The Mark Ortiz Automotive

CHASSIS NEWSLETTER

PRESENTED FREE OF CHARGE
AS A SERVICE TO THE
MOTORSPORTS COMMUNITY

August 2004

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 CENTER MIGRATION, SOME MORE

The discussion of roll center definition in the June newsletter prompts this question from a reader:

Would you be able to discuss the effects of front lateral roll center migration for an oval track car with a solid axle rear end (NASCAR style) – perhaps an example on a short track where there are low speeds and aerodynamic loads, and higher amounts of vehicle roll where the left side suspension could be travelling into rebound?

The questioner mentions that he is an engineer for a major car manufacturer, and expresses a desire to remain anonymous, which is my usual practice in any case. Knowing that the questioner is an engineer, I am going to assume here that the reader is conversant with the basics of roll center theory as usually understood, and will not start at square one.

As those who read the June newsletter will know, I do not believe that the intersection of the front view projected force lines can properly be considered the roll center, or moment center, or anything of the kind. There are situations where you don't get big modeling errors if you use the force line intersection as a roll or moment center, and other cases where you get huge errors. This merely illustrates that an incorrect analysis method can coincidentally produce correct or nearly correct answers in certain cases, despite the incorrectness of the method itself.

I have also said that the roll center, properly assigned, should be considered a point in side view (of the car), and its lateral position should be considered undefined. It lies in the transverse plane containing the wheel center in all cases, or, in side view, it lies straight down or straight up from the wheel center. So we really need only one number to define its position, namely its height. This height is not the same as the height of the force line intersection. Rather, it is the mean height of the two force line intercepts on a line I call the **resolution line**.

The resolution line is a vertical line in the front view, positioned according to distribution of lateral force generated by the two tires. For example, if the right front tire is generating 75% of the front lateral force, the front suspension resolution line is 75% of the track width away from that tire.

Unfortunately, we do not know this distribution of lateral force exactly, in most cases. We have to estimate it. That means our modeling of the suspension's behavior is only as good as this estimate. This is unfortunate, but ignoring the fact doesn't make it go away. The behavior of the suspension really does depend on the distribution of lateral force. To predict the jacking forces each of the individual wheels generates, and thereby calculate an anti-roll or pro-roll moment, we must not only know the suspensions' geometry, but also the forces at the contact patches. Any analysis method that takes this into account, even using an estimate for the lateral force distribution, is better than a method that ignores this factor altogether.

What we're doing here is directly analogous to modeling longitudinal anti effects – anti-dive, anti-squat, anti-lift – in side view. It is widely recognized that when modeling longitudinal anti effects, we have to know the front/rear distribution of longitudinal force, or try to estimate it with reasonable accuracy. For example, for braking short of lockup, we use the calculated brake bias. If the front brakes make 70% of the rearward force, we construct our resolution line 70% of the wheelbase back from the front wheel center. We then look at where the front wheel side view force line intercepts this resolution line. We take the height of this intercept as a percentage of sprung mass center of gravity height, and that is our percent anti-dive. We can do the same for the rear wheel, and that's our percent anti-lift. When these are both 100%, the car will not pitch at all in braking, regardless of wheel rates, nor will the whole car jack up or down.

We can likewise define a percent anti-roll for the right and left wheels in an independently suspended front or rear pair, and we may also average these to define a percent anti-roll for the wheel pair. The average height of the intercepts makes a good value to use for roll center height – much better than using the force line intersection height, though in some cases the two values may be similar. The average height of the intercepts, or roll center height, may also be described as the sprung mass c.g. height times the percent anti-roll for the wheel pair. Also, the height of each of the intercepts, as a percentage of sprung mass c.g. height, is that wheel's percent anti-roll.

This definition of the roll center provides a number that can be accurately used for load transfer and roll angle calculations, for it is a valid measure of the suspension's geometric anti-roll properties.

Assigning a roll center location is useful not only for modeling or analysis, but also for discussion. To use the method I'm advocating for discussion, it is useful to have default assumption for lateral force distribution. I think assuming that the outside wheel generates 75% of the force is appropriate, absent better information.

