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CARS SUSPENSION GEOMETRY - MAIN PARAMETERS

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Abstract: *When it comes to design suspension geometry from scratch, you need to understand every suspension parameter influence to get a good result. Once understood, the design process begins by choosing target values to get to the expected behavior. After the design process comes the validation step to check suspension parameters variations with suspension motions. All these steps of the design process are explained in a small set of articles starting with this one: suspension parameters.*

Keywords: *Design, Suspension Design, Automotive engineering, Double wishbone suspension*

INTRODUCTION

Suspension is a really important system as it is responsible of the handling, the safety and the comfort of a car. It is also a really complex system as there are lots of different parameters to take in account. Each parameter has an influence on a certain driving situation (cornering, braking, over bumps …) that will define the final handling of the car. The designer role is to create a solution that makes all parameters working together without one influencing another (except if being wanted and under control). These articles will first define the different important suspension parameters and their influence on the car behavior. Then will be explained the whole conception process to see step by step which parameters are defined. Finally, we will show the checking and validation of the suspension geometry using 3D CAD software via SolidWorks.

SUMMARY

This article has the aim of showing an overview of the main suspension parameters to take in account in the design process. Each parameter will be explained and linked to his influence on the car behavior. In addition, general magnitude set-up values will be shared to quantify these parameters according to applied on road or racing cars.

A. Car parameters:

Before going any further in explanations, it is important to set the spatial car referential and the different possible

Wheelbase: Horizontal distance between the front and rear wheel centers. Wheelbase influences longitudinal stability. Long wheelbase gives more stability and comfort (pitch diminution) and short wheelbase helps on cornering reactivity. Wheelbase is also important for defining the spaciousness of the car.

Track: Horizontal distance between left and right wheel centers. Larger the track is, better will be cornering performances (roll and lateral load transfer diminution).

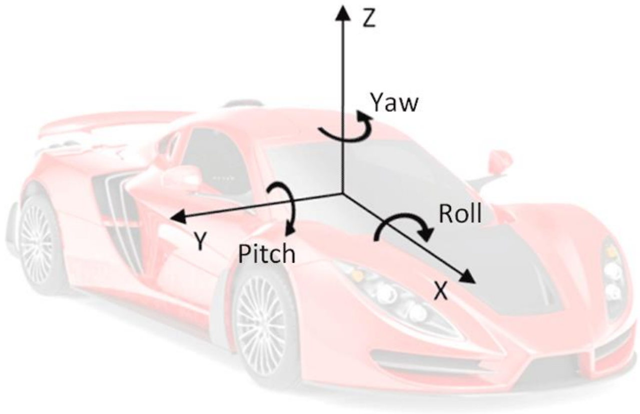

Figure 1: Car referential

B. Suspension generals

For road cars, the suspension is made for guiding the vehicle and filtering road irregularities. Guiding the vehicle is not only meaning allowing him to turn. It also includes providing safety (safe behavior in case of sudden braking/steering input) and good driving feeling (steering force feedback, direction holding, inclined road sensitivity, acceleration/braking stability…). Suspensions are also designed to filter road irregularities to get a comfortable car by reducing noise and vibrations.

For racing cars, the main purpose is to get the maximum performance out of the tires. The suspension also needs to ensure wide set-up possibilities as well as fast and easy set up changes. The comfort factor is not taken into consideration.

To achieve these goals, there are different technologies used like: Mc Pherson suspension, double wishbone suspension, multi-link suspension, dependent suspension, torsion beam suspension.

