The Mark Ortiz Automotive

CHASSIS NEWSLETTER

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WELCOME

Mark Ortiz Automotive is a chassis consulting service primarily serving oval track and road racers. This newsletter is a free service intended to benefit racers and enthusiasts by offering useful insights into chassis engineering and answers to questions. Readers may mail questions to: 155 Wankel Dr., Kannapolis, NC 28083-8200; submit questions by phone at 704-933-8876; or submit questions by e-mail to: markortizauto@windstream.net. Readers are invited to subscribe to this newsletter by e-mail. Just e-mail me and request to be added to the list.

ROLL CENTER THEORY

Over the years I have come across a few articles that both state how important the roll center can be towards vehicle handling, and articles that simply state roll centers are overrated and they don't do anything. What's your stand on this topic? I know the basic theories of roll centers and their role in determining the car's geometric stiffness and jacking forces (which raise the car's cg = bad). But, on some cars I've seen the roll center move laterally way outside the wheels when the vehicle rolls. What happens then? Do we simply ignore a roll center's lateral movement and only concentrate on its height? What happens if the roll center's height is off the charts way below ground? When designing pure race cars you can get the roll center where you want, but when working with factory street cars with funny geometry the roll centers start acting wildly. I'm sure making the vehicle stiff enough that we don't have to analyze these movements is the easy answer but am I missing something here?

The topic of roll centers is a godsend to automotive writers. It creates endless controversy, and we'll probably be writing articles about it forever. I've written quite a few, and even produced a video that's mostly about the subject, which is still available.

Here, I will assume that the reader is at least a little familiar with the concepts of front view projected control arms, front view instant centers, and front view force lines (the lines from contact patch centers to instant centers, whose intersection is conventionally taken as the "kinematic roll center").

Quick answer to the question of whether roll centers matter is: yes, but most people don't define them properly, and many don't have a very clear understanding of what we mean by a roll center, and what we use it for when analyzing car behavior.

Slightly longer answer: actually, it's the anti-roll or pro-roll properties of the suspension linkage that matter, and also its anti-pitch or pro-pitch properties. It is potentially useful to describe these properties in terms of roll and pitch centers, but only if those accurately reflect or predict the actual moments generated by the wheel pairs at issue. Taking the force line intersection, or the height of that point, as the roll center, does not do that, except when the force line slopes are equal and opposite – i.e. when they cross in the middle of the car.

The force line slopes matter, and the ground plane forces matter, and the moments generated as a result matter. But you can't analyze the effects by looking at where the force lines cross each other.

It is entirely possible to dispense with the whole concept of roll centers, and some think that's the best approach. However, most people still use the concept.

Use it for what? Properly, as a shorthand, easy-to-visualize way of expressing the relationship between sprung mass lateral inertia force at one end of the car, and the anti-roll moment induced in the suspension linkage in response to that lateral inertia force. It is a notional coupling point between the notional two-wheel suspension system and the sprung mass, for lateral forces: an imaginary roller in a vertical slot.

Since the roller doesn't transmit vertical forces, its lateral location doesn't matter, and can just as well be considered undefined. But its height matters. Its height, H_{rc}, is correctly assigned in terms of predicting geometric anti-roll moment M_{xG} when the sprung mass lateral inertia force F_{ySM}, times H_{rc}, equals a moment equal and opposite to M_{xG}:

$$H_{rc}\,(F_{ySM}) = -\,M_{xG} \qquad (1a)$$

This can also be written:

$$H_{rc}\,(F_{ySM}) + M_{xG} = 0 \qquad (1b)$$

The second form is sort of an algebraic expression of the way a roll center is described in SAE J670e: a point at which we can exert a lateral force on the car and no roll will result. The SAE definition is somewhat problematic, but at least its current version includes a caveat that it is not to be construed as a true instantaneous center of rotation.

With independent suspension, geometric anti-roll comes from positive or negative support forces induced in the linkage upon application of transverse (y axis) force at the tire contact patches. These support forces, F_{zGR} and F_{zGL}, depend on the magnitude of the ground-plane force and the slope of the force line, and nothing else. The moment created by these forces is the difference between them, times half the distance between them – the distance between them being the track width, L_y.

$$M_{xG} = (F_{zGR} - F_{zGL})\,L_y/2 \qquad (2)$$

H_{rc} then has to be the value that makes the moments cancel. Substituting the right side of Equation (2) into Equation (1a):

$$H_{rc}\,(F_{ySM}) = -(F_{zGR} - F_{zGL})\,L_y/2 \tag{3a}$$

Or:

$$H_{rc} = -(F_{zGR} - F_{zGL})\,L_y\,/\,(2F_{ySM}) \tag{3b}$$

Or:

$$H_{rc} = -(F_{zGR}/F_{ySM} - F_{zGL}/F_{ySM})\,L_y\,/\,2 \tag{3c}$$

Note that this implies that the roll center height depends only on the relationship of the right and left induced support forces to the total lateral force, and the track width.

