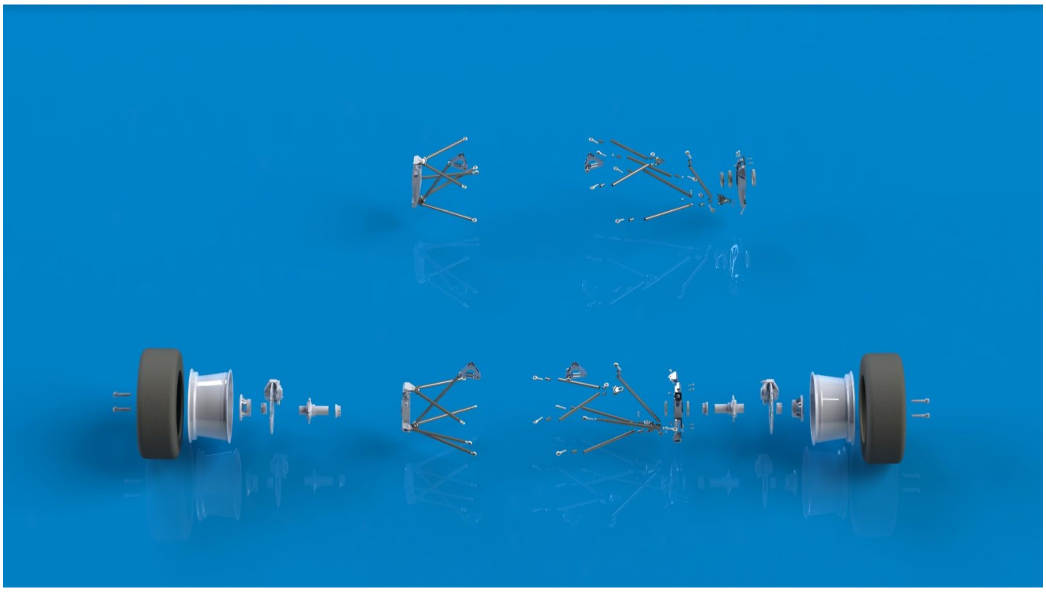
WIKI

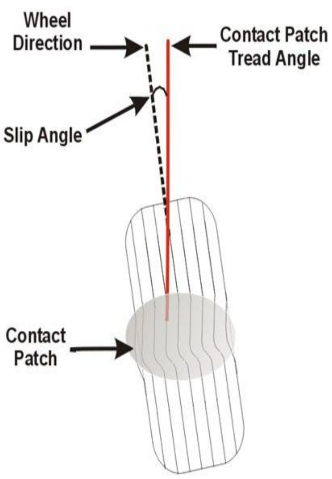
Suspension Department

Summary



1. Tyres

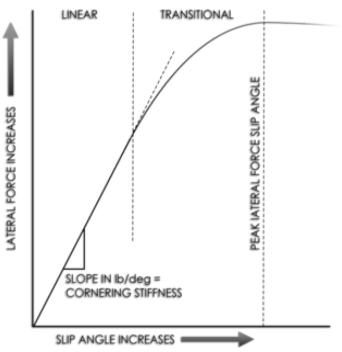
1.1 Slip angle



Wheel Turning Left

Slip angle is one of the most important concepts in vehicle dynamics and I recommend reading tune to win and then RCVD for a more in depth understanding. Essentially slip angle is the difference in angle between the tire contact patch threads and the rest of the wheel thread. The slip angle occurs from the fact that tires are made from rubber and it deforms while turning.

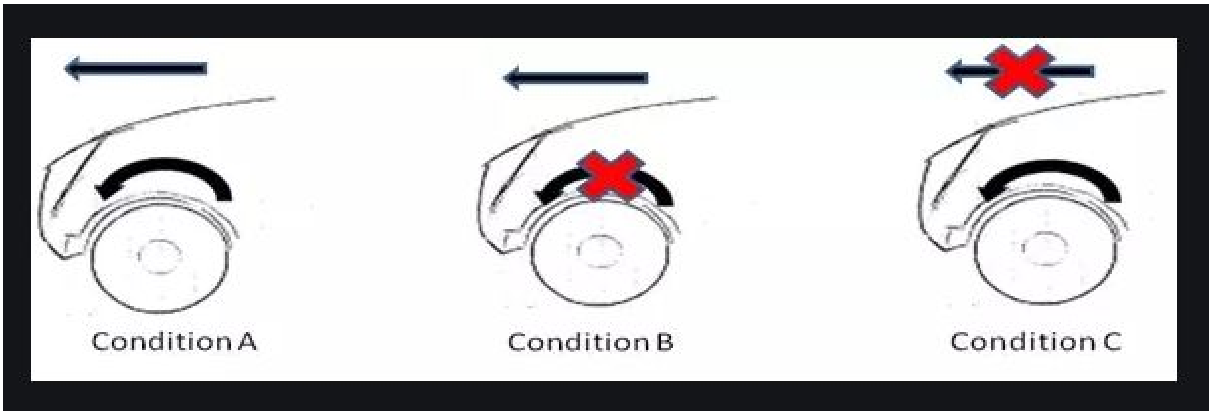
Slip angle should not be mistaken for steering angle. The deformation of the rubber and its elastic properties is what creates the force necessary to cause the car to turn.



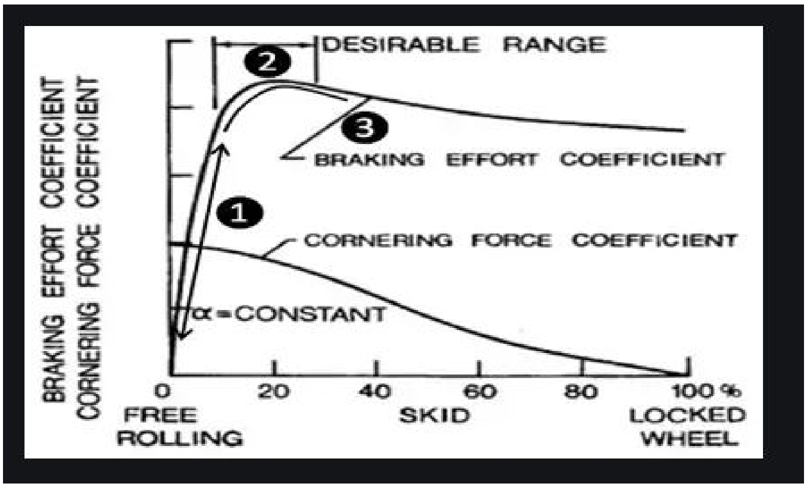
As slip angle increases (up to a certain point before a limit is reached), the lateral force or grip also increases. Higher slip angles also cause the tires to wear faster. This is exactly why in F1 cars the soft tires are the fastest but wear the quickest and the hard tires have the opposite properties.

Another confusing point to know is that no slipping is actually occurring between the tire and road: https://www.youtube.com/watch?v=W8UiE7yvO_M#action=share

1.2 Slip ratio



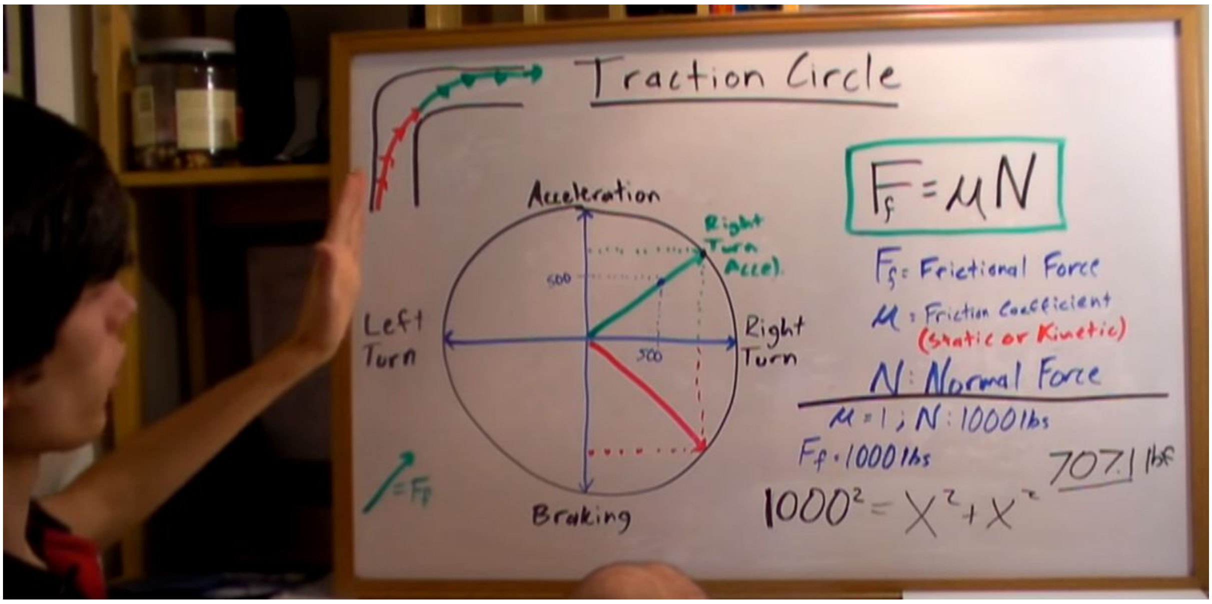
Slip ratio is essentially the slip angle defined as the deflection of the sidewall in a longitudinal sense in order to produce the longitudinal force to move the car forward.



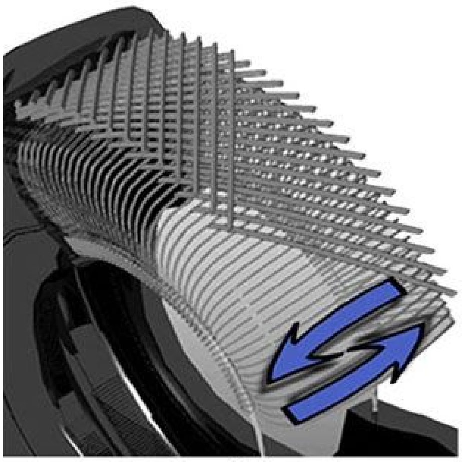
There are many different ways to define slip ratio but for the purpose of explaining it now we will say a slip ratio of 0 is a free rolling wheel, -1 is a skidding wheel (accelerating but not moving eg in a burnout) and 1 is a locked wheel braking. Some definitions use a number between 0 and 1 to define.

1.3 Traction Circle

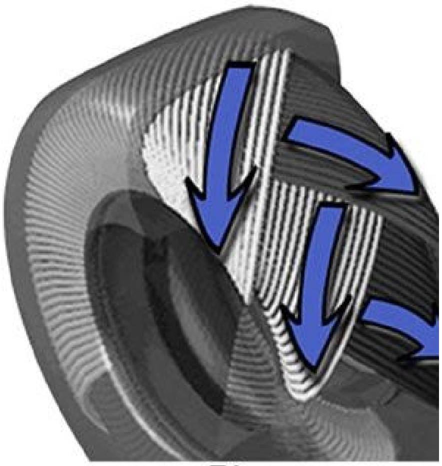
Now with definitions for both slip angle and slip ratio we can show that combining the right amount of slip ratio with slip angle, we can follow a 'traction circle' which is essentially the max amount of grip we can achieve with both longitudinal and lateral forces. A pro race car driver attempts to follow this circle.
It can be seen combining both cornering with braking and acceleration will follow the traction circle. While cornering, a process such as the top left of the picture should be taken to get maximum traction.



