

Rolling about

An explanation of the limitations of a previous load transfer article, bringing jacking forces into the mix

BY CLAUDE ROUELLE

First things first. The suspended mass does *not* rotate around the kinematic roll axis. After reviewing the previous simplified explanation of how load transfer works, this month we'll explain why it first had to be presented this way, and give a more correct perspective.

In earlier articles we decomposed lateral load transfer into suspended and non-suspended situations. We also broke down the suspended mass load transfer due to lateral acceleration acting on the suspended mass c of g in a geometric and elastic load transfer, the repartition of which depends on the geometric roll centre altitude vs the ground.

We did this by assuming the suspended mass rotates about the roll centre in 2D or roll axis in 3D. **Figure 1** is a quick reminder.

What is wrong with this picture? The equilibrium of the moments is respected. No matter how we decompose it, the roll moment resulting for the centrifugal acceleration acting on the suspended and non-suspended mass cs of g is balanced by the variation of tyre vertical load.

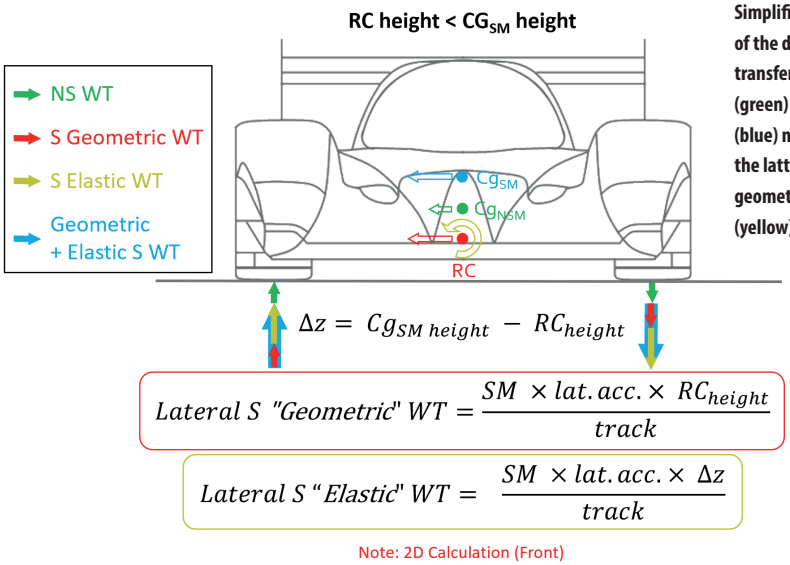
But wait, there aren't any horizontal opposite lateral forces to the ones acting on the two cs of g.

In **figure 2**, we only look at the decomposition of the suspended mass centrifugal applied at the kinematic roll centre and the geometric load transfer (red) of the suspended mass. The non-suspended mass load transfer (shown in green in **figure 1**) and the elastic part of the suspended mass load transfer (yellow in **figure 1**) are not represented here.

At least there is an equilibrium of the centrifugal force: *F =M* V2/R* and the reaction at the outside and inside tyres. Still two things are fundamentally wrong in this sketch though. Firstly, there is little chance the kinematic roll centre would stay in the same position once the car gets some tyre and suspension deflection and, secondly, the tyres' lateral forces cannot be equal as the outside tyre is more loaded than the inside one.

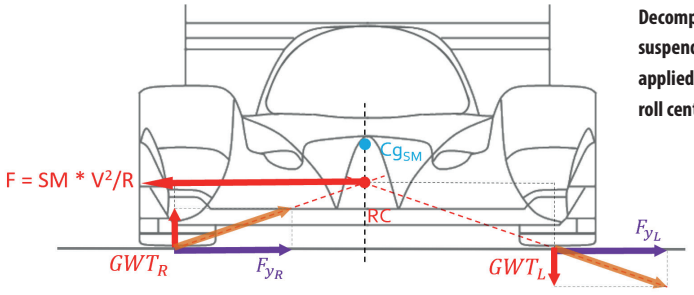
Figure 3 therefore represents a more realistic perspective, with a more pragmatic roll centre position and distribution of lateral forces between the tyres.