The sprung mass inertia force F_{ySM} is equal and opposite to the sum of the opposing transverse forces at the two contact patches, F_{ySMR} and F_{ySML}.

$$F_{ySM} = F_{ySMR} + F_{ySML} \tag{4}$$

Finally, the induced support forces and the lateral ground-plane forces at each wheel are in the same ratio as the rise and run of the force line. If the angle of elevation of the force line is θ, that ratio is $\tan\theta$. So for right and left wheels, we have $\tan\theta_R$ and $\tan\theta_L$.

$$F_{zGR} = F_{ySMR}\tan\theta_R \tag{5a}$$

$$F_{zGL} = F_{ySML}\tan\theta_L \tag{5b}$$

Substituting into Equation (3c):

$$H_{rc} = -(F_{ySMR}\tan\theta_R\,/F_{ySM} - F_{ySML}\tan\theta_L\,/F_{ySM})\,L_y\,/\,2 \tag{6a}$$

Or:

$$H_{rc} = -\big((F_{ySMR}/F_{ySM})\tan\theta_R - (F_{ySML}/F_{ySM})\tan\theta_L\big)\,L_y\,/\,2 \tag{6b}$$

Or:

$$H_{rc} = \big((F_{ySML}/F_{ySM})\tan\theta_L - (F_{ySMR}/F_{ySM})\tan\theta_R\big)\,L_y\,/\,2 \tag{6c}$$

F_{ySMR}/F_{ySM} and F_{ySML}/F_{ySM} are the portions of total transverse force for the right and left wheels, respectively.

Graphically, we can find H_{rc} in a front view by:

1. constructing a vertical line at a distance from the right wheel equal to that wheel's portion of the total lateral force times the track – I call this the resolution line;
2. finding the intercepts of the right and left wheel force lines with that resolution line;
3. averaging the heights of those intercepts.

We can also find the total jacking force for the wheel pair by adding the support forces:

$$F_{zG} = F_{zGR} + F_{zGL} \tag{7}$$

In roughly symmetrical independent suspensions, it does hold that more geometric roll resistance implies more upward jacking. However, it is actually possible to have an independent suspension with a roll center above ground (net geometric anti-roll) and downward jacking! This occurs when the majority of the anti-roll force comes from the inside wheel, despite that wheel having lesser ground-plane force. That is possible when the inside wheel has a lot of anti-roll geometry and the outside one has little, or slight negative, anti-roll geometry. This can occur in a strut suspension in a rolled condition.

It is also possible with beam axle suspension to add upward jacking while subtracting geometric roll resistance, and vice versa. This happens in a NASCAR-style stock car when we lower just the right end of the Panhard bar. The rear jacks up in a left turn, yet geometric load transfer is less than if we raised the right end of the bar to make it level. Conversely, if we raise the right end of the bar above level, leaving the left end unchanged, we increase roll center height and geometric load transfer, yet the rear jacks down.

It is quite possible to have a force line intersection outside the car, and toward either the inside or the outside of the turn, and have net pro-roll, or a roll center below ground. It is also possible to have a force line intersection below ground and outside the car toward either the inside or outside of the turn, and have net anti-roll, or a roll center above ground. This does not imply that the geometry doesn't matter. It implies that the force line intersection cannot be taken as the roll center.

Some thinkers note that the jacking force can itself induce roll moments, in the presence of off-center sprung mass c.g.'s or spring splits, and try to come up with ways of assigning roll center height that include spring split and/or c.g. location. I do agree that jacking-induced roll and pitch moments are real, and in some cases big enough to matter. However, they act on the entire mostly-rigid sprung mass, as does elastic roll resistance. They cannot be analyzed in isolation for the front and rear, or right and left in the case of pitch. Therefore it is not analytically productive to try to incorporate them in calculation of geometric properties of the front or rear, or right or left wheel pair suspensions.

Is it possible to spring the car so stiffly that roll centers don't matter, or don't matter much? Yes. But it has to be really stiff – stiff enough so that it essentially has no suspension except the tires. Short of the point where we produce a big go-kart, we do not reduce the geometric component of the load transfer by reducing roll. We reduce roll displacement, but not elastic or geometric roll moment.

It is also possible to spring just one end of the car stiffly enough so that geometric anti-roll doesn't matter much at that end. In that case, roll center height at the other end becomes very important. An instance of that would be a stock car with a coil-bind or stiff bump rubber setup at the front. Once the front is bottomed, there isn't going to be much further elastic load transfer at the rear, because the car can't roll much, but the rear will still have increasing geometric load transfer if lateral load increases, and that will be determined by the Panhard bar height.