1.4 Radial and bias ply tires



Radial



Bias

https://www.formulastudent.de/pr/news/details/article/pats-corner-formula-student-tyres-for-dummies/

https://www.formulastudent.de/pr/news/details/article/tyres/

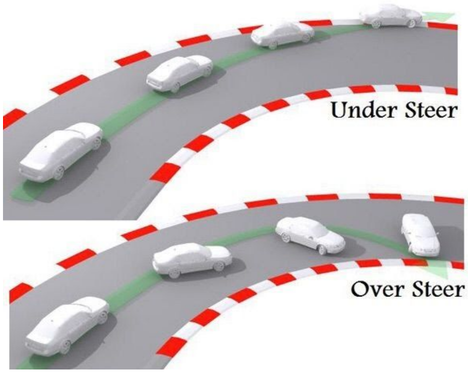
Radial and bias ply are two ways of constructing tires. Each has its advantages and disadvantages, and a lot of these come down to driver preference and experience. For more details on tyre load sensitivity and some more good tire stuff, check out this link: https://www.paradigmshiftracing.com/racing-basics/tire-science-for-racers#/

2. Some Vehicle Dynamics

We like to talk in terms of Vehicle Dynamics terms sometimes. I'll throw a couple of terms and concepts down here to make the rest of the read just a little bit easier.

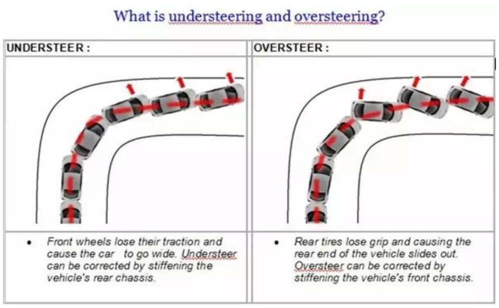
2.1 Understeer and oversteer

If you've ever watched top gear or formula one you'll have heard these terms been thrown around. Generally the driver will complain of understeer or oversteer.



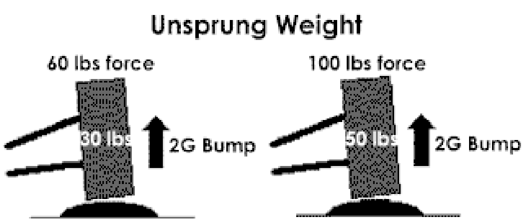
Understeer is when the front wheels lose grip before the rear. This causes the car to be unresponsive to steering input and the car to follow an arc outside of the intended cornering arc. Oversteer is when the rear loses grip before the front and the back end of the car begins to give way. This causes the car to follow an arc inside of the intended steering arc.

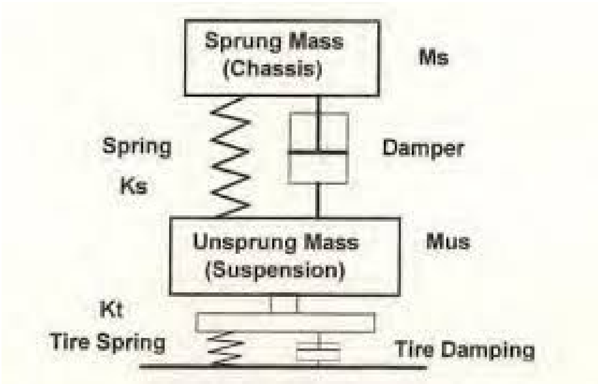
Front wheel drive cars usually suffer from understeer. Since understeer is a lot safer than oversteer, road cars usually purposely tend to understeer. Rear wheel drive cars usually tend to oversteer. Drifting is a controlled form of oversteer. The first thing that is done when a driver complains of either U/S or O/S is the suspension is tuned.



2.2 Unsprung and Sprung mass

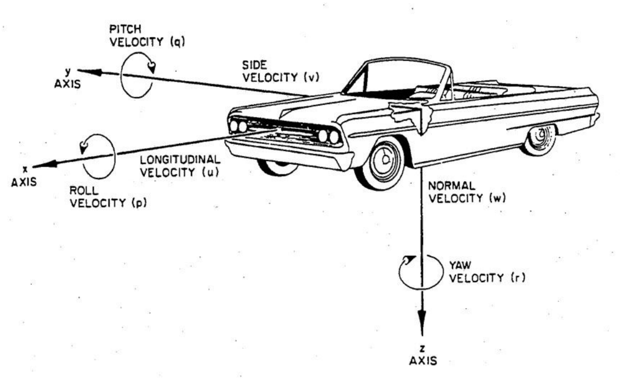
You'll often hear terms such as sprung and unsprung mass being thrown around.





It is important to keep unsprung mass down as it improves the reaction of forces into the chassis. The more unsprung mass you have, the more inertia you will have at the tire when you go over a bump, and therefore the more force that has to be reacted by the chassis and springs.

2.3 Vehicle Axis system



This is the vehicle axis system that is used by the Society of Automotive Engineers (SAE) that we will also use to describe the motion of our vehicle.

This is how we talk about the motion of our sprung mass i.e the chassis and everything it holds.

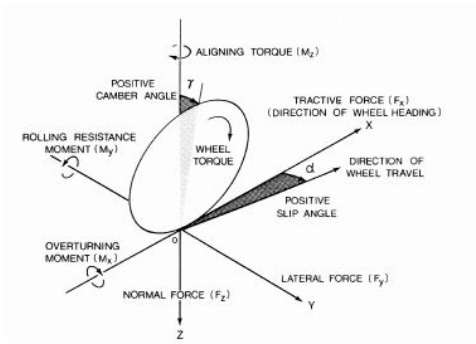
2.4 Tire Axis system

This is the axis system we use to talk about the tire. We will explain the terms later but note the direction of the axes as this is important and is the universally accepted axis for racing (also matches the above axis for sprung mass).

X axis - Forward / Longitudinal direction

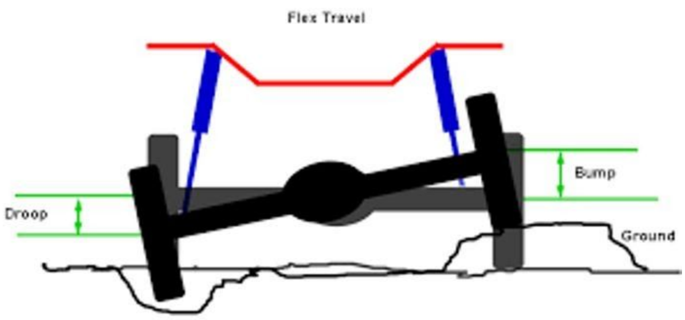
Y axis - Side / Lateral direction

Z axis - Up / Normal direction.



2.5 Tire Axis system

How we describe suspension travel: Flex Travel about a fixed plane is undertaken through the springs, which absorb the roll and bumping from the ground to keep the chassis and hull level.



3.Rules

There are not too many rules that apply to suspension but most of dynamics should be familiar with the following set of rules.

We are mainly concerned with the wheelbase, track width parameters for designing geometry as well as the minimum suspension travel (+- 25.4mm).

It is also important to note that we will attempt to bottom out the suspension before we hit the ground. This is when we reach the max travel of our springs and dampers. As awful as bottom out is to parts and the car, we do not want to be disqualified/ damage components more expensive than dampers.

3.1 Wheelbase(T2.3) :

The wheelbase regards the distance between the axles, measured from the centre of ground contact of the front and rear tires with the wheels pointed straight ahead.

3.2 Vehicle track:

The smaller track of the vehicle (front or rear) must be no less than 75% of the larger track.

3.3 Driver's Leg Protection (T5.8):

(T5.8.1): To keep the driver's legs away from moving or sharp components, all moving suspension and steering components, and other sharp edges inside the cockpit between the front roll hoop and a vertical plane 100 mm (4 inches) rearward of the pedals, must be shielded with a shield made of a solid material. Moving components include, but are not limited to springs, shock absorbers, rocker arms, anti roll/sway bars, steering racks and steering column CV joints.

(T5.8.2) Covers over suspension and steering components must be removable to allow inspection of the mounting points.

3.4 Suspension (T6.1):

(T6.1.1): The car must be equipped with a fully operational suspension system with shock absorbers, front and rear, with usable wheel travel of at least 50.8 mm (2 inches), 25.4 mm (1 inch) jounce and 25.4 mm (1 inch) rebound, with driver seated. The judges reserve the right to disqualify cars which do not represent a serious attempt at an operational suspension system or which demonstrate handling inappropriate for an autocross circuit.

(T6.1.2): All suspension mounting points must be visible at Technical Inspection, either by direct view or by removing any covers.

(T6.2): Ground clearance: must be sufficient to prevent any portion of the car, other than the tires, from touching the ground during track events. Intentional or excessive ground contact of any portion of the car other than the tires will forfeit a run or an entire dynamic event.

Wheels (T6.3)

(T6.3.1): The wheels of the car must be 203.2 mm (8.0 inches) or more in diameter.

(T6.3.2): Any wheel mounting system that uses a single retaining nut must incorporate a device to retain the nut and the wheel in the event that the nut loosens. A second nut (“jam nut”) does not meet these requirements.

(T6.3.3): Standard wheel lug bolts are considered engineering fasteners and any modification will be subject to extra scrutiny during technical inspection. Teams using modified lug bolts or custom designs will be required to provide proof that good engineering practices have been followed in their design.

(T6.3.4): Aluminium wheel nuts may be used, but they must be hard anodized and in pristine condition.

Tires (T6.4)

(T6.4.1): Vehicles may have two types of tires as follows:

a. Dry Tires – The tires on the vehicle when it is presented for technical inspection are defined as its “Dry Tires”. The dry tires may be any size or type. They may be slicks or treaded.

b. Rain Tires – Rain tires may be any size or type of treaded or grooved tire provided:

i. The tread pattern or grooves were molded in by the tire manufacturer, or were cut by the tire manufacturer or his appointed agent. Any grooves that have been cut must have documentary proof that it was done in accordance with these rules.

ii. There is a minimum tread depth of 2.4 mms (3/32 inch).

NOTE: Hand cutting, grooving or modification of the tires by the teams is specifically
prohibited.

(T6.4.2): Within each tire set, the tire compound or size, or wheel type or size may not be changed after static judging has begun. Tire warmers are not allowed. No traction enhancers may be applied to the tires after the static judging has begun, or at any time on-site at the competition.

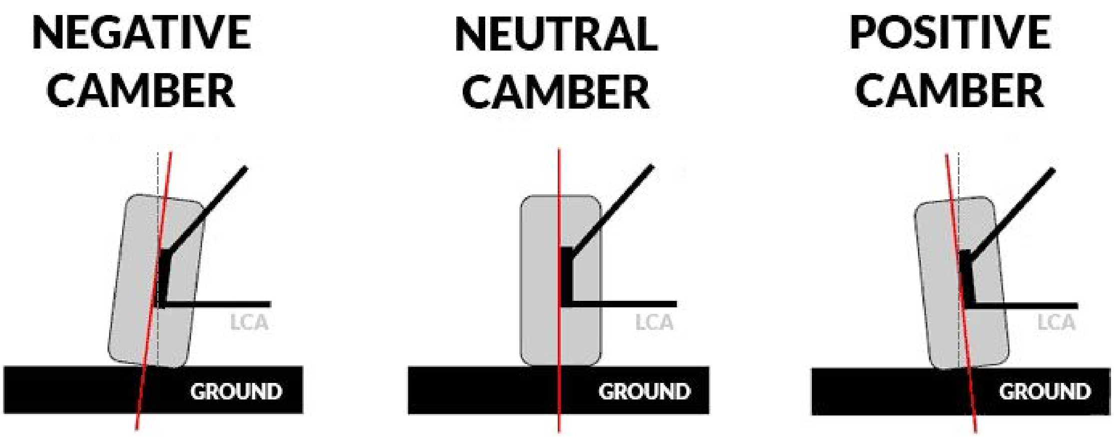
Rollover stability (T6.7)

(T6.7.1): The track and center of gravity of the car must combine to provide adequate rollover stability.

