

The anti-antis

When it comes to longitudinal dynamics, many engineers consider front anti-dive and anti-lift, or rear anti-squat and anti-lift, as separate entities. Here's why that is the wrong approach

BY CLAUDE ROUELLE

Several years ago I remember experimenting with some vehicle dynamics software alongside one of my colleagues, and we were wondering how much higher we could keep the front edge of the splitter in the braking zone by increasing the anti-dive from 20 to 30 per cent, while all other car characteristics were kept the same. That included tyres, aero map, masses, their c of g position, their inertia, suspension kinematics, stiffness and damping, brake balance, brake inputs and subsequent deceleration.

The answer looked strange at first as, on average, the car was 2mm lower. 'But we just increased the anti-dive so, if anything, the front splitter should be higher,' we thought. Until my colleague noticed the rear had gone up 10mm more!

Reason being we had more pitch angle, and that is why the front splitter was lower, despite an increase in front anti-dive.

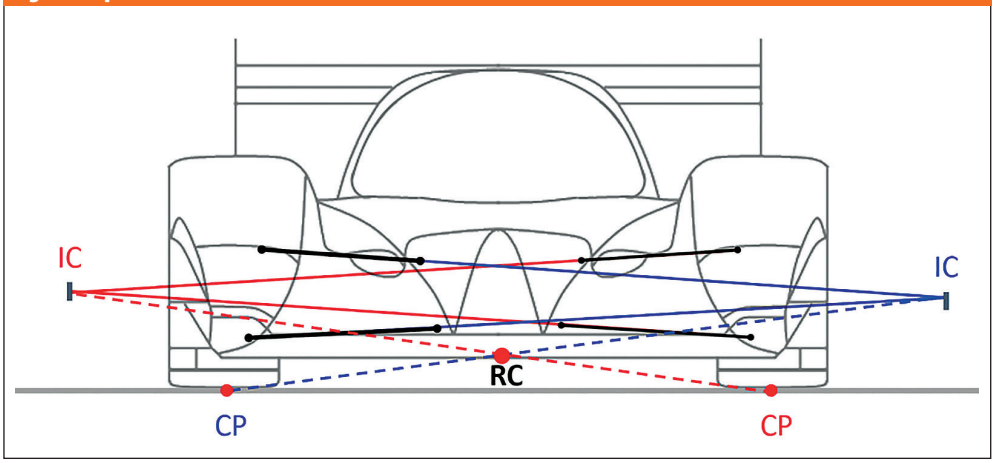
A few questions were subsequently raised: where is the point (or axis) about which the suspended mass rotates in braking or acceleration, and how did those point coordinates change when we altered the anti-dive? We were speaking about the pitch centre (in 2D) or pitch axis (in 3D).

2D load transfer

When we study a simple 2D lateral load transfer (only the front, or only the rear suspension) we link the left and right kinematics to define the roll centre. That roll centre position then helps us to split the suspended mass load transfer in a geometric load transfer (passing from one tyre to the other through the top and bottom suspension linkages) and elastic load transfer (passing from one tyre to the other through springs, dampers, maybe bump stops, and an anti-roll bar).

But why in a simple 2D longitudinal load transfer would we look at only the front suspension anti-dive properties, ignoring the rear, or look at the rear suspension anti-lift, ignoring the front?

Fig 1: Simplified definition of the kinematic roll centre



If we go this way, why don't we discuss independently in lateral dynamics the kinematic 'anti-up' of the outside wheel and the kinematics 'anti-down' of the inside wheel?

I believe the reason for this is that most engineers are not familiar with the notions of pitch centre and pitch axis.

So, let's start the presentation of this topic with a quick review of the kinematics roll and pitch centre definitions.

Figure 1 shows the simplified definition of the kinematic roll centre in 2D. Each wheel is assimilated to an infinitely small thickness disc that has only one point of contact with the ground: the contact patch, or perhaps we should say the contact point (CP). The intersection of the extension of the suspension wishbones gives the instantaneous centre (IC) of rotation of the wheel about the frame.

The intersection of the lines joining each IC to its relative CP gives us the kinematic roll centre (RC). That is the instantaneous centre of rotation of the suspended mass about the ground.