Figure 1



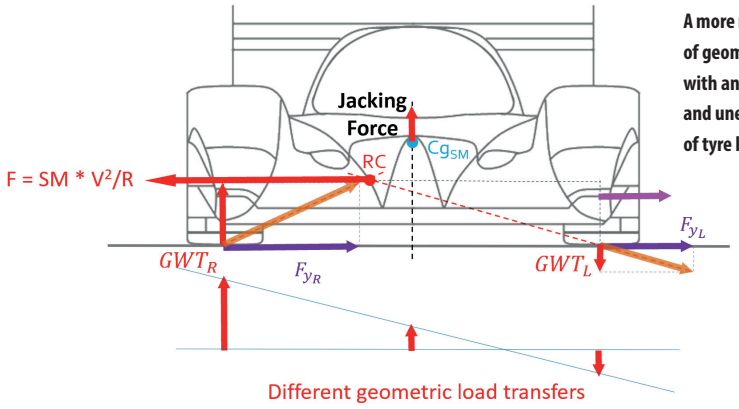
Simplified 2D view equations of the decomposition of load transfer in a non-suspended (green) and suspended (blue) mass load transfer, the latter decomposed into geometric (red) and elastic (yellow) load transfer

Figure 2



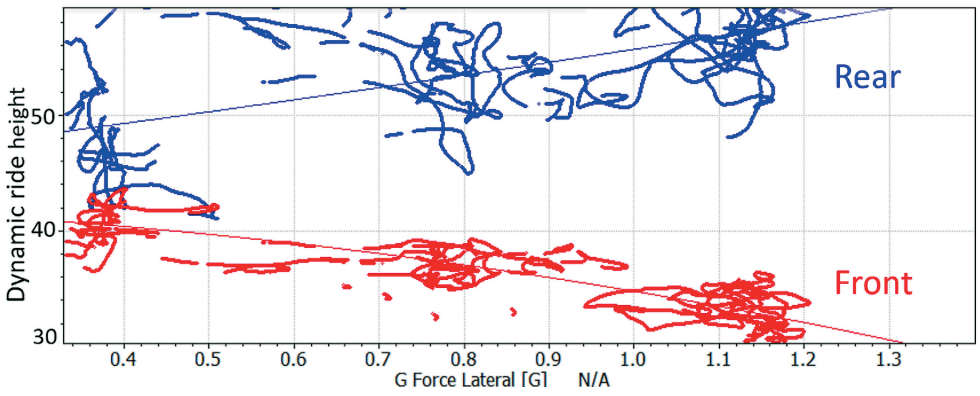
Decomposition of the suspended mass centrifugal applied at the kinematic roll centre

Figure 3



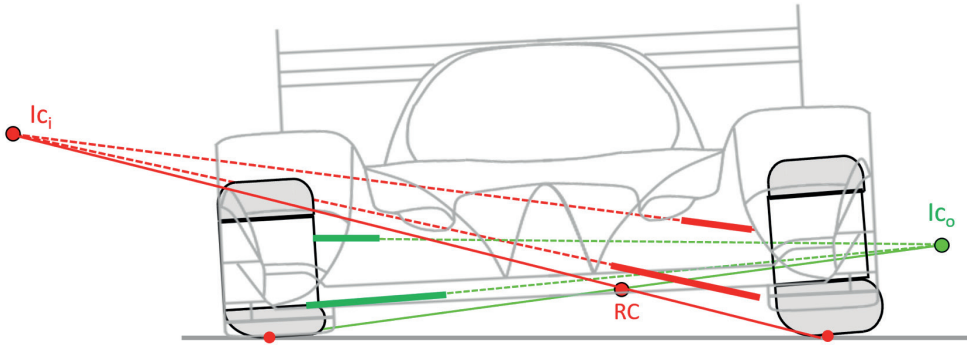
A more realistic decomposition of geometric load transfer with an off-centre roll centre and unequal distribution of tyre lateral forces