Note that suspensions only generate geometric anti-roll or pro-roll moments in response to car-horizontal (lateral or longitudinal) forces. Force line slopes, force line intersections, and force line intercepts of the resolution line do not affect any tendency to roll, or resist roll, in response to car-vertical forces. (Spring splits, or wheel rate splits, do affect this. So does an offset c.g., or static left percentage other than 50%.)

Of course, the questioner here is not asking about effects of changes to the location of the roll center as I prefer to define it. He is asking about effects of lateral migration of the roll center as most people conceive it, namely the intersection of the front view force lines.

And in fact we can say some things about the position of the force line intersection, and the conclusions we can draw from it, for particular classes of situations. We can't necessarily say the car has more tendency to roll, other things held constant, if the intersection moves to the inside of the turn, nor that the car has less tendency to roll if the intersection moves in the direction of roll, even in a banked turn. However, we can make some more complex and qualified statements, for particular sets of conditions or assumptions.

To begin with, there are certain situations where we don't know much at all from the force line intersection. If the force line intersection is at the contact patch center for either of the wheels, we know that the opposite wheel's force line is horizontal, and therefore the opposite wheel has no anti-roll or pro-roll. However, the force line for the wheel on top of the intersection could be at any angle, and therefore this suspension could have any amount of anti-roll or pro-roll. In this situation we can't say anything about the overall amount of anti-roll or pro-roll in the geometry from the location of the force line intersection, nor can we infer the location of the roll center as I define it, without additional information.

Parallel lines do not intersect. When the force lines are parallel, there is no force line intersection. In this situation, users of force line intersection as the roll center will either say the roll center is undefined, or that it has disappeared, or – arbitrarily – that it is on the vehicle centerline, at the average height of the two force line intercepts of the centerline, which will be at ground level. However, the parallel force lines could be at any angle, relative to car-horizontal. We don't know what that angle is; all we know is that it's the same for both of them. We know that one wheel has anti-roll and the other has pro-roll, but we don't know how much. We know that the anti-roll and pro-roll forces are equal if the tires are making equal car-lateral force, which would equate to a roll center at ground level. But if the tire forces are unequal – and they usually will be – we cannot say how much overall anti-roll or pro-roll the system has, and we cannot define the roll center my way, without additional information.

There is a third unique class of situation – or, if you like, a special case of the parallel force line situation – the one where both force lines are horizontal. In other words, the force lines are not only parallel, but coincidental. In this case, we cannot say what the lateral location of the force line intersection is. We may say there is an infinitely large number of them. We do know, however, that all these points are at ground level, and we can say with certainty that the suspension has no anti-roll or pro-roll, regardless of the magnitude of car-lateral forces at the contact patches. We can also say that the resolution line intercepts of both force lines are at ground level, no matter where the resolution line lies. Therefore we can define a roll center height my way, at ground level, despite the fact that we cannot define a single force line intersection. In this case only, we can do this without knowing, estimating, or assuming lateral force distribution.

For all cases except the above three classes, we can calculate the slopes of the force lines from their intersection. Knowing this, and a known, estimated, or assumed lateral force distribution, we do know enough to assign a roll center my way, and to say something about the overall anti-roll or pro-roll characteristics.

We can also say which direction the force line intersection will move, for a known roll displacement, if we know one more characteristic of the suspension: how the force line slope changes with suspension movement.

William C. Mitchell, in his SAE paper no. 983085 entitled *Asymmetric Roll Centers*, introduces a definable parameter that is useful in discussing this. He calls it the **incline ratio**. I find this nomenclature to be suggestive of a different meaning, and I think Bill deserves recognition for coming up with the idea, so I call it the **Mitchell index**.

By either name, we calculate this number as follows: We look at the centerline intercept of the force line, and we note its rate of height change as the suspension moves in ride. We express the rise and fall of the intercept as a proportion of the ride motion, and that's the incline ratio, or Mitchell index. If the intercept moves up and down at the same rate as the sprung mass, we have a Mitchell index of 1. If it doesn't move at all, we have a Mitchell index of zero. If it moves up when the sprung mass moves down, we have a negative Mitchell index. If it moves down when the sprung mass moves down, by a lesser amount, we have a Mitchell index between 1 and 0. If it moves down when the sprung mass moves down, by a greater amount, we have a Mitchell index greater than 1.