As the article will focus and take examples from double wishbones suspension, here are a few links to get information about the other systems.

https://www.autodeal.com.ph/articles/car-features/beginners-guide-car-suspension-types-and-why-they-matter

https://www.caranddriver.com/news/a15340751/explained-the-five-most-common-automotive-suspensions/

C. Technology: Double wishbone

As said before, suspension goals are to guide the vehicle, filter road irregularities and optimize tire performances for race cars. In order to do it, suspensions systems needs to link the chassis and the wheels. Before being linked to the chassis, the wheel is considered free (3 translations and 3 rotations). At the end, we want the wheel to have a vertical translation to move over bumps and roll and a rotation around vertical axis for the front wheels to be able to make the vehicle turn. In order to get to it, two wishbones are connecting the upright to the chassis. Each wishbone has got 2 connecting points on the chassis and one on the upright. These connections can be ball-joints or bushings but are cinematically considered as ball-joint. With this assembly, each wheel has now only one vertical translation and one rotation around the vertical axis. It is the result wanted for the front axle; we add a rod linking the upright to the steering rack to allow the driver to master the rotation of the front wheels. This rod is called a “tie rod”. At the rear, we need to lock the rotation. A rod will be linked to the chassis to lock the rotation of the wheel.

In addition to locking the rotation, this rod can be lengthened or shortened to adjust the toe parameter which led his name: “toe-control arm”.

This suspension technology is omnipresent in motorsport as it allows a lot of set up possibilities.

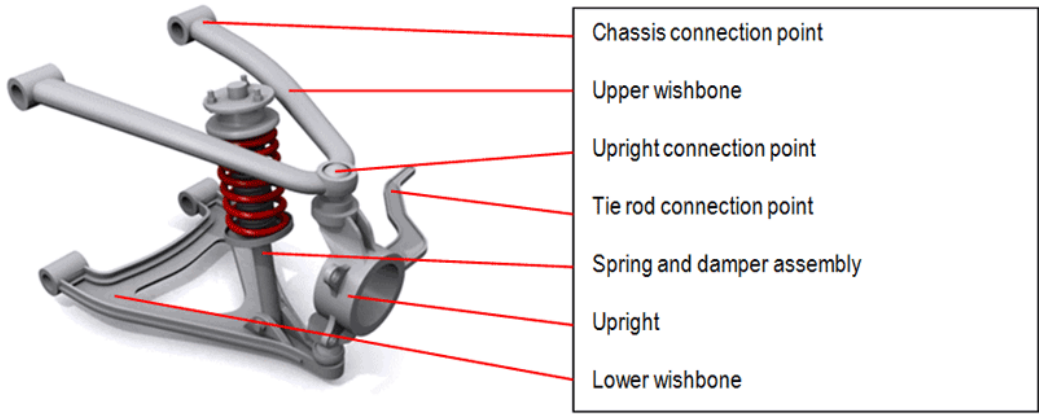

Figure 2: Double wishbone suspension composition

D. Suspension parameters

Camber angle: Inclination of the wheel median plane relative to the XZ plane of the car, seen from YZ plane. It is called "positive" camber when the upper part of the wheel points out of the car and "negative" when the upper part of the wheel points in. Both roads and racing cars are generally set with negative camber to optimize cornering stability. The difference is the value of the camber angle: for road car it is generally between 0° and -1.5°, for racing cars it is more between -2° and -5°. These are static values that change over bumps and under roll with suspension travel. This phenomenon is called "camber gain" and needs to be taken in consideration during the design process. This is why the static values are negative. As a car takes roll on a corner, the outer wheel camber will tend to a positive value. Having a negative initial value permits to get close to a neutral value on the outer wheel while cornering and optimize tire contact patch. Having a "wider" tire contact patch gives more grip, and more grip means more stability and performance.