Figure 4



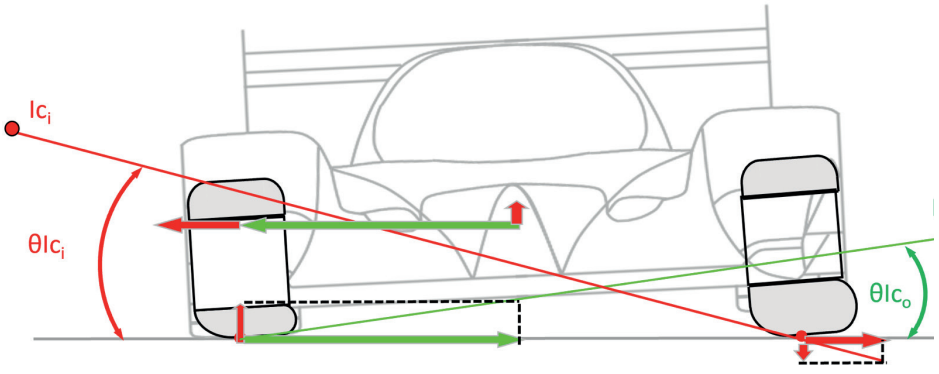
Front and rear ride height variations vs lateral acceleration observed in a variable velocity skid pad test

Figure 5



Traditional definition of kinematic roll centre. The inside wheel instant centre of rotation (red) and the outside wheel instant centre of rotation (green) about the suspended mass are determined by the suspension kinematics

Figure 6



For each tyre, the angle between the ground line and the instant centre to contact patch line, and the side force applied at the tyre, determines the amount of geometric load transfer (red vectors). These forces are pointing in opposite directions but, if they have unequal absolute value, a jacking force is created

We can now observe that the outside and inside geometric load transfers are unequal. This is what imposes jacking force and subsequent ride height variation. Depending on the positive or negative difference between the outside and inside geometric load transfers, the car suspended mass could be dynamically lifted or pushed down.

The suspension stiffness and kinematics, the distribution of inside and outside lateral forces (that depends on so many factors: slip angle; vertical load; camber; pressure; temperature…), and the amount of lateral acceleration will dictate the ride height variation. It could be in the order of 1mm with stiff suspension or as much as 10mm with soft suspension.

It is interesting to note that the jacking forces and resultant ride height variations could have a significant influence on the aerodynamic downforce and downforce distribution, both of which are front and rear ride height sensitive.

Skid pad testing

Figure 4 shows the front and rear ride height variation observed on a skid pad with a car driven on a constant radius at increasing speed (it is worth mentioning the test was conducted on a car with moderate aerodynamic downforce). We can observe an increasing rear ride height and a decreasing front ride height, most probably due to a rear roll centre above the ground and a front roll centre below the ground.

This type of test can be used to find jacking at different lateral accelerations. Then, using damper potentiometers and knowledge of suspension motion ratios, the suspended mass vertical movement from jacking can also be found.

The main reason why the simplified explanation on load transfers without jacking forces was not developed in previous articles is that knowledge of the front and rear side forces and their distribution depends on the tyre model, and not everybody has access to that.

Elaborating further, **figure 5** shows the classical way kinematic roil centre is found.

In **figure 6**, we apply a side force on the outside tyre (green) and an inside tyre force (red), the total of which are logically equal to the suspended mass multiplied by the lateral acceleration. The angles θIc_i and θIc_o are determined by the ground line and the line going from each tyre contact patch to its

No matter how we decompose it, the roll moment resulting from the centrifugal acceleration acting on the suspended and non-suspended mass cs of g is balanced by the variation of tyre vertical load

A force acting on the line tyre contact patch to its instant centre would not create any wheel movement vs the suspended mass

respective instant centre. These angles will determine the amount of the jacking forces.

We realise that with an unchanged suspension kinematic (and therefore the same θIc_i and θIc_o angles), if we had a different tyre lateral forces distribution, we would have had a different jacking force.

In **figure 7**, we have the same kinematics, the same instant centres position, the same kinematic roll centre but a different distribution of inside and outside forces (that could come, for example, from different tyre temperatures). Despite that, their total is unchanged and still equal to the product of suspended mass by the lateral acceleration. It is the different tyre side force distribution that affects the jacking force.

The same consideration could be made by keeping the same tyre side force distribution and modifying the kinematics.