The case the questioner raised in the June newsletter, where a short-and-long-arm suspension has the lower arms shorter than the uppers, illustrates a Mitchell index substantially greater than 1. Likewise, a strut suspension has a Mitchell index greater than 1. A pure trailing arm suspension has a Mitchell index of 0. Most short-and-long-arm layouts have Mitchell indices fairly close to 1 or a bit greater. With unusually short upper arms, stock car front ends can have a Mitchell index a bit less than 1. To get a Mitchell index of zero with a short-and-long-arm suspension, we need either very long lower arms, or very short uppers. The lengths have to be in accordance with Olley's Rule: the lengths of the control arms have to be inversely proportional to their height above ground level, usually as measured at the ball joints. For typical stock car lower arm and spindle (upright) dimensions, that means upper arms somewhere around six to seven inches long, rather than the lengths of 9 inches or more commonly seen. Not surprisingly, Mitchell indices less than zero are uncommon.

The Mitchell index can be different for the right and left wheels, and in oval-track stock cars it usually is, though not by much. It also varies some as the suspension moves, but it does not undergo large, sudden changes. We also end up defining it differently if we take the centerline as being where the frame builder marked it, or as being at the midpoint of the front track, or as being the edge view of the longitudinal c.g. plane. These nuances aside, if we consider roll to be angular motion about the ground intercept of whatever centerline we've defined, then we can say certain things about how the force lines and their intersection will move in particular combinations of ride and roll, based on the Mitchell indices of the two individual wheel suspensions.

If the Mitchell index is 1, the force line slope doesn't change in roll. If the Mitchell index is 1 for both right and left wheels, the force line intersection doesn't move in roll.

To take the most common category of cases first, suppose that, at static condition, the force line intersection is above ground level and between the wheels. In this condition, if the Mitchell index is greater than 1, the force line intersection always moves laterally opposite to the direction of roll. The force line for the outside wheel (right wheel in a left turn) loses inclination, while the force line for the inside wheel gains inclination. In the case the questioner cites, the intersection would move to the

right. If the Mitchell index is less than 1, the force line intersection moves toward the outside wheel instead. The outside wheel force line gains inclination, while the inside wheel force line loses inclination.

In general, the former case implies a decrease in overall geometric anti-roll, and the latter implies an increase in overall geometric anti-roll, even with no change in force line intersection height, because the outside wheel generates more lateral force. Correspondingly, the roll center, defined my way, drops in the former case and rises in the latter case, even with no change in force line intersection height.

Now let's change things a little. Let's suppose the force line intersection is between the wheels but below ground level. This is actually not an uncommon condition in stock cars, especially drop-snout cars on banked turns.

Now, if the Mitchell index is greater than 1, the force line intersection moves toward the **outside** wheel in roll! The outside wheel is still losing anti-roll, or should we say gaining pro-roll. The inside wheel is still gaining anti-roll, or losing pro-roll. So the change in roll resistance is still the same as when the force line intersection was above ground, but the lateral migration of the force line intersection is in the opposite direction – toward the outside wheel.

If the Mitchell index is less than 1, again the change in roll resistance is the same as with an above-ground intersection – it increases. And again, the lateral migration of the intersection is in the opposite direction – toward the inside wheel.

This illustrates that we cannot infer the change in roll resistance knowing only the direction of lateral migration of the force line intersection, even supposing that the intersection height isn't changing.

The wildest migrations of the force line intersection occur when the force lines are close to horizontal, and close to parallel. Small changes in force line angle will make the intersection move all over the place. Small ride motions can make it move from above ground and way out to the right to below ground way off to the left. Does this mean the geometric anti-roll or pro-roll moment is varying all over the place, or that the car's properties in a banked turn are varying all over the place? Not at all, because the force line slopes and individual wheel anti-roll and pro-roll are not changing much. And, correspondingly, the height of the roll center as I define it doesn't change much.

All of this holds true regardless of whether the turn is banked, and regardless of what kind of suspension is at the other end of the car.