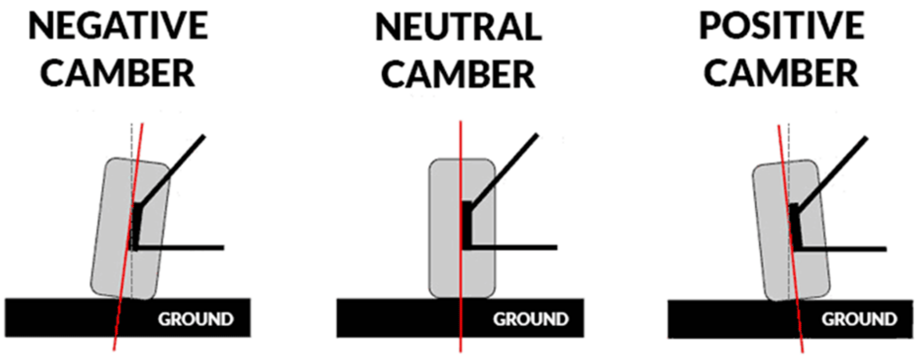

Figure 3: Different camber angle cases

For racing, you adapt the camber value according to the track. For example, having a big camber angle will be good for fast corners but will cause the inner part of the tire to wear more on straight. All is about compromise. The perfect value will be found at the track while testing. The goal is to get a tire temperature that is nearly equal in the inner, middle and outer side of the tread. A usual difference accorded between inner and outer tire temperature is around ±10°C.

TOE: Inclination of the wheel median plane relative to the XZ plane of the car seen from XY plane. It is called "toe-out" when the front part of the wheel points out of the car and "toe-in" when the front part of the wheel points in. Both roads and racing cars are generally set with toe-out in the front axle and toe-in in the rear axle to generate an understeer tendency behavior. Like for the camber, these toe angles are related to a static position. The suspension design and especially the steering rack/tie rod position are influencing a lot toe variation under bumps and roll. Theses toe variations due to vertical wheel displacement are called "bump steering" phenomenon. This is a geometric phenomenon related to wishbones and tie rod lengths, positions, mounting points as well as steering rack position.

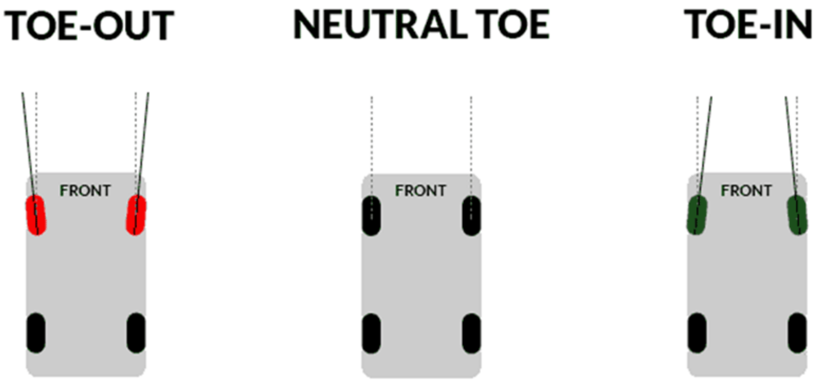

Figure 4: Different TOE angle cases

As for every suspension parameters, we want to avoid big values variations over bumps, under roll or during steering. It does not mean that the goal is zero variation but that each change under solicitation must be wanted and controlled. For bump steering, it is common to accentuate the static setting under compression to keep an understeering behavior. It generally means a slight increase of toe-out for the front axle and an increase of toe-in for the rear axle. There are some geometrical methods to get the right positions of wishbones and tie-rod to reduce or even nearly cancel bump steering. Most of the time, the wishbones position is already defined and you play with the tie rod length and position to match your bump steering expectations.

Caster angle: Inclination of the axis between top and lower ball-joint of the upright and vertical axis seen from the side of the car (XZ plane). It is called “positive” when the top of the axis is going toward the rear of the car and “negative” when pointing forward. First of all, caster angle in automotive applications is always positive. Negative caster angle would cause the steering wheel to roll up while turning which is not safe at all. This phenomenon is only happening went driving in reverse gear as the caster angle stays the same but the car is going in the other way, it becomes negative caster.

The caster angle influences the steering wheel force feedback and his ability to come back to neutral position. The more this angle is important; the easier the steering wheel will come back to his neutral position, but it will include a high force feedback. For road cars, caster angle is between 3° and 12° whereas from 2° to 5° for racing cars. The fact that the vehicle is equipped with power steering influences a lot the caster angle value. Caster angle has also a big influence on camber angle while steering as the rotation axis of the upright is not vertical. Taking the example of a left hand turn, the inner front wheel (left) will get some positive camber and the outer wheel (right) will get some negative camber. This phenomenon is useful as it allows the outer wheel to get negative camber while cornering. It can so compensate the positive camber change caused by roll on the corner. This phenomenon needs to be kept under control to avoid generating too much negative camber.

