The Mark Ortiz Automotive

CHASSIS NEWSLETTER

PRESENTED FREE OF CHARGE
AS A SERVICE TO THE
MOTORSPORTS COMMUNITY

February 2006

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: markortiz@vnet.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 AXIS INCLINATION

What is the influence of a roll axis inclination biased to the front suspension – meaning a front roll center always closer to the ground than the rear? At least in passenger cars, the roll axis is always inclined to the front except in some special cases, for example the BMW Series 1 which is reported by BMW to have the roll axis parallel to the ground.

I supposed I had an explanation, but after reading Race Car Vehicle Dynamics by Milliken my potential explanation has flown away. My explanation was based on the idea that the more the roll axis is inclined toward the front, the more load transfer there will be at the front axle, and the more understeer the vehicle will have.

But I have put into an Excel spreadsheet the formulation from Milliken and I find to my surprise that the higher the front roll center, the greater the load transfer at that end – which works against my intuition.

Can you explain this?

Short answer: higher roll center at the front implies more geometric roll resistance at the front, hence more load transfer at the front, other things being equal. So the typical nose-down roll axis inclination does not increase front load transfer.

There are cars that have a nose-up roll axis. They are all rear-engined. Probably the most extreme example is the Hillman Imp, which had a front roll center near hub height and a rear roll center near ground level.

Like many things, the subject of roll resistance and load transfer is fairly simple once you understand it, but will drive you crazy until you get to that point.

When discussing this subject, I am always quick to plug my video, *Minding Your Anti*, which covers the subject at length. It costs US$50.00, shipping included, payable by check or money order to me at 155 Wankel Dr., Kannapolis, NC 28083-8200, USA.

In steady-state cornering (constant speed, on a constant radius), on an unbanked road surface, the total load transfer from the inside wheels to the outside wheels depends entirely on the height of the whole vehicle's center of mass (center of gravity, or c.g.) and the track width at the c.g.

Suspension design and tuning have almost no effect on the magnitude of the total load transfer. What we mainly do with suspension design and tuning is control the distribution of that total, between the front and rear wheel pairs.

We customarily consider the car to be a rigid object, supported by a single compliant structure at each end. The sprung structure is the rigid object; the front and rear suspension systems are the compliant structures.

As an analogy, imagine that you and a friend are carrying a sailboard, as used for windsurfing, along the beach. Each of you is carrying one end of the sailboard. The sail is up, and there is a breeze blowing. The force of the wind on the sail tries to overturn the sailboard.

The overturning force depends entirely on the design of the sailboard and the amount of wind. The total counterforce that you and your friend together need to exert to balance this does not depend on you and your friend. However, the amount of counterforce that you individually need to exert depends on the amount exerted by your friend, and the amount of counterforce he has to exert depends on you.

You and your friend are like the front and rear suspension systems. The sailboard is like the sprung mass.

There are portions of the load transfer that come from the unsprung components, and there are portions that come from the dampers if the car is rolling upon corner entry or de-rolling on exit. However, for simplicity in answering the present question let's look just at the components of the load transfer that come from the inertia force (centrifugal force) of the sprung mass acting through the suspension, in steady-state cornering. There are only two such components: elastic load transfer and geometric load transfer. Elastic load transfer comes from elastic roll resistance: the roll resistance supplied by the springs and anti-roll bars. Geometric load transfer comes from the properties of the structural components attaching the wheels to the sprung mass, which can be arranged to generate forces opposing roll, or geometric roll resistance.

With independent suspension, these two components influence each other more than is commonly recognized. The load distribution on an independently suspended wheel pair affects how much geometric roll resistance the wheel pair has, for any given suspension geometry. To illustrate with an extreme case, if the inside wheel is off the ground, the geometry of its suspension linkage is irrelevant and only the geometry of the outside wheel has any effect on the car. My video deals with these effects in detail. For simplicity, I will ignore them here, but I do want note in passing that they exist.

When we speak of roll center height, we are speaking of an imaginary point whose height represents the amount of geometric roll resistance for the front or rear wheel pair. If this point is assigned properly, we can closely approximate the geometric load transfer at one end of the car as: roll center height times sprung mass centrifugal force at that end of the car, divided by track width at that end of the car.

When the suspension is symmetrical, the point you generally see in the chassis books – the force line intersection – is a good approximation. When the suspension is not symmetrical, using the force line intersection as the roll center can lead to major mis-predictions of car behavior. Sometimes the force lines may be parallel, in which case there is no intersection.

We may define a line connecting the front and rear roll centers, called the roll axis. The car doesn't really roll about this line, but as a crude approximation we can reasonably think of it as doing so.

If we raise the roll axis at both ends, the geometric roll resistance is greater at both ends. If we raise one end of the roll axis and lower the other, leaving its height at the c.g. unchanged, the total geometric roll resistance is unchanged, but we increase the geometric roll resistance at one end and lower it at the other. The elastic elements – the springs and anti-roll bars – are not affected by this.

So the end where we lowered the roll center has less geometric load transfer and the same elastic load transfer as before – hence less load transfer overall. This will make that tire pair grip better, because they will be sharing the work more equally. At the opposite end, the elastic component will likewise be unchanged, but the geometric component will be increased – hence more load transfer overall.

Okay, so if we want understeer for most drivers, why have a nose-down roll axis? There are a number of explanations.

The most obvious explanation is that when the car has independent suspension in front and a beam axle in back, we don't have much choice. Independent suspensions with roll centers much above four inches generally jack excessively. Front suspensions with high roll centers generate lateral contact patch motion over bumps, which creates kick at the steering wheel. It is possible to build a beam axle suspension with a roll center below any component of the suspension, but the linkage required is somewhat complex. Consequently, beam axles on cars with enough ground clearance to be practical on the street generally have roll centers at least six inches high, and usually at least ten inches. Of course, with independent rear suspension, the roll center is usually much lower, but most often still a bit above the front one.

The next most obvious reason is that passenger cars are generally too nose-heavy to have balanced handling, and the front suspension doesn't control camber when cornering nearly as well as the rear suspension. Consequently, we need to kill understeer, not increase it.

A somewhat less obvious reason has to do with driver-perceived car behavior in abrupt transient maneuvers, such as the lane-change test commonly used in passenger car testing. With a nose-down roll axis, there is a small yaw component with roll. The nose points out of the turn slightly, relative to the four contact patches. This makes the car feel steady to the driver, rather than twitchy.

Another reason sometimes cited is that when a car is abruptly steered into a turn, the geometric component of the load transfer is the first to act on the car. If this component is greater at the rear, we will momentarily have less understeer and the car will turn in more responsively. Note that this explanation is somewhat at odds with the one immediately preceding it.

There are somewhat logical variations on both of these two explanations. We could say that if the main mass of the car is yawing out of the turn relative to the four contact patches, that steers the contact patches into the turn, or steers the rear wheels out of the turn, momentarily adding oversteer!

Some people also believe that tire load sensitivity momentarily works backwards until the tires start heating. I personally don't believe this, but if so it means that if there is initially more rear load transfer, that adds understeer rather than oversteer, and makes the car feel stable.

Isn't this fun? If it weren't for vehicle dynamics, I'd have to do something sane for a living.