy), the shocks then goes into rebound. If there isn't enough damping then the cycle begins again until the car returns to the original ride height, with a bouncing motion to the car. Another trait of under damping is that loads go into tire and suspension relatively slowly, this combined with the bouncing effect means a constant varying download force on tires. Acceleration, braking or cornering in this state, will also vary due to the various download rates. It is important to have enough bump stiffness to be able to deal with uneven surfaces.

If there is too much damping, then it is effectively like running no suspension and any upward motion will be transmitted directly to the chassis. Over damping will result in an increase in the loads acting on the suspension and the tires. The handling will feel very harsh and hard, this will effect street driving in terms of comfort levels, this might not be desired for a daily driver.

It is undesirable in both under and over damping settings, as it will reduce the handling of the car and will affect acceleration, braking and cornering loads.

Problem	Possible Causes
Too Much Bump Setting	Initial bump reaction harsh. Slow chassis roll. Car may jack up in long corners (higher ride height).
Too Little Bump Setting	Soft bump reaction. Car prone to dive or squats, lots of longitudinal weight transfer. Lots of car roll, inside front on turn in and outside rear on exit could fall over

Rebound:
During rebound (following the bump compression phase) the shocks extend back to their original positions, using up the stored energy from the springs. The rebound stiffness needs to be set at a higher value then the bump setting as the stored energy is being released. If there is not effect damping on the rebound, the wheel will quickly return through the static level and start to bump again, with the bouncing effect unsettling the suspension with little control. Any racecar which intends to ride the curbs on apexes, watch out- the compressed wheel could jump of the curb in extreme instances of rebound setting being too low.

If there is too much rebound stiffness, then the wheel could hold longer in the wheel arch then needed, effectively losing contact with the road as the force to push the wheel back down is slower to respond to the changing surface levels. This state is again far from ideal and it is best to make sure a good level is set for optimal tire contact with the road.

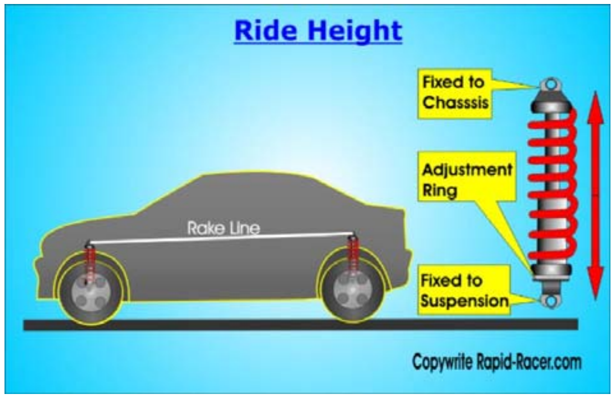
Problem	Possible Causes
Too Much Rebound Setting.	Wheel cannot keep up with road surface changes. Inside cornering wheel could be pulled of road by shock. Car could become jacked down in long corners (lowered ride height).
Too Little Rebound Setting.	Car will oscillate after bumps (bounce along the road). Hard to put down power.

Damping Effect on Cornering Characteristics.
Below we have an indication of how bump and rebound will affect handling characteristics, at the front and the rear of the vehicle:

Bump Setting	Effect
Front Bump Increase.	More Understeer.
Front Bump Decrease.	More Oversteer.
Rear Bump Increase.	More Oversteer.
Rear Bump Decrease.	More Understeer.

Rebound Setting	Effect
Front Rebound Increase.	More Understeer.
Front Rebound Decrease.	More Oversteer.
Rear Rebound Increase.	More Oversteer.
Rear Rebound Decrease.	More Understeer.

7.0 Ride Height



Depending on the exact road or racing environment, generally speaking the suspension should be as low as possible to the floor without the car bottoming out (wheels, chassis, or ground making contact with each other). If this happens than the car will become unstable and will lose traction, until the suspension settles again.

It is also worth bearing in mind that mechanical damage could also result, with front air dam and splitters, front wings, flat under-bodies and diffusers for example.

There are good reasons for reducing the ride height:

- Lower center of gravity-reducing weight transfer levels and aiding handling characteristics on the limit.
- Lower suspension system roll centers- depending on the exact suspension configuration, roll centers which are too high cause too much lateral loads during cornering, overloading tires.
- Increased aerodynamic down force- the front ride height should always be slightly lower than the rear to gain a rake effect (reducing lift) to aid down force. This works especially well with flat under-bodies and diffuser combinations.
- Reducing drag levels and increasing fuel economy, by restricting high pressure air from entering under the body. Especially effective with aerodynamic devices like front splitters and air dams for example.