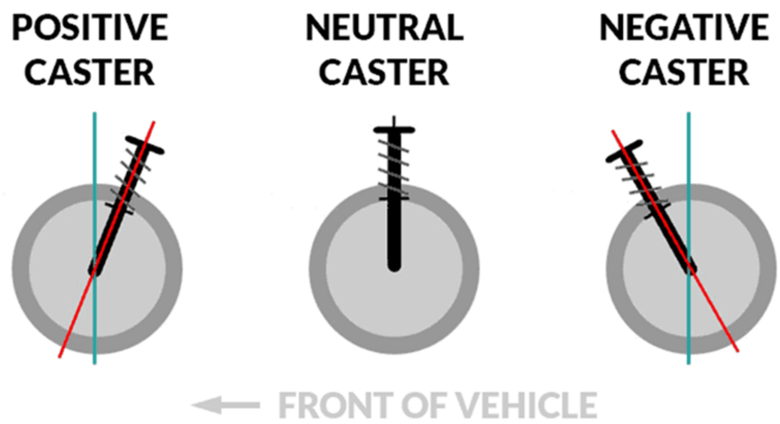

Figure 5: Different caster angle cases

Steering axis inclination (SAI): Also known as "king pin angle", this parameter is linked with the caster angle. It is also the inclination of the axis between top and lower ball-joint of the upright and vertical axis but seen from the front of the car (YZ plane). Do not confuse SAI with "included angle" which is the angle between the two upright ball-joints (like for caster and SAI) and the median plane of the wheel. It means that included angle is changing according to camber value.

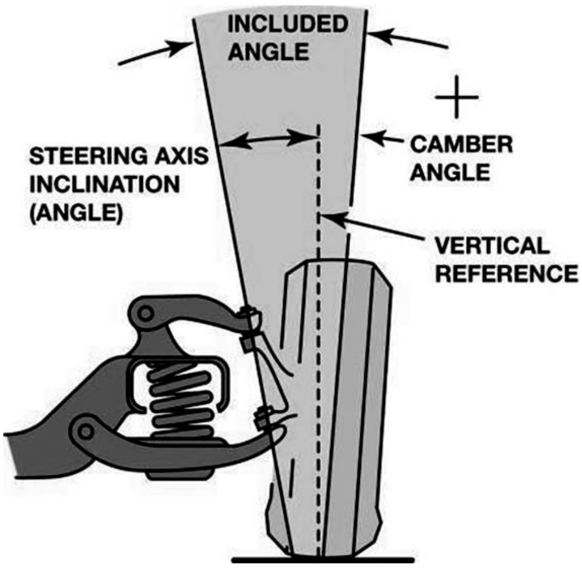

Figure 6: SAI and included angle modification

Like caster, SAI is always set in a unique direction, with the top of the axis pointing toward the inside of the car and it is called "positive". The value of this angle is generally between 9° and 13°. Like caster, SAI provide camber changes while steering but compared to caster influence, it is nearly insignificant. This angle is really important though because it introduces another parameter: scrub radius.

Scrub radius: This parameter is obtained by measuring the distance between the ground/SAI meeting point and the center of the tire contact patch. Like for SAI, the measure is taken looking the car in YZ plane. Scrub radius is called "positive" if the SAI/ground meeting point is between the car and the center of the tire contact patch. It is called "neutral" or "zero" when the points are meeting and "negative" if the SAI/ground meeting point is on the outer side of the tire median plane.