The validation

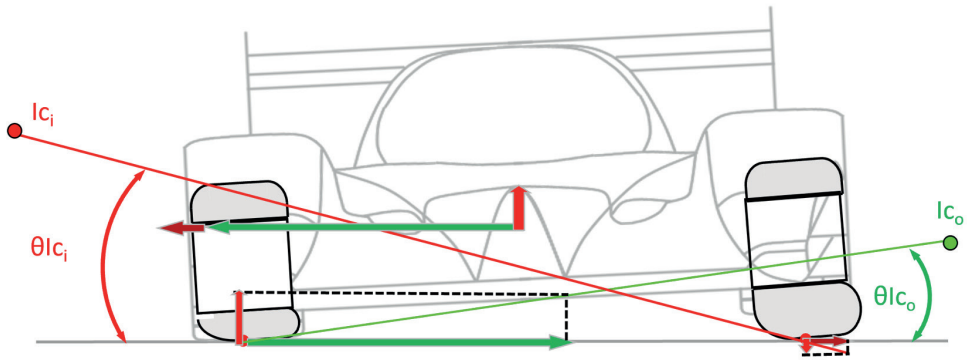
In fact, more than the kinematic roll centre, it is the angles θIc_i and θIc_o that determine the jacking forces. The proof is that a force acting on the line tyre contact patch to its instant centre would not create any wheel movement vs the suspended mass. This validates the definition of geometric load transfer that only produces forces in the suspension linkages with no spring, damper or anti-roll bar movements.

The last thing to note is that if the kinematics and / or the tyre side force distribution affects the geometric load transfer, jacking forces and ride height, it also affects the elastic part of the suspended mass load transfer, as seen in **figure 8**.

No matter what, load transfer is *only* a function of mass, lateral acceleration, track width and c of g height. The total of the non-suspended mass load transfer (green) and the suspended mass load transfer (red and yellow) remains the same.

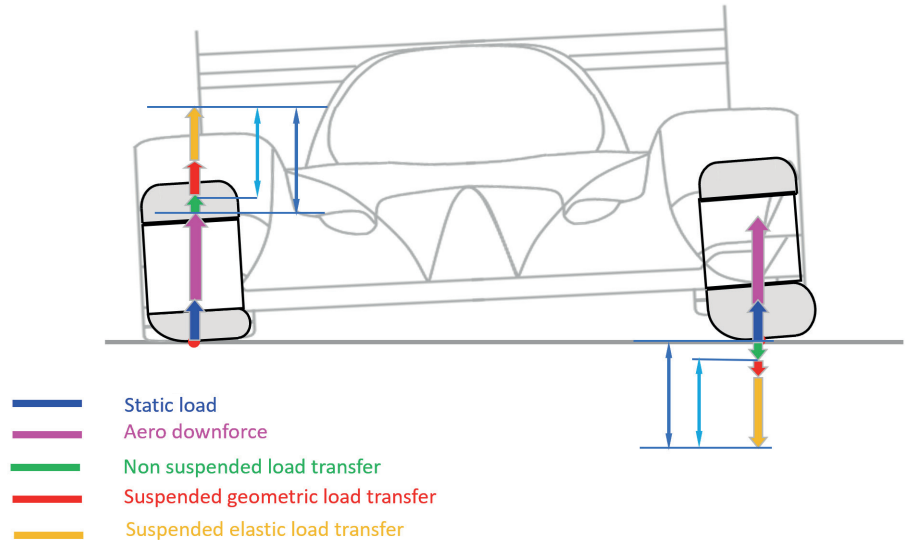
What could change is the *distribution* of the geometric (red) and elastic (yellow) parts of the suspended load transfer. However, as their *total* do not change, if we have more geometric, we will get less elastic and *vice versa*.

Figure 7



Same kinematics as in figure 6 but with a different side force distribution results in a different jacking force

Figure 8



Analysis of all vertical load and load variation on the tyres in a 2D simplified view

No matter what, load transfer is *only* a function of mass, lateral acceleration, track width and c of g height

As the elastic load transfer affects the forces and movements of springs, dampers and anti-roll bars, we understand that kinematics and tyre side force distribution will also affect roll angle and car attitude vs the ground. These are all different perspectives of the same load transfer and its consequences.

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

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