Adjustments of the ride height will require fitting of adjustable coil overs, shocks, or shorter springs. Care must be taken in lowering the car as it has a diverse effect on other suspension geometry and this could end up hindering the performance potential. It could even affect tire wear rates, causing too much negative camber in the corners for example.

Ride height adjustment can also be used to change the corner weights of cars which do not have even weight distribution. This is done through a process called corner weighting. A spring perch is increased to affect static weight distribution on the opposite and diagonal wheel.

Ride Height and Downforce Levels:
We have already highlighted that the car´s ride height has a direct impact on the down force generation of the aerodynamic package. If for example we adjustments to the ride height are made, this will in turn affect current wing angle of attack settings which are already present. Suspension adjustments should always be made first and wing angles should be adjusted to compensate.

Ride Height Adjustment:	Angle of Attack Effect:
Lower Front Ride Height	Increased angle of attack for both wings.
Raising Front Ride height	Decrease angle of attack for both wings.

Another point to bear in mind, is that the pitch and softness of the front or rear suspension, will also have an effect on the aerodynamic package. Especially under acceleration and deceleration to a certain degree.

8.0 Spring Rates

Spring rate is a ratio indicating the resistance of a spring during bump (compression) of the suspension system. Known also as suspension rate, it is critical for setting the correct ride height and is proportionate to the movement of the length of component travel in its stoke phases. If the spring rate is too soft, then the ride height will need to be increased to compensate, otherwise the car will bottom out (chassis making contact with the wheels or floor) during road irregularities.

As we know the whole job of suspension is to keep the wheels and tires in contact with the ground at all times, for total performance. If the spring rate is not correct, then the damper rate (bump and rebound) will not be correct, leading to even more suspension worries. That is why it is critical to adjust spring rates and then ride height setting as a way to bench mark other suspension settings.

It is also important to understand that the overall spring rating of a car, should be as equally split both front and back as possible, depending on the weight distribution and drive line configuration. Otherwise we are setting the car up to either understeer or oversteer.

Spring ratings should equal the total weight of the car, with none down force producing aerodynamics vehicles. Down force levels have an effect on the overall spring rates and we need to add this onto the spring rating of vehicle mass. Otherwise the car will bottom out causing a whole lot of issues.

If we had solid axles, any vertical movement form the road surface would be transmitted to the chassis and a change on one wheel would be transmitted to the other wheel. This is why we have independent suspension, to isolate each wheel movement separately. For each individual wheel to be able to operate effectively, it is idea to have any spring ratings on an axle equal. If we need to adjust the weight balance from left to right we would need to adjust diagonal corners spring rates (corner weighting) to counteract this weight distribution.

High Spring Rates.
By having the ability to change the spring rate, heavier vehicles can have a higher setting to stop the suspension bottoming out under extreme loads, or if the car has big

down force generation abilities, with increased speed the down force generated is square to the velocity of travel. This would mean that we have to have a spring rate which will be able to handle the down force levels at their maximum. If the car bottoms out at speed, down force will be vastly reduced and the car will become unstable. This spring rate would therefore need to be higher than is needed to support the mass of the vehicle, we would need to also include down force levels.

Stiffer springs resist more vertical and lateral loads, as they store more of this energy. Having a spring rate which is too high, will result in a car´s suspension not being able to absorb all road regularities. This is because of the amount of force needed to compress the spring. The ride will be harsh and somewhat choppy, it will be hard putting power down on corner exits, with lots of wheel spin.

High Front Spring Rates:
If the front spring rate is too high at the front of the car, you will get understeer handling tendencies. The car could initially point into the apex on turn-in well, but gradually develop more understeer. If you hit a bump with high front spring rates, the tires could lock up and also be more prone to sliding.

High Rear Spring Rates:
If the spring rate at the rear of the car is too high, the car tends to have oversteer handling characteristics, especially on throttle applications at corner exits. The tire will be more prone to wheel spin also, which reduces grip levels and increases wear rates.

<u>Low Spring Rates.</u>
Softer spring rates could be an advantage in rougher terrains or raised curbs at apexes. With circuits with lots of camber and elevation changes, lower spring rates will most likely be needed. Unless of course you enjoy bouncing down the track, or even off the track in worse case examples.
It is also vital to remember to reduce spring rates for tracks with lower down force levels as there will not be as much download on the tires.

If the car bottoms out, then we know that our spring rates are too soft and will need increasing. Chassis meets wheel, chassis meets tarmac are far from an ideal set up, let alone the damage which could result from contact. The wheel will have lots of vertical suspension movement and the overall feel for the car will be floaty in nature. The car will roll more in the corners.