(T6.7.2): Rollover stability will be evaluated on a tilt table using a pass/fail test. The vehicle must not roll when tilted at an angle of sixty degrees (60°) to the horizontal in either direction, corresponding to 1.7 G's. The tilt test will be conducted with the tallest driver in the normal driving position.

4. A - Geometry Part 1 - Jargon and Concepts

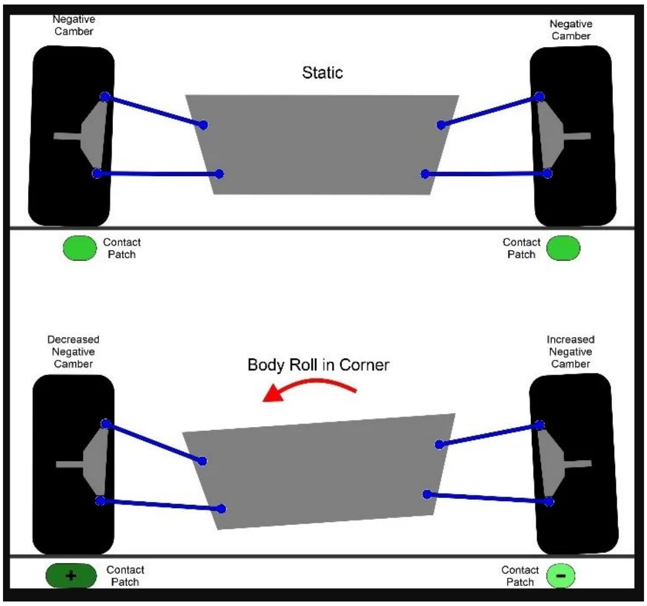
4.1 Camber



Static Camber is essentially when you tilt the wheel in front view.

The reason you would do this is to gain more grip while cornering. When cornering and the body rolls, the weight is transferred to the outside tires. We therefore need the most amount of grip at the outside tires. Another thing that happens is the wheels begin to tilt or camber as we corner.

If we set the wheels to negative camber while going straight, as we turn and the body rolls, the outside tires tilt toward a neutral camber giving us the most amount of grip on the outside tires during cornering.



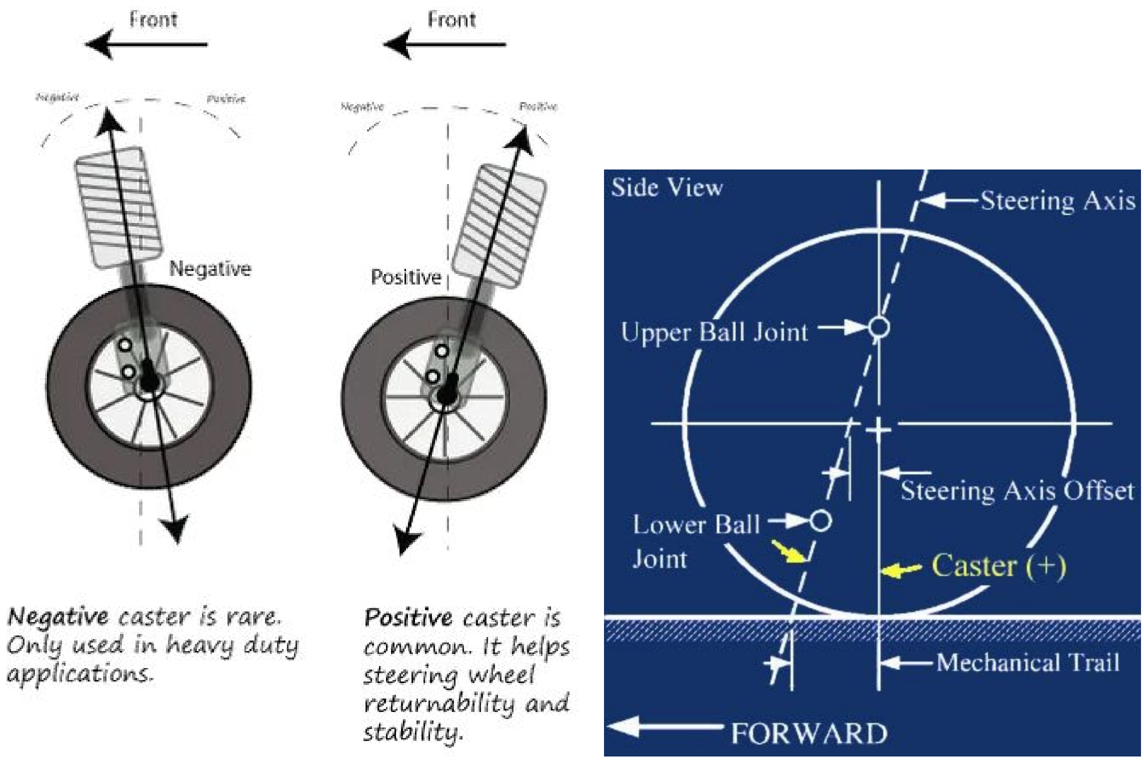
For this reason almost all cars will set some negative static camber. As you can see the outside tires contact patch becomes larger while cornering.

No car will ever set positive camber in static position as then the outside loses grip with cornering.

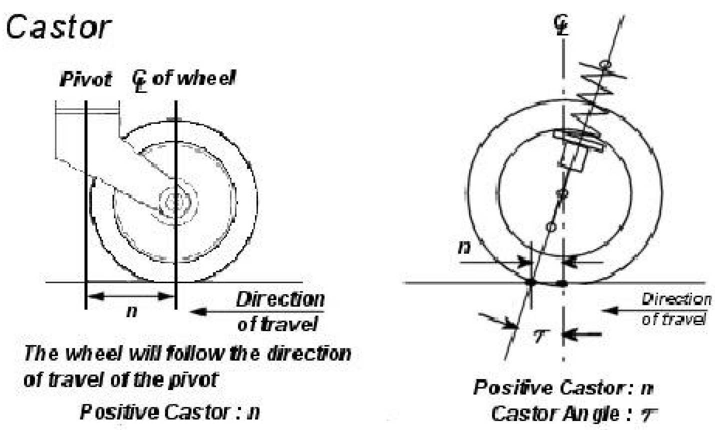
As we will discuss, other dynamic phenomena can cause positive camber changes which we will try to reduce.

There are many disadvantages to too much negative camber such as less grip in the straight and increased tire wear. A good way to know if you have too much or too little camber is to check the tire temperature across the tire when it comes off the track. The temperature should be evenly distributed.

4.2 Caster



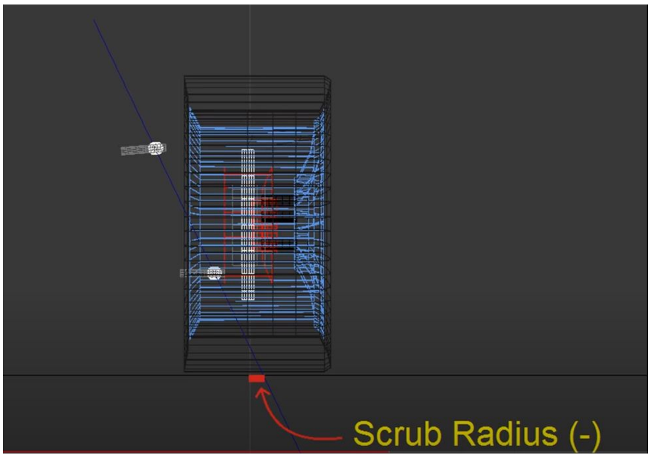
Caster is the angle of the steering axis in side view. The benefit of this is it creates a ‘mechanical trail’ that the wheel follows. This will provide self centering effects for the steering wheel. Caster is the reason why the wheels on desk chairs or trolleys follow the direction you push them.

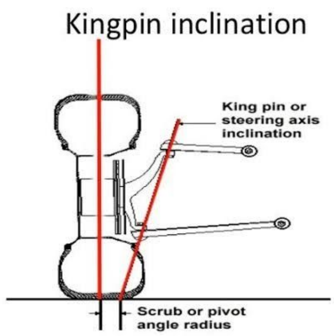


Caster will make the steering feel heavier if you have too much. Caster will also give the wheel negative camber as you turn the wheel which is a good thing as you don't have to run as much static camber.

4.3 King pin inclination

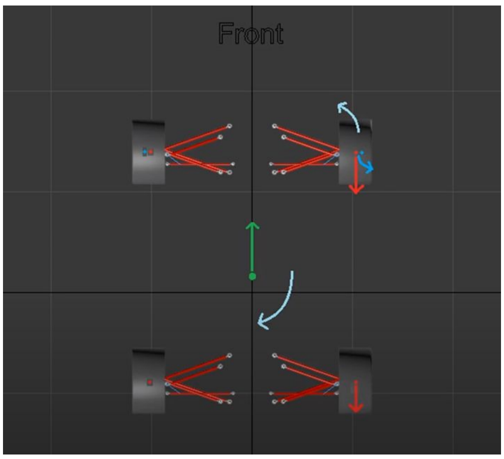
Often referred to as 'KPI' or 'Steering axis inclination', this is the axis the steering axis is tilted in front view.

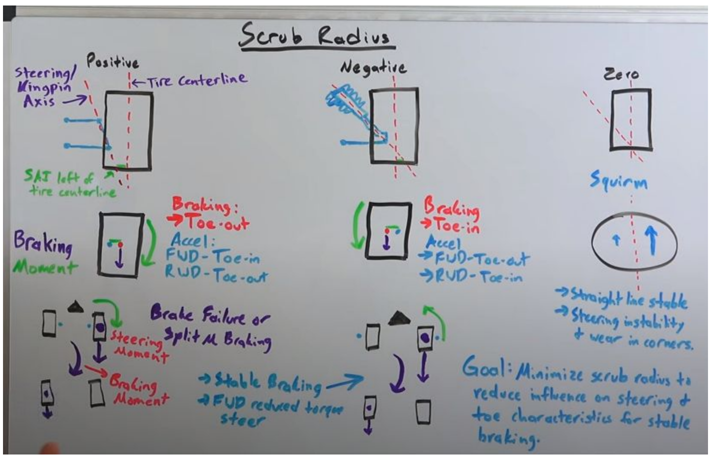




This will tend to lift the car as you turn which can give some good self centering force to the tire. KPI will cause the inside tire to gain negative camber which is good but the outside tire will lose camber or tend toward 'positive camber' which is not good at all for racing since the outside tire does most of the work.

As seen in the above pictures KPI also determines the **scrub radius** which is the difference in the point where the steering axis intersects the ground and the tire contact patch.