All that because of the theorem of Aronhold-Kennedy (that we will not develop here) that says the three instant centres must be aligned.

It is a very simplified definition for several reasons. Firstly, this a 2D view. The front and rear pick-up point of the top wishbone and / or the bottom wishbone do not necessarily have the same z coordinates. Ditto for the bottom wishbone.

Some engineers consider that by switching to 3D, instead of intersecting two lines they just need to intersect the top and the bottom wishbones planes to find the wheel instant axis of rotation about the chassis. That approach would be proved wrong because, if there is bump steer, the wheel movement will define an envelope of which the instant axis will not be the intersection of the top and bottom wishbone planes.

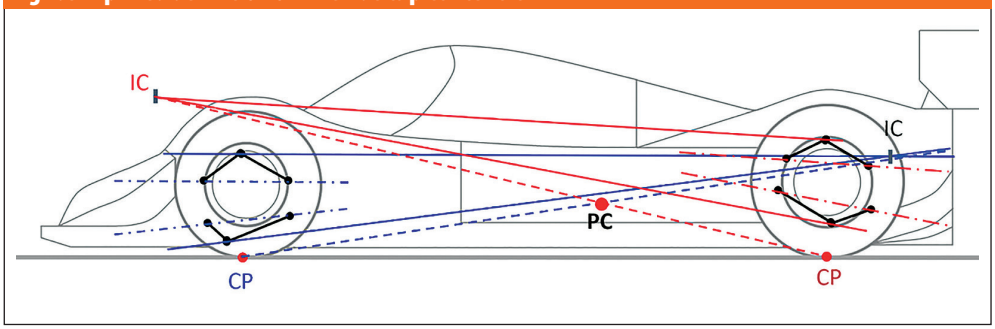
To finally question the validity of this top and bottom wishbone planes intersection method, let us ask ourselves a simple question: where are the top and bottom wishbone planes in a five-link suspension?

Other limitations include the fact there is no such thing as a tyre contact patch. In the real world, there is a contact surface and the centre of the forces acting in that surface is not necessarily in its geometric centre.

Once the car is in roll, the roll centre won't stay in the same place. That is why we refer to it as an instantaneous roll centre. If in static the roll centre depends on the

Why in a simple 2D longitudinal load transfer would we look at only the front suspension anti-dive properties, ignoring the rear?

Fig 2: Simplified definition of kinematics pitch centre



intersection of the extension of the top and bottom wishbone lines, dynamically the roll centre trajectory will be determined not only by the intersection of the extension of the top and bottom wishbone lines, but also by their relative length.

Lastly, there is no compliance. The tyre is considered rigid and the suspension upright, linkages and chassis are considered undeformable.

All that said, we will use **Figure 1** as it is: a simplified representation of the kinematic roll centre.

2D pitch centre

Figure 2 shows the simplified definition of the pitch centre in 2D, in blue for the front suspension, and in red for the rear suspension. For the top and bottom wishbones we draw them parallel to the axis connecting the inboard (chassis) pick-up points that pass through the corresponding outboard (upright) pick-up point.

The intersection of these lines defines the side view instantaneous centre of rotation of the front and rear wheel about the chassis. Just as for the kinematic roll centre, the intersection of lines from each IC to its wheel CP give us the kinematic pitch centre.

A few comments on this.

1. In **Figure 1**, we can see that if the left and right suspensions are symmetrical, the kinematic roll centre will be in the middle of the car. If the suspended mass c of g is also in the middle of the car the roll centre will be right under this c of g. At least at rest.

   However, in **Figure 2**, we can see the front suspension is not necessarily a 'mirror' of the rear one. In fact, that is rarely the case. Therefore, the pitch centre is not necessarily in the middle of the wheelbase and / or right under the suspended mass c of g.
2. As we have seen in previous articles that analyse lateral load transfer, jacking force is a function of the initial position, as well as vertical and lateral movement of the kinematic roll centre. We will not debate here the usefulness of a kinematic roll centre above or under the ground. There are good and bad arguments for both.