Low Front Spring Rates:
Too low front spring rates results in the front of the car bottoming out under braking, this could lock up the tires and greatly reduce braking efficiency. The car will be subjected to lots of body roll during cornering and will have an increased tendency to understeer.

Too low rear spring rates will result in lots of rearward weight transfer under accelerating and cornering. This could further unload the front unladen tire hindering cornering and the tire could even lift off the ground in extreme situations. There will also be an increase in rear negative chamber levels which will restrict acceleration abilities. There is normally more oversteer on corner exits, with throttle applications, due to the outside tire falling over.

Spring Rates Overview.

Problem:	Possible Causes:
Too Much Spring Rate: General.	Harsh and choppy ride, hard to put power down on corner exit. Sliding and excessive wheel spin on corner exits.
Too Much Spring Rate: Front.	Turn in understeer, but car may point to apex well. Front tires locks on bumps and may break away.
Too Much Spring Rate: Rear.	Excessive wheel spin. Oversteer on corner exit.
Too Little Spring Rate: General.	Car prone to bottom out on race track. Excessive vertical chassis movement. Floating ride feel. Unresponsive feel. Car may take multiple sets to settle.
Too Little Spring Rate: Front.	Bottom out under braking loads. Car rolls excessively during corners. Understeer on turn in.
Too Little Spring Rate: Rear.	Acceleration squat and increased negative camber. Power oversteer tendencies on throttle application.

9.0 Wheel Rate

Wheel rates are similar to spring rates in essence, but measurements are taken at the wheel instead of at the suspension linkage of the springs. Wheel rate is the amount of travel the wheel moves under bump and rebound (compression and expansion) during suspension loads. It is effectively the actual resistance of motion the wheel has to forces acted upon it.

If we had an equal wheel rate and spring ration (1:1), any motion or forces which the wheel will experience will be equal to spring forces and movement. If for example we had a wheel rate of 100 lb./kg for each inch/cm of travel, for every inch/cm of travel we would have a resistance of 100lb/kg (imperial or metric measurements can be interchangeable for this example). With a ratio of 1:1, the spring rate would also be the same, resulting in 100lb/kg of resistance.

The above example is a highly unlikely situation, due to packaging constraints and other suspension factor of the vehicle. Normal wheel rate to spring rate ratio are 2-3:1. Bear in mind that the various suspension components are connected and motion through the wheel will act as a lever to the springs. Wheel rate force will effectively be multiplied depending on suspension set up, configuration etc.
It is important to know that the wheel rate would always normally be less than the spring rate, as the wheel will travel a larger distance through compression or expanding than the springs themselves, plus factor in the lever effect. Ideally we also want the wheel rate to increase as the springs are compressed (more wheel travel), but more than likely having a linear ratio between the two is acceptable. This helps to keep all the other suspension settings in check.

We can now see that the wheel rate is used to help you identify the required spring rate minimums and then go on to set up the ride height of the car. Having spring rates and ride heights which are too low will cause a lot of problems with the whole suspension, handling, and aerodynamics of the car. This is one of the real reasons that we need to know the wheels rates, in order to get compliant suspension system which maximize the tires contact patch with the road.

How to Calculate Wheel Rate

Required Formula:	Calculation:
Motion Ratio=	$\frac{\text{Wheel Travel}}{\text{Spring Travel}}$
Wheel Rate=	$\frac{\text{Spring Rate}}{(\text{Motion Ratio})^2}$

Above are some formula to be able to calculate the motion ratio and then the wheel rates.

Comparing Wheel Rates:
Wheel rates are critical in cornering balance and have a major impact on other suspension tuning settings, directly affecting the spring rates. It can be confusing comparing wheel rates of different vehicles for a number of reasons. Some people compare spring rates and not wheel rates themselves.

You could have two different cars, with two totally different cars, including vehicle weight, suspension systems, spring rates etc., but they could have the same wheel rates. Wheel rate is therefore important to calculate overall springs and ride heights, to prevent the car bottoming out under suspension travel.

10.0 Track and Wheelbase Dimensions

The length of the wheel base and the width of the track will have an impact on the way the car behaves under different driving conditions. Depending on your overall performance goals, it may be possible depending on budget, to increase your cars dimension for optimum performance.

Long Wheel Base:
Long wheel bases will help create better straight line stability especially at higher speeds. Less longitudinal loads transfer rates (less need for anti-squat or anti-dive devices or suspension set ups) and also less pitching, polar movement of inertia. You get more room from a packaging point of view.