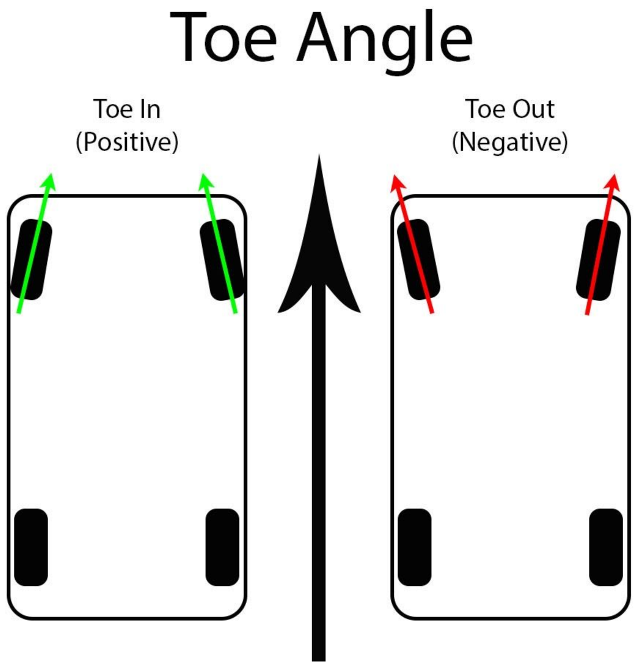




The scrub radius can provide an aligning torque that can help the wheels stay centred during hard braking or acceleration. It can be used to counter moments if one braking system fails keeping the vehicle straight if the brakes were to fail. Minimising scrub radius so that we can minimise the effects on the toe is desirable.

4.4 Toe

Toe is the angle from the top view that the wheels point. Toe can be used to create more grip in certain situations due to an increase in ‘slip angle’.



Toe In

On the front of the car, toe in increases straight line stability. This is because if one of the wheels is disturbed during straight line driving and is pulled rearward of the steering axis then the wheel will steer outwards.

This minimal outward steering would only straighten the wheel and develop zero toe so would help the car stay straight. However, upon turn in, the inside wheel is more hesitant to turn making for a less responsive turn in. This can be compensated for by using high Ackermann angle steering geometry.

Toe in on the rear also improves the straight line stability of the car for the same reasons as above. Toe in is also used on the rear to induce a slip angle on the tyre to increase the straight line grip and performance of the tyre to transmit as much torque as possible to the ground.

Toe Out

On the front of the car, toe out decreases straight line stability. When a wheel is disturbed in a straight line with toe out, pulling the wheel rearward of the steering axis, it increases the toe out and effectively turns the inside wheel more outward, pulling the car into yaw. This decreases straight line stability as it makes the car develop a twitchy nature which can be uncomfortable at high speeds.

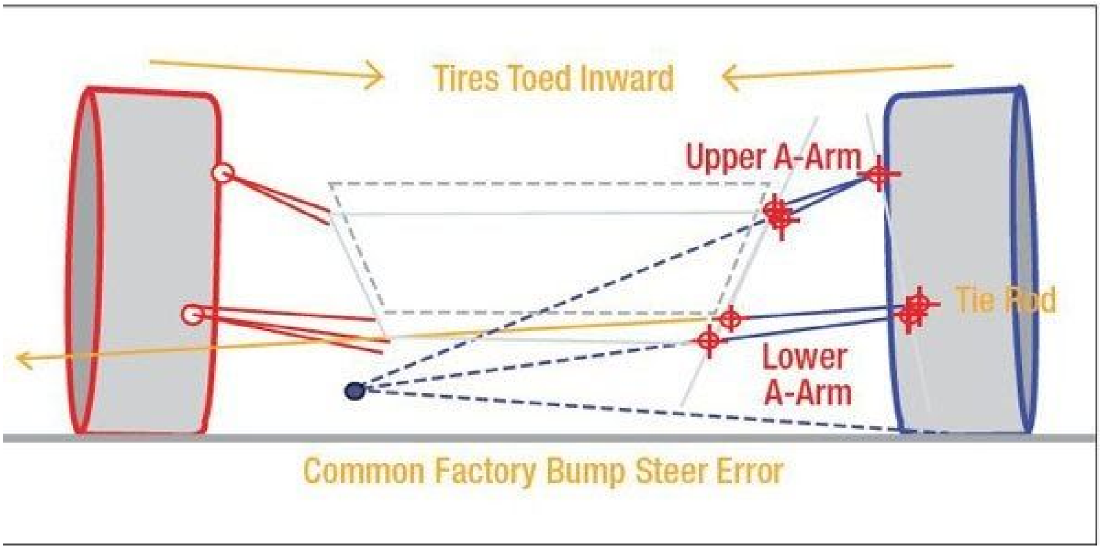
However, running toe out makes for faster turn in on the front end.
Toe out on the rear will induce a slip angle on the tyre to increase rear end grip for acceleration. However, during cornering the toe out increases the tendency for the rear of the car to oversteer which is especially bad for rear wheel drive racing cars.

Zero Toe

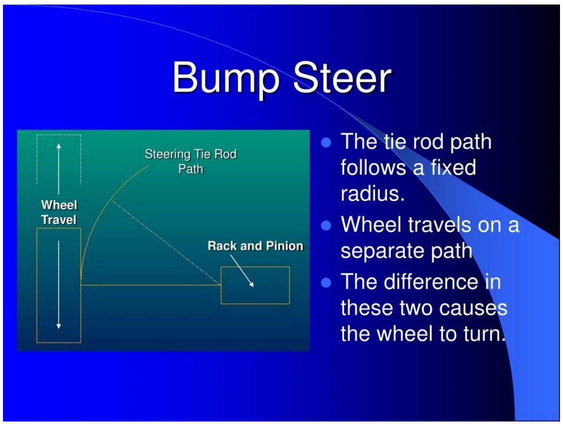
Running zero toe at the front and/or rear of the car results in minimum tyre wear and power loss. This is because if any toe is run, it develops scrub of the tyre in a straight line due to the incurred slip angle, decreasing the rolling efficiency of the tyre.

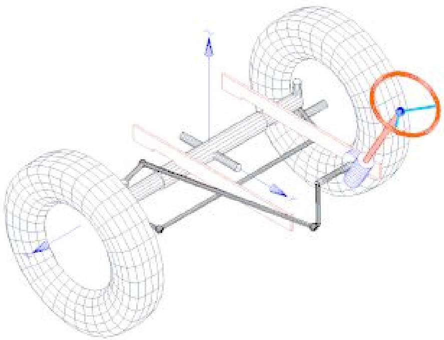
Toe in and toe out can be used to change to U/S O/S effects of the car depending on the track your running on. Toe angles are usually kept very miniscule and are under 1 degree.

4.5 Bump steer

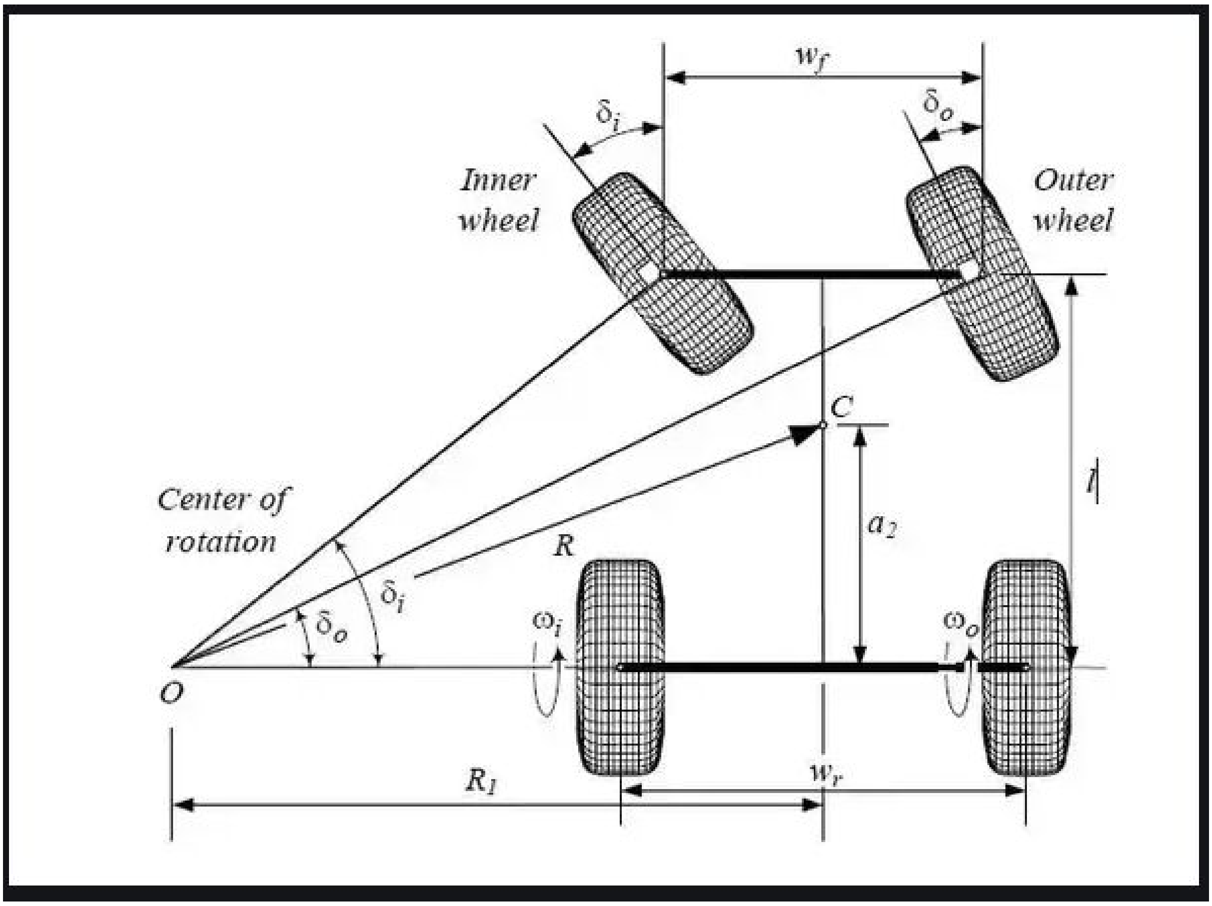


Bump steer is a phenomenon that occurs in bump and droop where the wheels will change toe. This is generally very undesirable and will be minimized as much as possible. Bump steer cannot be eliminated but it can be minimized as much as possible. Changing the position of the tie rod angle or length can be used to change the bump steer depending on the current characteristics of the bump steer.
Bump steer can be beneficial to race cars on smooth tracks as the increase in slip angle can be used to gain more grip in corners, however bump steer is generally kept to as minimum as possible. In off road cars it is of utmost importance to minimize bump steer.