   What we need to understand is that the closer the roll centre is to the ground (above or under it), the smaller the angles between the ground and the lines from the wheel CP and its IC, which could make the roll centre lateral movement quite difficult to control.

   If, however, with a very small change in roll angle variation, and only one of the two IC to CP lines inclined vs the ground changes, the roll centre will necessarily move sideways a lot. And neither the car, tyre nor driver likes a roll centre that crosses the inside or outside wheel plane.

   The same consideration is valid for the effect that low angles between the ground and the lines side view IC to wheel CP could do for the pitch centre longitudinal movement.
3. Some books, with which I disagree, use the intersection of the top and bottom wishbones' inboard pick-up points to define anti-dive and / or pitch centre. Why would we use points belonging to the suspended mass to describe the instantaneous centre of rotation *of the wheel*?
4. The reader can use their imagination here. If the lines that connect the front top and bottom wishbones' inboard pick-up points are as shown in **Figure 2**, but the lines that connect the rear top and bottom wishbones' inboard pick-up points are both parallel to the ground, the instantaneous centre of rotation of the rear wheel about the chassis will be

The vast majority of cars have four wheels, be they production or race versions, and the interactions between all four should be considered in any discussion of chassis dynamics



Jakob Ebrey

infinite and the line between that IC and the CP will be the ground itself. Which, in turn, will put the pitch centre at the front wheel contact point, with not a lot of front suspension movement expected.

There could be some serious issues in designing one suspension with 'anti' and the other one without.

5. Suppose a racecar designer draws a car with no anti-dive or anti-squat. The lines that connect the front top and bottom wishbones' inboard pick-up points are both parallel to themselves and to the ground (if the car itself is parallel to the ground). But, if the race engineer then decides to introduce some rake (a higher rear than front ride height) into the car set-up, the wishbones' inboard axes remain parallel to themselves, but not to the ground, and there will now be some anti-dive and anti-squat.

Dive and squat

In **Figure 3**, we see the usual definition of anti-dive and anti-squat, with the green vectors showing the front and rear braking forces and the blue vector representing the suspended mass longitudinal load transfer, which is split into geometric (red vector) and elastic (yellow vector) load transfer.

What determines the distribution between the geometric load and the elastic longitudinal load transfers is the angle A, which is kinematics dependent as it is defined by the line that connects the front wheel CP with the side view front wheel IC.

The purple vector is the composition of the front braking force and the front suspended mass load transfer, while angle B by the inclination of that purple vector.

The anti-dive is defined by Atan (A) / Atan (B). Usually, we express this in percentage.

We now realise that anti-dive is a function of brake distribution. If the brakes were inboard, the purple vector would be originating at the wheel centre and angle A would be defined by the angle between the horizontal passing through the wheel centre and the line connecting that wheel centre and the IC.

On a hybrid car, such as recent LPM1, the anti-dive will have to be calculated twice:

Fig 3: Basic definition of anti-dive

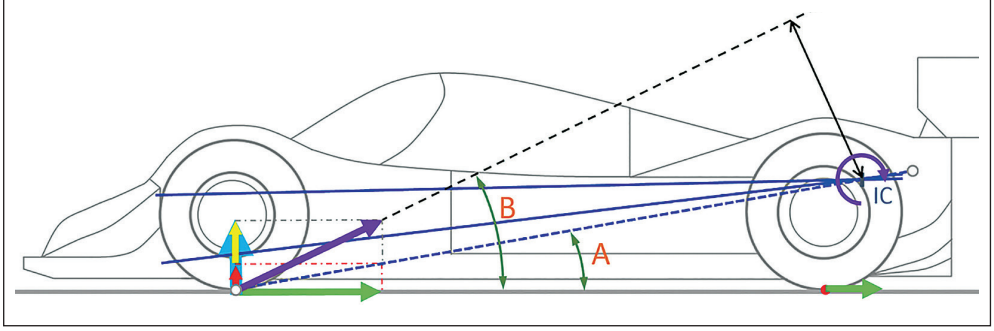
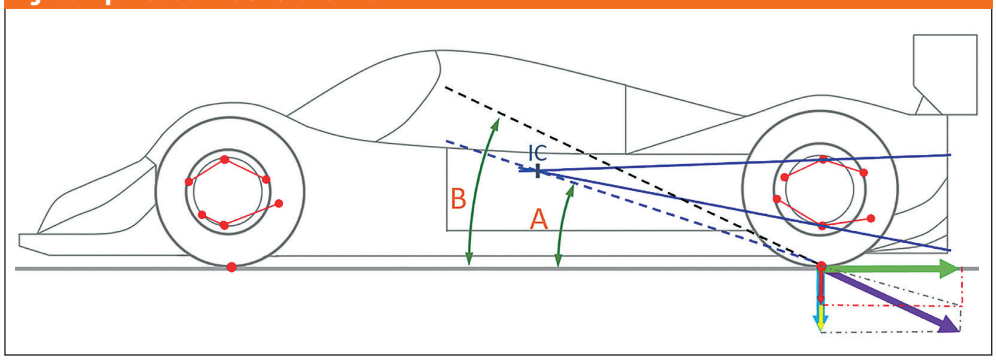