Short Wheel Base:
With short wheel bases, the first great advantage will be reduced weight. Also the cornering and maneuverability will be further increase, especially on tight turns. Effectively a tighter turn circle.

Wide Tracks:
Wide tracks will give you more resistance to lateral load transfers under centrifugal forces, effectively meaning better cornering capabilities. With the extra room longer suspension links can be made, further reducing roll to aid cornering. The increased frontal area of the wider track will also have an impact of aerodynamic drag, with open wheel racing cars, this is not a real problem as the increased cornering capabilities far out weight the drag penalties.

11.0 Toe In and Toe Out

Toe-In or toe-out is another important suspension setting, it affects the handling of the car in terms of tire wear, straight line stability and cornering characteristics. There are three different states of toe settings as follows:

- **Toe-In:** the wheels point inwards from the wheel centerline.
- **Toe-Out:** the wheels point outwards from the wheel centerline.
- **Zero-Toe:** the wheels point straight ahead.

The toe setting are normally measured in degrees from the wheels´ centerline, toe in is represented as negative degrees (-) and toe out is positive degrees (+).

Sometimes the toe setting of a car is referred to as tracking, especially with road cars. Due to road imperfections, curbs and even pot holes, the wheel alignment can be knocked out of place and will need adjusting for optimum tire performance.

You will know if you tracking is out if the car pulls to one side when braking, the car does not drive straight ahead when the steering is held straight, or with even is the steering will is crooked in the neutral position.

Toe-In and Toe-Out and Tire Wear

Toe Setting:	Tire Wear Effect:
Too much Toe-In.	This causes the outsides of the tires to wear out more quickly.
Too much Toe-Out.	This causes the insides of the tires to wear out more quickly.

As we can see the toe settings of the wheels has a big impact on the wear rates of the tires. Uneven tire wear is a good sign that the tire´s contact patch is not fully working to its full capacity. This will reduce all lateral and longitudinal acceleration forces including acceleration, braking and cornering.

Toe-In and Toe-Out and Straight Line Stability

Problem:	Possible Causes:
General Straight Line Instability.	Too much toe-in or toe-out settings. Rear toe-out static due to incorrect setting.

Problem:	Possible Causes:
Straight Line Instability: Under Hard Acceleration	Too little rear toe-out setting.
Straight Line Instability: Car Darts over Bumps.	Too much toe-in or toe-out setting.

If straight line stability is affected by the toe-in and toe-out settings, we will see a reduction in overall acceleration and braking capacities. This will have a big impact on lap times and tire wear rates, as previously highlighted.

Toe In and Toe Out and Cornering

Problem:	Possible Causes:
Corner Entry Understeer: Car Turn In Good, then Progressively Washes Out.	Too much front toe-in setting.
Corner Entry Oversteer.	Too much rear toe-in setting.
Corner Exit Oversteer: Progressively Increasing on Throttle Application.	Low rear toe-in setting.

Cornering capabilities are also affected but toe settings, this is also another indication that the tires are not working at full potential. Inducing both oversteer and understeer handling characteristics.

Toe Setting Overview

Toe Setting:	Effect:
Too Much Toe-In: Front.	Car darts over bumps during braking loads and corner entry. Hard to turn in on corner entry, if extreme will turn in then wash out.
Too Much Toe-Out: Front.	Car wanders under braking. Unstable in straight lines. Reacts to wind gusts, one wheel, or diagonal bumps.
Too Much Toe-In: Rear.	Rear end unstable and light on corner entry.
Too Little Toe-In: Rear.	Power oversteer on corner exit.
Toe 0ut: Rear.	Straight line instability. Power oversteer on corner exit.
Too Much toe-in in bump: Front.	Increased understeer on corner turn in. Car darts over bumps.
Too Much toe-out in bump: Front.	Increase understeer after turn in on corner entry. Car wanders under braking.

Toe Setting:	Effect:
	Car may dart over one wheel bumps or gusts of wind.
Too Much toe-in in bump: Rear.	Darting on throttle application on corner exits. Roll understeer on corner turn in. Rear end instability on corner turn in.
Too Much toe-out in bump: Rear.	Increased oversteer on power application. Similar to static toe-out, to a lesser degree.

Above is a general indication of what different toe settings will do to the car´s performance, drive line configurations, tire wear rates, tire pressures, tire temperatures, and even track conditions will have an impact as well. We can see that toe settings can be a complex suspension tuning setting and as also recommended, make small little adjustments to perfect vehicle handling.