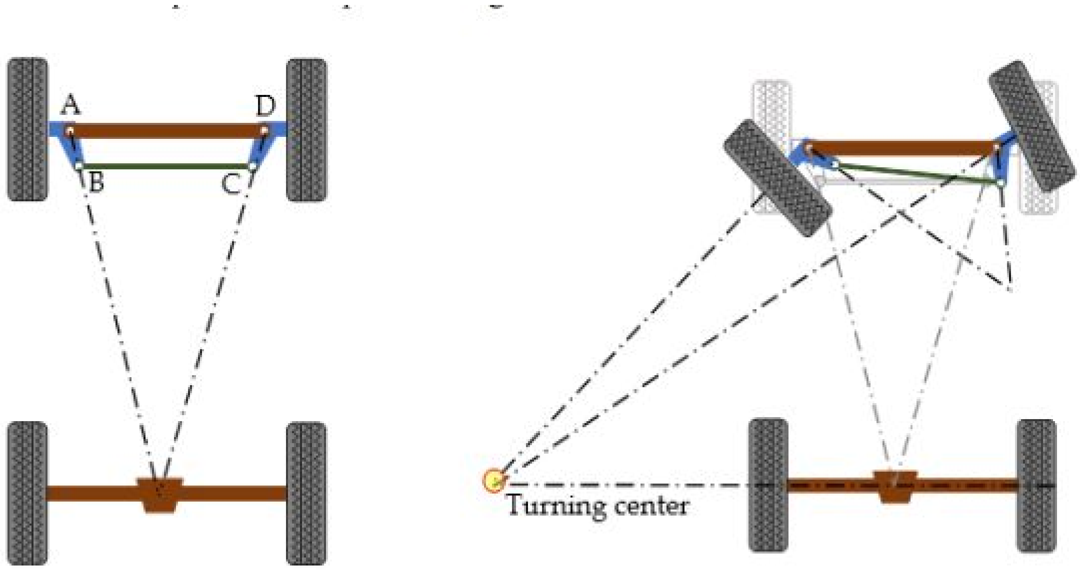




4.6 Ackerman steering geometry

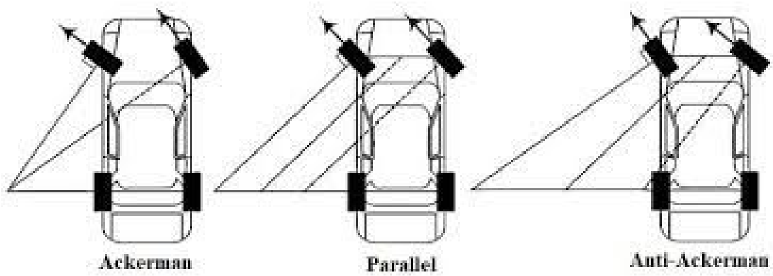


When cornering, the two front wheels clearly follow two different paths of different radii. This means for the wheels to follow the cornering path exactly the inside tire has to turn more than the outside.



This can be achieved by having the tie rod ball joints intersect the centre of the rear axle.

An anti-ackerman geometry can also be achieved where the outside wheels turn more than the inside. This can be useful for tracks with sharp corner as the outside wheels get an increase in slip angle and therefore an increase in grip.



4.7 Instantaneous Centre and Roll Centre

The instantaneous centre is the point at which an independent suspension tends to arc about. It is of use to the designer of the geometry when describing other geometric parameters. The Instantaneous centre is where you could place one long linkage to replicate the motion of two shorter links. Essentially, it is the point the suspension arms arc about.

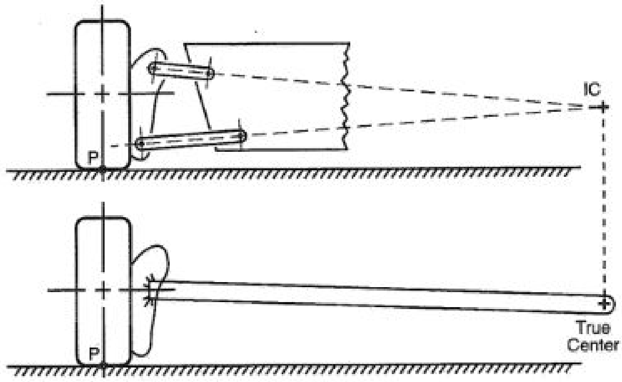
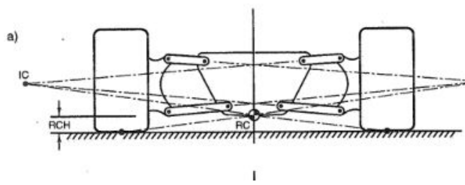
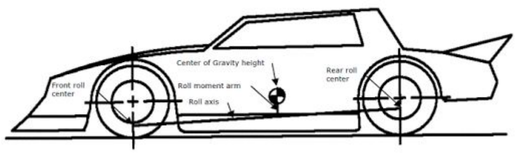


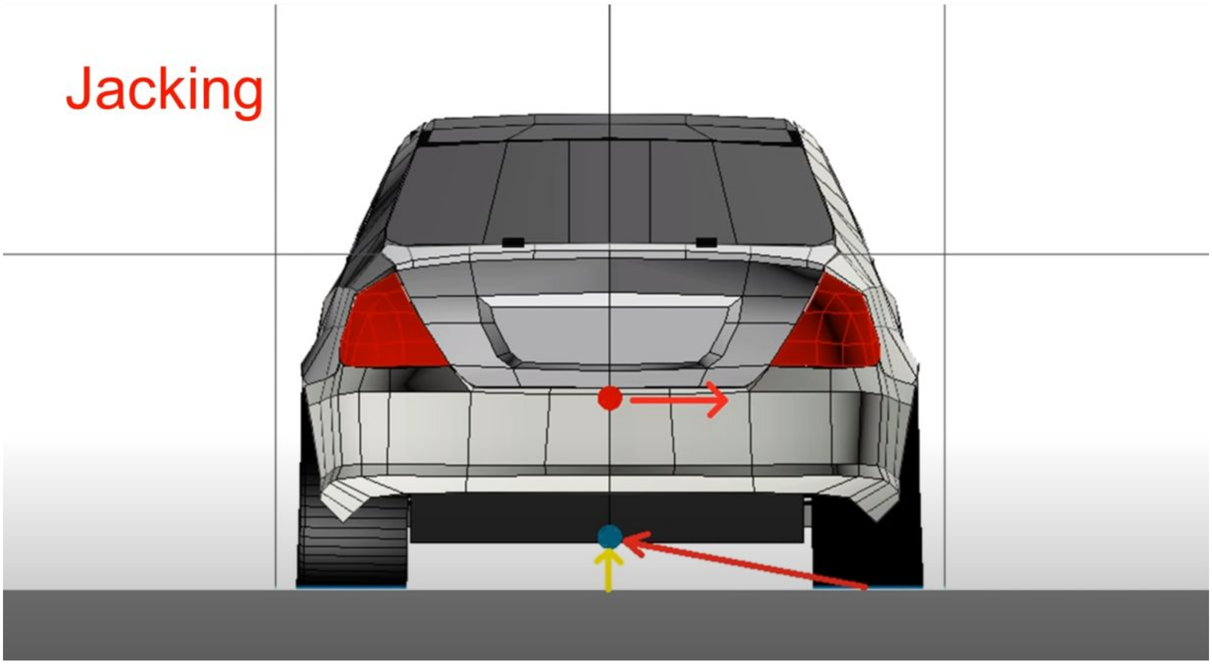
Figure 17.5 Instant center concept.

Roll Centre is found through the intersection of lines to the instant centre and tire contact patch lines. It is a virtual pivot point about which the car rolls. The intersection of the front and rear roll centres provide the roll axis.



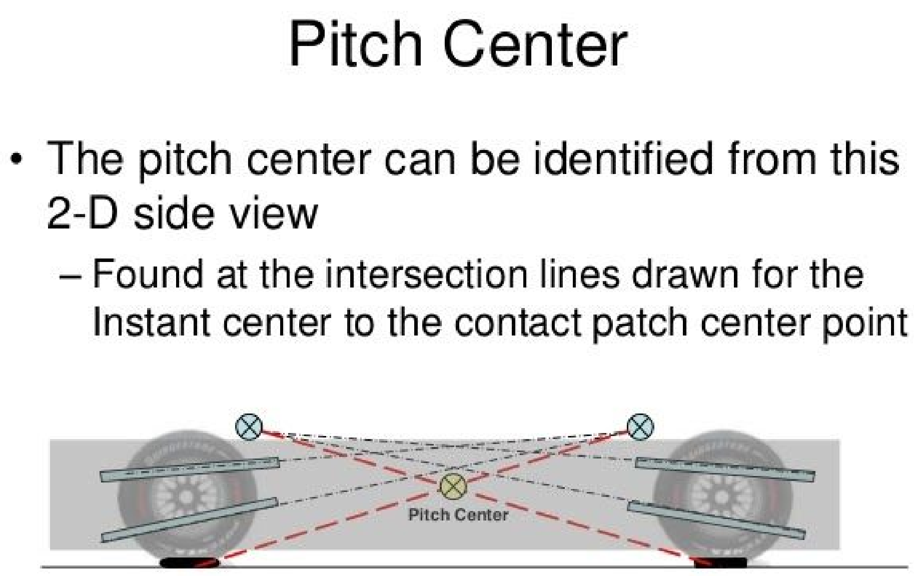


The height of the roll center with respect to the centre of gravity causes a moment arm which makes the car roll. Therefore if the roll axis went trough the CG the body wouldn't roll, however as you increase the roll centre height the higher the vertical component of the lateral acceleration, which created a ‘jacking’ force.



It should be noted that the roll centre moves as the body rolls and is not static.
https://www.paradigmshiftracing.com/racing-basics/how-karts-work-part-1-a-three-wheeled-vehicle#/ - good article on jacking forces for solid rear axle cars.

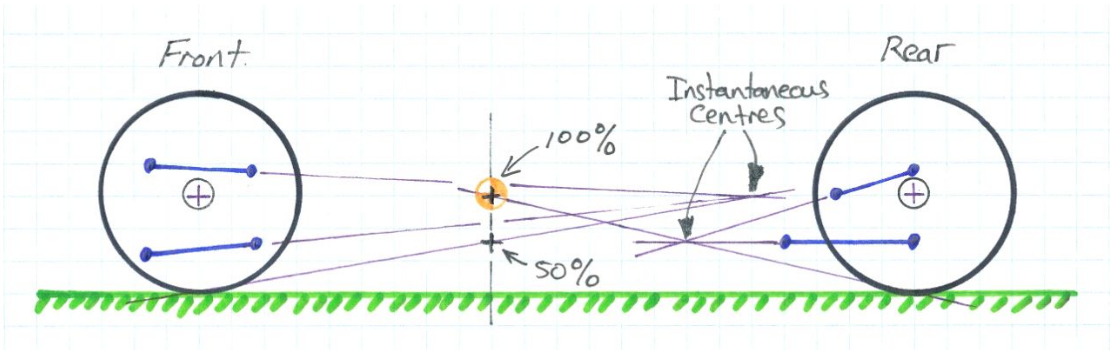
4.7 Pitch Centre



Pitch centre is essentially the roll centre in side view. It is a virtual pivot point at which the vehicle will pitch due to acceleration and braking.

4.8 Anti dive and anti squat

Anti dive and squat geometry is techniques used to decrease the pitch. This is similar to jacking and roll center heights. Depending on where the side view instant centres intersect the line corresponding to the centre of gravity a certain percentage of anti dive or squat can be achieved. As the anti dive or squat is increased from 0-100%, more of the pitching force is reacted in the suspension members rather than the springs of the suspension. Eg at 100% anti lift/squat all the forces are reacted by the suspension members and at 0% all the force is reacted by the suspension springs. This is generally used on aerodynamic vehicles to maintain certain ride heights as downforce is increased. As anti dive/squat is increase, the stiffer the suspension becomes.



B - Geometry Part 2 - Optimization

Probably the biggest part of suspension is designing the geometry. Usually teams would spend a good few months getting this area right to set up every other department nicely.

4.9 Packaging

The first step is figuring out how much space you have. This step by step guide is listed in the suspension geometry section of RCVD so I won't list it all, but essentially what you do is establish your rim size, establish how much room the brake caliper needs, and this locates your lower ball joint. If working on the front you must compromise between scrub radius and KPI which locates the line for your upper ball joint, and the upward position is located by space in your rim.