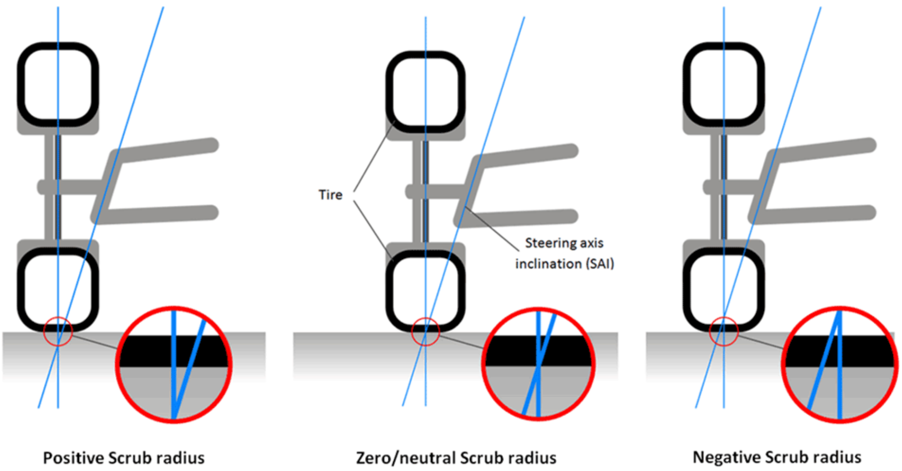

Figure 7: Different scrub radius cases

This parameter is the "lever arm" of longitudinal loads applied on tire base. In most of the case, a negative scrub radius will be chosen for the front axle. A negative front scrub radius gives steering stability on straights (steering auto- centring) and under braking. Having a negative front scrub radius will create a counter momentum in case of asymmetric tire loads and provide braking stability even with a grip difference between the two wheels.

The ability to create a counter momentum in case of asymmetrical tire loads can be used on rear wheel drive cars rear axle. The scrub radius is then set to be positive to generate more stability on acceleration.

In case of zero scrub radius, the tire torsion will generate an elastic steering feeling. The wheel will also tend to squirm under braking or acceleration generating a loose steering feedback. For these reasons, there is no interest in using zero scrub radius.

Roll centre: The roll centre represent for an axle his instant centre of rotation in relation to the ground. His position is defined using wishbones inclinations, the car mid plane and the centre of the tire contact patch in YZ plane. Firstly, extend until they cross the wishbones centrelines (materialized by ball-joints centres). This cross point is the instant centre of rotation of the wheel in relation to the chassis (point A). Then draw a line joining the centre of the tire contact patch and point A. The created line will then cross the mid plane of the car. The crossing point is the roll center of the car. Note that this is the roll centre location for a special position of the suspension and that it will move for every suspension movement. After defining the roll canter of each axle of the car, joining them create the roll axis. It is the axis around which the car will turn under roll.

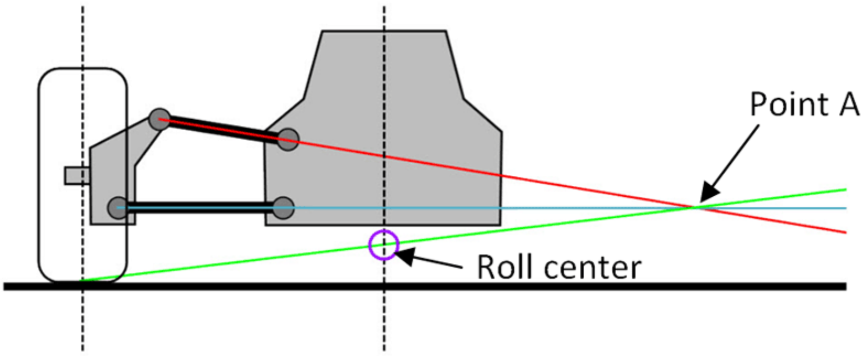

Figure 8: Roll centre position

Measuring the distance between the ground and the roll center gives you the roll center height. It is commonly agreed that the front roll center height is between 0mm and 50mm above the ground and between 50 mm and 100 mm for the rear axle. Once having roll center height, you can compare it to the center of mass height. If the center of mass is above the roll center the body roll will go towards the outside of the corner. If both centers are at the same height, the car will not get body-roll on the corners. However, not having body roll does not mean that there is no load transfer. The last case is when the roll center is above the center of gravity which is never the case in automotive sector. It would mean that the body-roll will go toward the inside of the corner, like a motorcycle.