Fig 4: Simplified definition of anti-lift



firstly, from the outboard brakes and secondly, from the inboard electrical motor.

Identical considerations are made for anti-lift in **Figure 4**.

Conclusion

What is the main point here? If we look at anti-dive, you focus on the front suspension, ignoring the rear. If we look at rear anti-lift, you focus on the rear suspension, ignoring the front. If, for the sake of absurd reasoning, we go this way, as shown in **Figure 5**, why not look at the 'anti-up' of the outside wheel, ignoring what happens on the inside wheel and where the roll centre is? Just as we would look at the anti-lift of the front wheel, ignoring what happens at the rear wheel and where the pitch centre is.

Why then would we speak about roll centre in lateral dynamics and not about pitch centre in longitudinal dynamics?

The whole suspended mass rotates about an instantaneous roll axis under lateral acceleration. The same suspended mass rotates about an instantaneous pitch axis under longitudinal acceleration. The car has four wheels. We can't look at the front suspension ignoring the rear, any more than we can look at the left suspension ignoring the right.

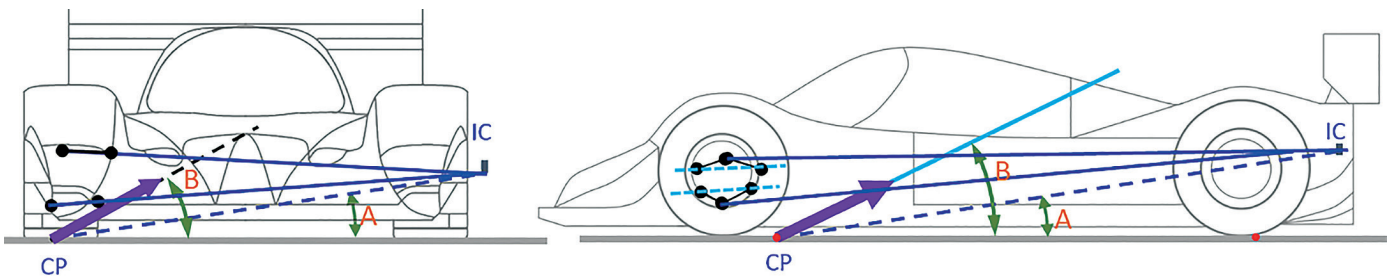
Slip Angle is a summary of Claude Rouelle's OptimumG seminars.

Public, on site, and online OptimumG seminars are held worldwide throughout the year. The Advanced Vehicle Dynamics and the Data Driven Performance Engineering seminars present several theories and best practices that can be used by engineers when making decisions on how to improve vehicle performance. OptimumG engineers can also be found around the world working as consultants for top level teams.

CONTACT
Claude Rouelle
Phone: + 1 303 752 1562
Enquiries: engineering@optimumg.com
Website: www.optimumg.com

OPTIMUMG

Fig 5: Does looking at one wheel in front or side view and ignoring the other make sense?



It is a common mistake in racecar engineering to focus on front and rear suspensions separately, yet their behaviours are directly interconnected, so a holistic approach is always better