It's a good idea to draw these diagrams in solidworks and rotate about the IC to make sure the lower/upper ball joints don’t hit the rim in full bump or droop which brings me to the next point.

4.10 Line diagrams

Next it's a good idea to start drawing your FVSA and RVSA diagrams with your tires and rims in. Depending on whether you have roll centre height requirements or KPi and scrub, you will have to move around some points. Please look at the rules for front and make sure front A arms don't get too long. Also leave the drivetrain some room at the rear. This will give you ball joint locations in Z and y locations. Now move to a SVSA diagram and set caster requirements for front and package rear in however you see fit. These will give you X locations for ball joints. These are ready to be put into software for optimization. - https://youtu.be/Ip4tPTes43E

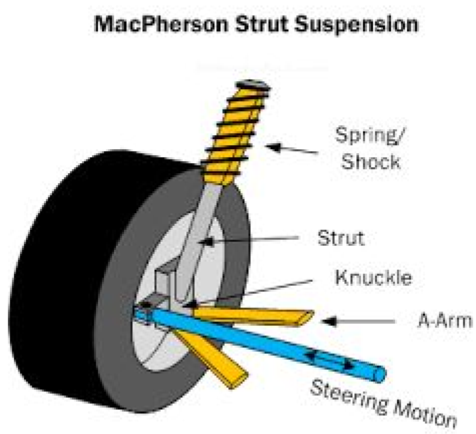
4.11 Optimization

This is a long process but to summarise you want to compromise between packaging, roll centre migration, camber curves and then very lastly tune bump steer. There is a debate on whether roll centre movement is relevant so I would read up on that. There are lots of resources on drive and tune to win also has a great section on this.

5. Suspension Types

5.1 Mac Pherson Strut

This suspension is used on most production cars because it's cost and space effective. The spring/shock is mounted directly to the chassis and also acts as an 'infinitely long upper control arm' since it moves linearly. Essentially the spring is the upper control arm. This isn't a very adjustable suspension.



5.2 SLA suspensions

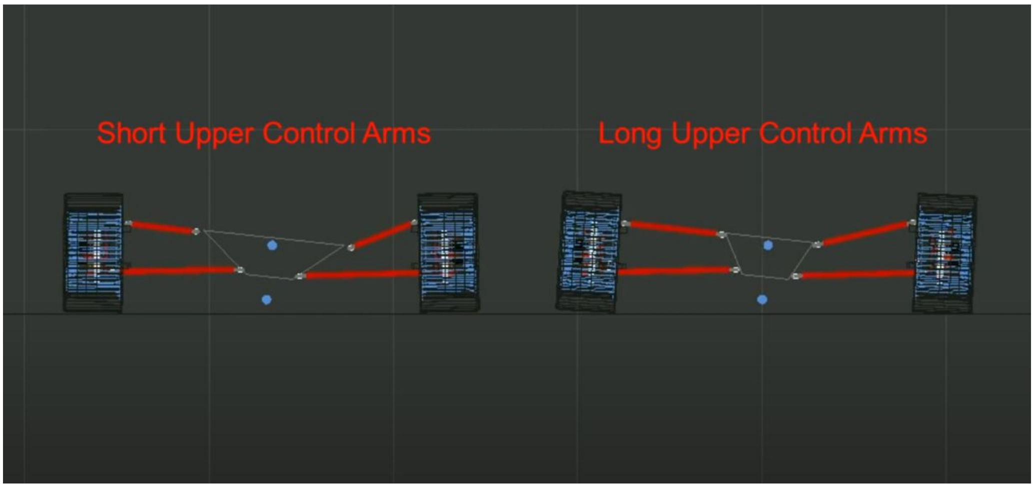
This family of suspension is most commonly used in racing. It is highly adjustable, easy to optimize and is an intelligent design. It is made from two A-arms, that are used only in tension and compression to constrain the 5 degrees of freedom necessary to build an independent suspension.

SLA stands for short long arms suspension referring to the length of the control arms/A arms/ wishbones (different names). To explain why use a shorter top control arm than the bottom we must explain what happens during pitch and roll with control arm length.

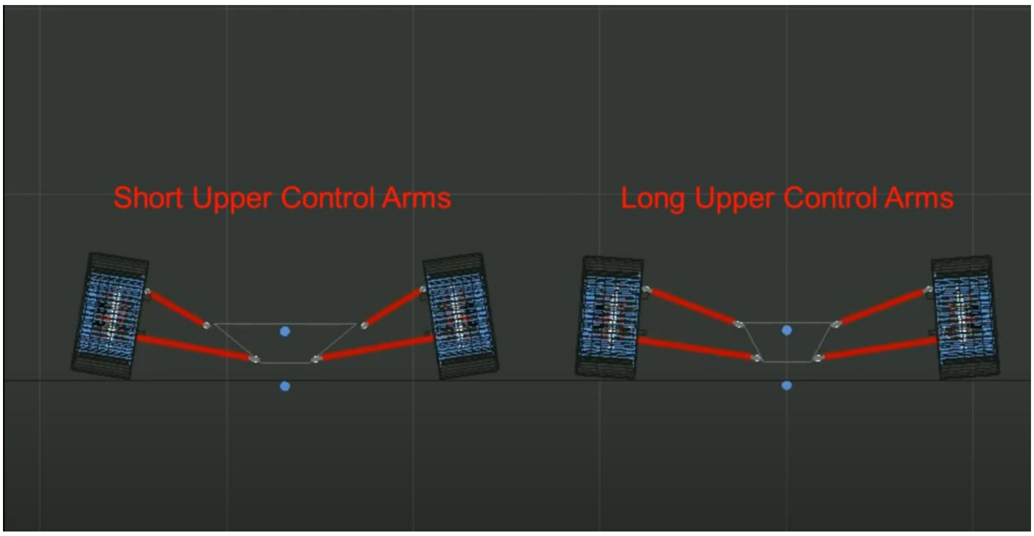
As can be seen from the picture below, with short upper control arms as we roll, we do not lose a lot of cambe when we corner, however with longer upper control arms we lose more camber. However when we pitch up or down with a short upper control arm we lose a lot of camber whilst with long upper control arms we don’t.

It's important to find a good compromise between a long and short upper control arm, however in racing a somewhat shorter control arm can be used as we know we will not be travelling in pitch (eg bumps and dips in road) than in roll.

Roll



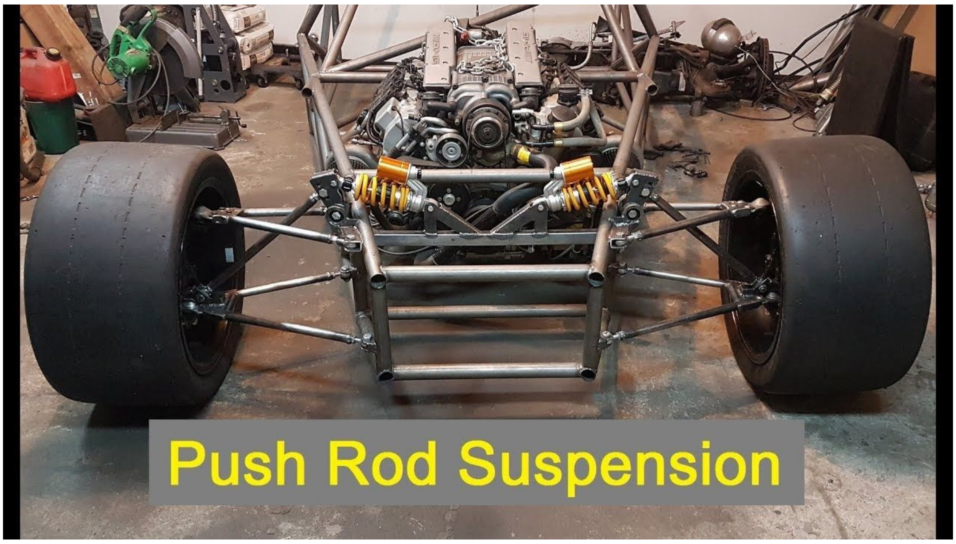
Pitch



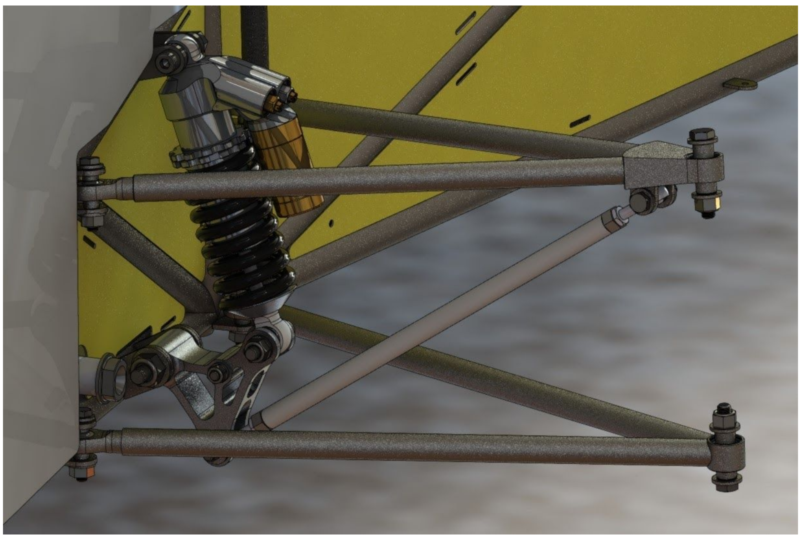
5.2.1 Push rod

The springs and dampers in SLA suspensions are actuated in many different ways. One of the most common is called a push rod suspension. A push rod is connected to the lower control arm. As the wheel moves up, the rod pushes the bell crank about a pivot to actuate the suspension.

An advantage of this over another suspension is that anti roll bar design is made easy and that the springs and bars are easy to access for tuning. Also the push rod can be at a greater angle which can allow for more flexible adjustments to the motion ratio.

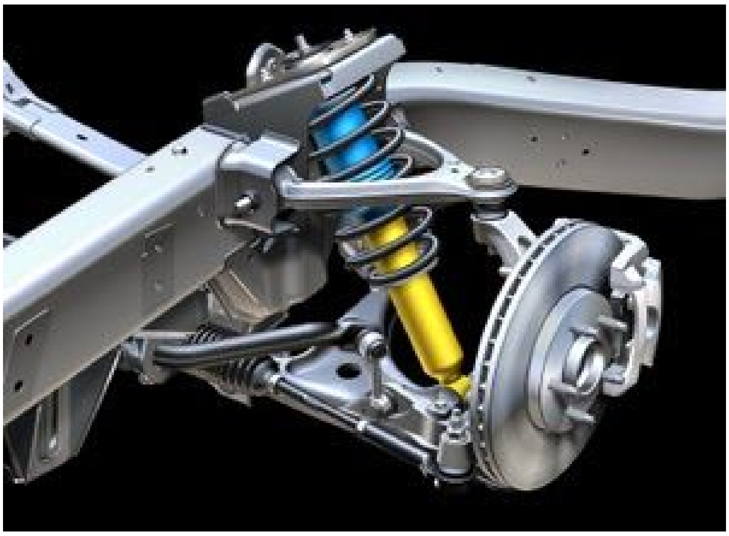


5.2.3 Pull rod



A pull rod suspension is exactly the same as a push rod suspension just flipped upside down. This will provide a lower CG as an advantage but disadvantages include hard anti roll bar integration in terms of fsae. Also the push rod previously used to act as a structural member holding some of the weight of the chassis. This is not the case in the pull rod suspension, which means the upper control arm has more load in it and usually has to be made bigger. Note in the picture above that the pull rod acts in tension as the wheel moves up.