Ackermann steering: This parameter is defining the way the front wheels are turning to get the best handling and the lowest tire slipping on corners. To make it happened, both four wheels needs to turn around the same instant center of rotation. For this reason, the front wheels needs to turn at a slightly different angle to get the same center of rotation (Ackermann case on the picture).

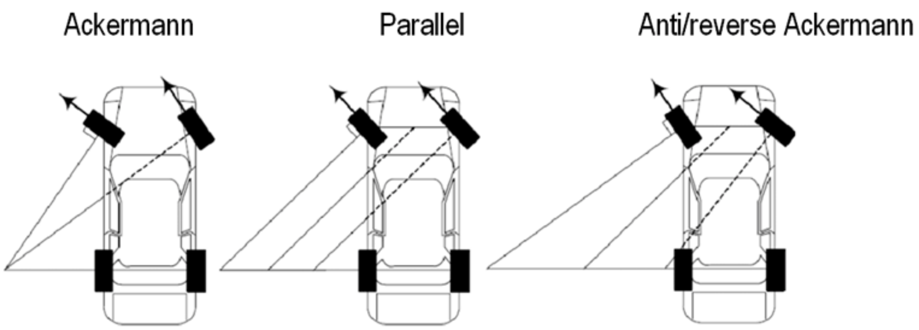

Figure 9: Different Ackermann steering cases

To define the different cases, we compare the angle difference between inside (β_i) and outside (β_o) front wheels trajectory perpendicular line. It is called "Ackerman" when $\beta_i > \beta_o$, "Parallel" when $\beta_i = \beta_o$ and "Anti" or "Reverse Ackermann" when $\beta_i < \beta_o$. There is a common method to create an Ackermann setting. Having the vehicle straight, lines formed by wishbone to upright pivots (ball joints) and tie-rod to upright pivot must cross the middle of the rear axle. As upright to wishbone pivots are usually defined first, Ackermann geometry is generally adapted with tie-rod to upright pivot position. Having the steering rack behind the front axle allows more flexibility for placing this pivot point. In case of a front mounted steering rack, the brake disc is limiting the space for placing correctly the tie-rod pivot point.

Reverse Ackermann is mostly used on racing cars. As load transfers are more important than road cars ones, the steering is mostly given by the outer wheel (more loaded). Setting reverse Ackermann permits to reduce the cornering radius of the car and to get more manoeuvrability.

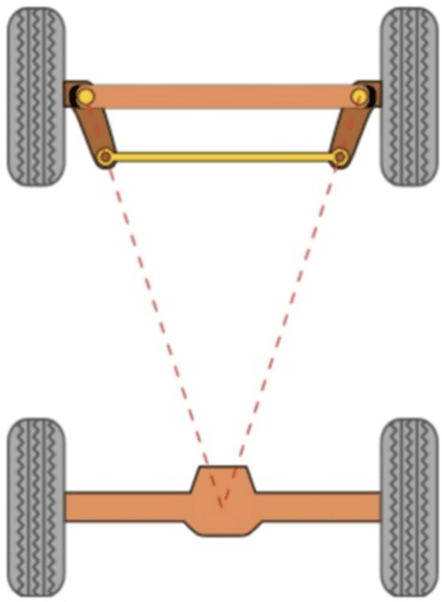

Figure 10: Tie rod connecting points position for Ackermann geometry

CONCLUSION

You now know a bit more about suspension parameters and the way they impact the vehicle behaviour. You are also able to choose target values for conception depending on whether you are designing a road or a race car. Keep in mind that these are only the general basics about each parameter and that explanations can be extended in a more scientific way. Also never forget that suspension geometry is designed to make the tire work at its best level and that the perfect set-up is achieved from a compromise between all parameters. Next step is now designing all suspension elements (defining size, mounting points, inclination…) to get to the target values you set. This will be the subject of the next article.

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