5.2.3 Direct acting suspension



In a direct acting suspension there is no rocker attached to the suspension. The spring & damper assembly acts as a pushrod and attached directly to the chassis. This will provide the lowest weight and unsprung weight out of all the SLA suspensions. Disadvantages include it being hard to change motion ratios, more aerodynamic drag, and in the case of open wheeled cars, hard to mount anti roll bars.

For FSAE this is probably the best design as there is not enough velocity to cause enough drag and also the anti roll bars require either an innovative solution or not running anti roll bars and relying on spring rates alone to resist lateral acceleration. If a team has an existing car, it could be very possible to alter spring rates to counter u/s or o/s, though never without one.

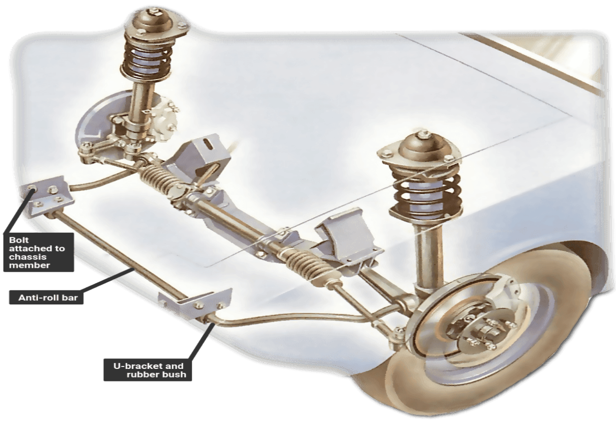
6. Anti-roll bars (ARBs)

An anti-roll bar or ARB (can also be called sway bars) is part of a formula car's suspension that helps to reduce the body roll during fast cornering or over bumps in the road. It connects opposite wheels together through short lever arms linked by a torsion spring. The addition of front and rear ARMS to the car will ensure faster and more stable cornering speeds and also will aid the car in staying upright during the daunting 60 degree tilt test part of the competition.

6.1 Principles of Anti-roll bars

The primary purpose of an ARB is to force each side of the vehicle to lower, or rise to similar heights, thus reducing the sideways roll of the car. This aids the car significantly when cornering. The ARB will work to force the opposite wheels' damper and spring to lower, or irse to a similar level as the other wheel. This will result in the car hugging the road more when cornering.

An ARB is a torsion spring that resists body roll motions. It is constructed out of a cylindrical steel bar (Aluminium is common choice) into a “U” shape. There are several variations of the standard U shaped bar however, they all follow the same basic design principles. The bar connects to the body of the vehicle at two points and at the left/right side of the suspension, at the rocker.



If the left and right wheels move together, the bar rotates about its mounting points. If the wheels move reactive to each other the bar is subjected to torsion and force to twist. Each end of the bar is connected to an end link through a flexible joint. The ARB end link connects to a point near the wheel, thugs transferring forces from the heavily loaded wheel/axle to the other side.

6.2 Adjustable Anti-roll bars

Adjustable ARBs allow the stiffness to be altered. This is an ideal feature of a Formula student car as the stiffness can be adjusted to suit each event. This is primarily done by increasing or reducing the lever arm of the system (see image below). This lever arm will connect to the vehicle at the rocker.

6.3 Video explaining the effects an ARB upgrade has on a sports car
https://www.youtube.com/watch?v=_uhxO4jvv2Y&t=62s

7. Springs

Coil springs are crucial components in a car's suspension system. Made from strong metal, a coil spring compresses itself to absorb the shock caused by bumps in the road as you drive along. In a Formula car, a spring is used in tandem with the shock absorber/damper to dictate the ride of the vehicle. A softer spring ensures more comfort for the driver however, it also means slower cornering and more body roll. As a result, a stiffer spring is often used in a formula vehicle to improve handling and prevent body roll. Stiffer springs will also assist with the tilt test.

7.1 Spring Rate

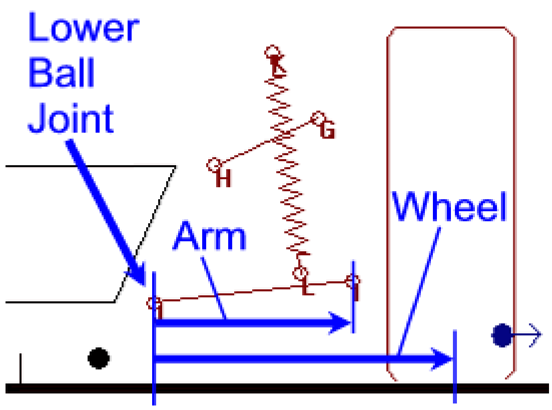
Spring rate refers to the amount of weight that is needed to compress a spring one inch. If the rate of the spring is linear, its rate is not affected by the load that is put on the spring. For example, say you have a 200 lb. per inch spring - it will compress 1” when a 200 lb load is applied to the spring. Springs more often than not are sold in the lbs/inch format so must be converted to N/mm when making calculations.

7.2 Motion Ratio

The displacement ratio between the spring and the wheel determines the actual rate the wheel works against for any spring rate. This displacement ratio is defined as the motion ratio. The rate at the wheel is defined as the wheel rate, the rate of the spring as we know is the spring rate. The displacement relationship is a function of both spring position on the load carrying member and the angular orientation of the spring to that member.

7.3 Wheel Rate

Wheel Rate is basically the Spring Rate but measured at the wheel instead of the where the spring attaches to the linkage. The figure to the right shows how wheel rate is determined. It is basically the Spring Rate multiplied by the motion ratio squared.



$$\text{Motion Ratio} = \frac{\text{Arm Length}}{\text{Wheel Length}}$$

7.4 Ride Rate

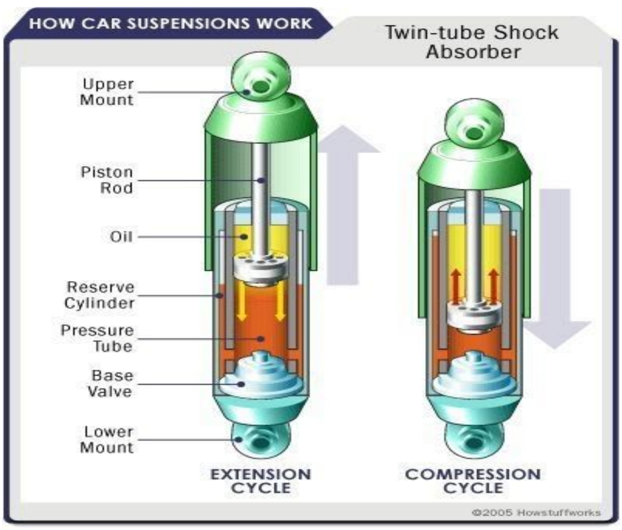
Ride rate is vertical force per unit displacement of the tires' ground contact reference point relative to the chassis. This is equal to the wheel center rate modified by the tire vertical rate

7.5 Springs video

https://www.youtube.com/watch?v=KOjD6NnZ9gQ&t=112s

8. Dampers

Dampers - commonly called shock absorbers - perform this function. A damper has a piston which moves inside a sealed, oil-filled cylinder with the up-and-down movement of the wheel.There are narrow control passages and one-way valves in the piston, which allow oil to flow through it from one chamber to another - but only very slowly.This action slows down the spring oscillations and returns the car to a level ride.



There are three types of damper. Telescopic dampers look like telescopes and shorten in the same way. One end is bolted to the axle , the other to the body. Strut inserts are similar, but are designed to fit inside a MacPherson strut (See Renewing MacPherson-strut inserts). Lever-arm dampers resemble hydraulic door closers. The damper, which contains one or two pistons, is fixed to the car body or frame, and a pivoted lever extends from it to the axle.

8.1 Damping ratio

See link for full explanation on Damping ratios:
http://www.kaztechnologies.com/wp-content/uploads/2014/03/A-Guide-To-Your-Dampers-Chapter-from-FSAE-Book-by-Jim-Kasprzak.pdf

8.2 High/Low speed Damping

Separate high and low speed controls typically use the velocity of the main piston (which is what's pushing the oil through the circuits) to determine where the oil volume can pass the various ports inside the shock.

Low speed compressions happen when you're pressing down on the shock, like when the driver sits into the vehicle, Or when you're riding over gradual bumps and inclines. The shock is simply absorbing your weight against gravity in a slow, controlled manner.

High speed compressions happen when you hit a stone or sudden bump and the shock has to compress quickly to absorb the abrupt impact. When this happens, the oil flows very quickly and with enough force to bypass the low speed circuit. Most shocks design the low speed circuit to get out of the way, or provide alternate flow paths for the oil to go around it during high speed compressions.

8.3 Compression vs Rebound Damping

Compression damping helps the suspension absorb bumps or road irregularity as the wheel moves upward in the stroke. Rebound damping helps the suspension return to the proper position, after a bump or other irregularity causes the fork to compress, in a smooth and controlled motion. Too rapid of a movement or too slow of a reaction will cause the car to handle poorly.

Typically Dampers come with an adjustment part whereupon the rate of compression vs rebound damping can be adjusted to suit the terrain which the car will be travelling over.

8.4 Tuning for Oversteer vs Understeer

SEE video: https://www.youtube.com/watch?v=yYxmuCSkePM

9. A arms

A arms or otherwise known as wishbones or control arms are the structural components that connect the upright to the chassis.
A arms only act in tension and compression.

9.1 Avoiding REIB

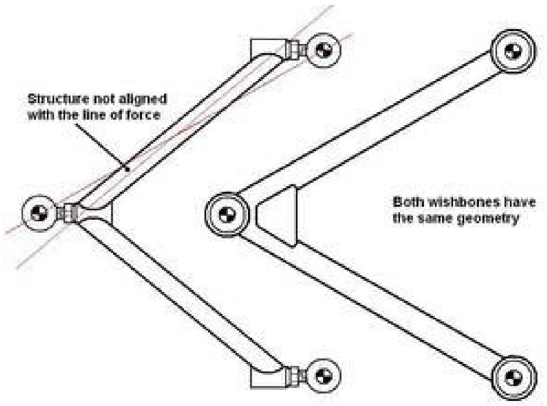
This is essentially all that A arm design is concerned with - how to build them whilst keeping the forces only in tension and compression.

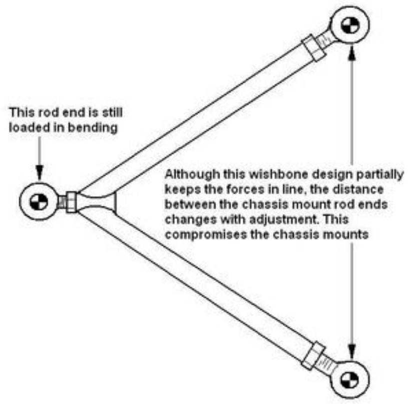
Judges also absolutely hate 'Rod ends in bending'. There are many ways to get around rod ends in bending but almost all of them use a spherical bearing at the upright ball joint instead of a threaded rod end.

Placing a spherical bearing at the out most point will ensure the forces only act in only in compression or tension. The two inboard points can used threaded rod ends or spherical rod ends but the outboard point has to use a spherical bearing in order to keep the forces in line. It tends to be hard to attach the spherical bearing as it has no shaft.

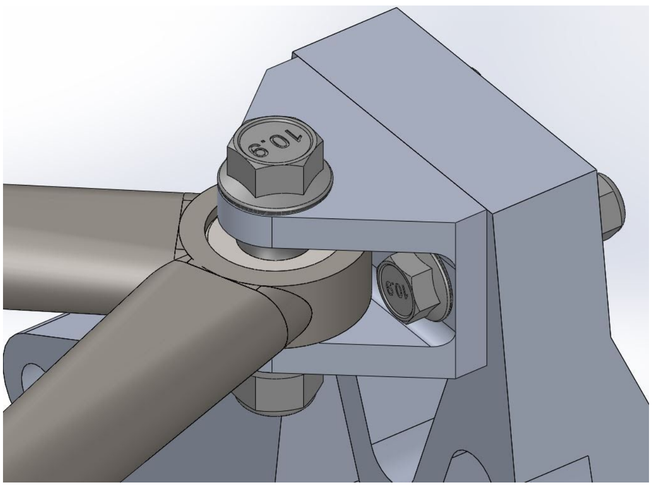
Spherical bearing

Threaded Rod end





This is a rod end in bending. Note where the centreline of the A arms intersect.



Using a spherical bearing will solve this issue, however this is hard to manufacture. The A arms above may need to be crimped and milled in a fish mouth shape in order to weld it to the bearing cup.

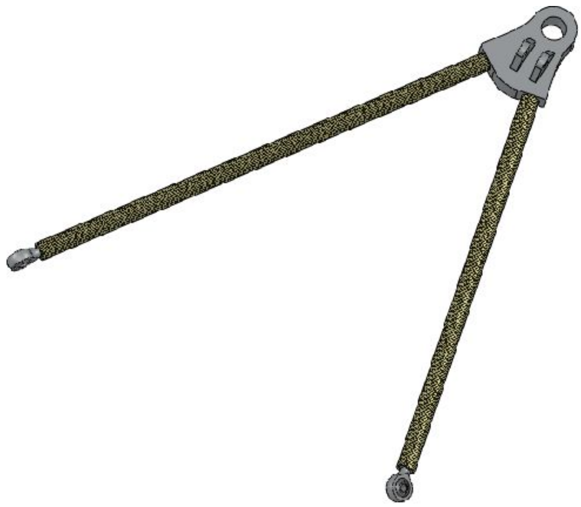
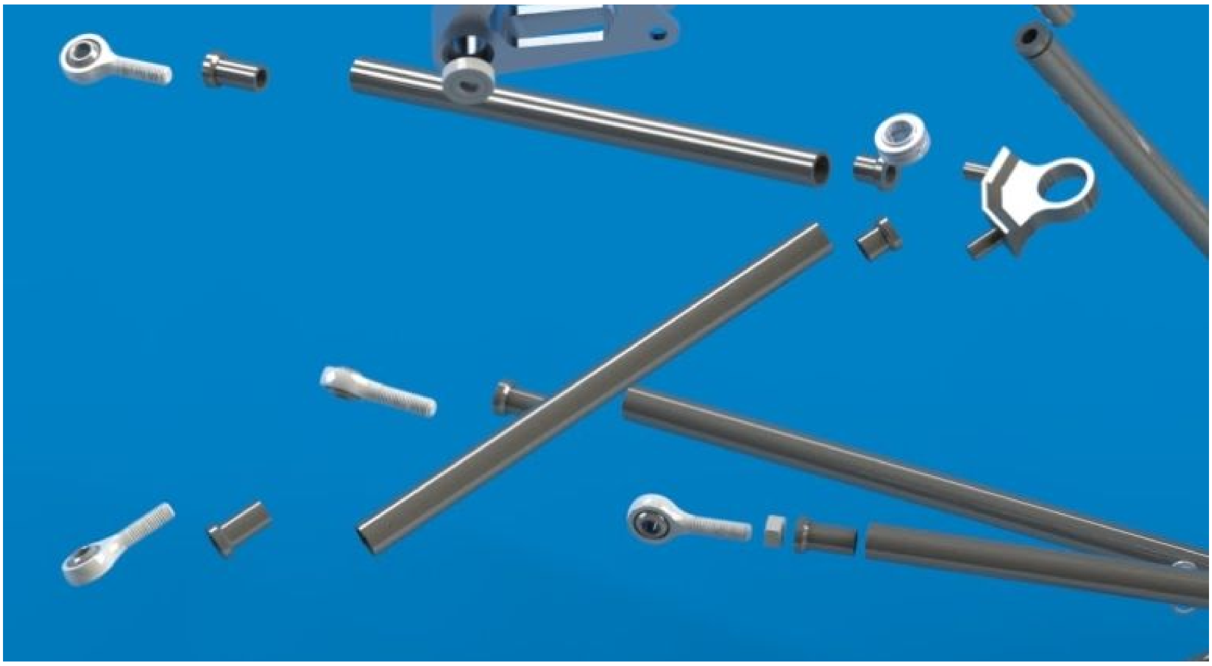


Figure 9: Lower A-arm Design

However sometimes a small CNC part is used to mount the bearing and arms together. In this case carbon fibre rods are used and binded to the cnc part using a poxy. If metal arms were used, a small bushing with threads can be manufactured and used to attach.



2019 design

9.2 Buckling

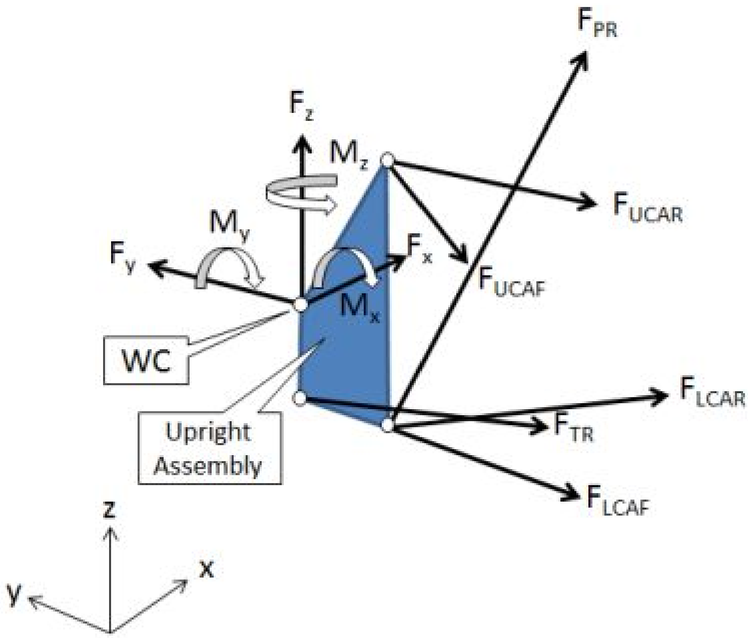
Buckling calculations must be carried out to determine the size of the tubes.

Equation (2.6). The recommend the end-condition constant for a fixed-pinned (or fixed-rounded as labeled in the reference) is $C = 1.2$ [10]. Using this constant, the critical load for a fixed-pinned member, given by Equation (2.7), becomes

$$P_{cr} = \frac{C\pi^2 EI}{l^2} = \frac{1.2\pi^2 EI}{l^2}, \qquad (2.7)$$

where C is the end-condition constant and the fixed-pinned value of 1.2 has been substituted into Equation (2.7). This calculation is what has been used by the VT-FSAE team to calculate critical loads for buckling for each of the suspension members in the control arms.

With this recommended end condition for the euler buckling equation the forces in the tubes have to be estimated.



A linear system of equations can be solved using Ax = B with 6 equations and 6 unknowns. I have put an excel sheet with these calculations in resources on drive.

9.3 Materials

Any material that is light and has strong tensile strength is suitable for making A Arms. A very common material is 4130 chrome alloy steel for its strong tensile properties, however it has to be tig welded which is expensive.

In my experience of designing A arms, using the material chassis use is a good option, but obviously with thinner tubes. If this is not a viable option, a structural steel (low carbon) option could also suffice if research is done into it. This can be Mig welded. T45 steel is a good well rounded option for A arms as it is very similar property wise to 4130 alloy but can be Mig welded.

9.4 Jigs

A jig is simply a method of holding things in place accurately while welding. Before construction of the A arms, a plan in terms of welding should be established. If in house welding is being used, a jig **MUST** be used to weld the control arms and any other components. If manufacturing is being outsourced the welder may choose to design their own jig or ask to have one made.

Depending on the design of the control arms, a jig can be constructed from wood or sheet metal.

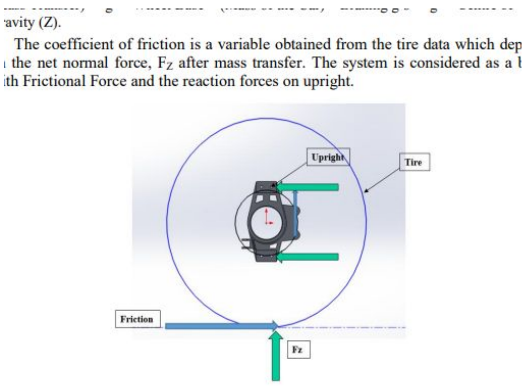
10. Uprights

10.1 Assembly overview

The parts of the above design that belong to suspension include the bearings which are bought, the upright which we design, and tires/rims. We will also be concerned with fitting the bearings into the uprights which can be done using circlips or by press fitting. The rest belong to ergonomics. - https://youtu.be/4u4ainhZvBA

10.2 Forces

There are many resources available on drive for exact calculations of loads in the uprights but essentially it is a statics problem. All the forces in a car originate at the contact patch and are reacted by inboard components. If we draw a free body diagram of the loads on an upright we can simplify the loads to the normal component, lateral component and longitudinal component. Note that the 'worst case scenario' for the load transfer is braking and cornering. Also note that dynamic loads will always be higher than the static analysis.


avity (Z).

The coefficient of friction is a variable obtained from the tire data which dep
the net normal force, F_Z after mass transfer. The system is considered as a l
ith Frictional Force and the reaction forces on upright.

Figure 1 FBD during Braking (Side View)

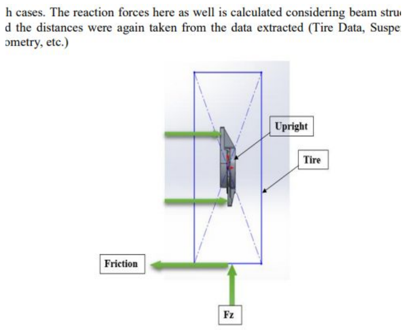

h cases. The reaction forces here as well is calculated considering beam stru
d the distances were again taken from the data extracted (Tire Data, Suspe
ometry, etc.)

Figure 2 FBD during cornering (Front View)

> So establish the degrees of freedom at each joint, and then do a simple vector analysis to figure out the forces that result. The limits of the forces will mostly be a function of the instantaneous traction produced at the tire contact patch. The transient dynamic loads will be higher than static loads, so be sure to use a conservative factor of safety. Also, be sure to account for any joint frictions in your analysis.

10.3 FEA model

There are several different ways to model the upright as an FEA model. It depends on how you want to model the forces coming from the contact patch being reacted in the upright. Since it is a 'model' there is no right way. Also hand calculations will always be more accurate than FEA. However if FEA is employed properly it can be a useful tool to lower the weight in areas where it is not necessary.