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: 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 BELOW GROUND

*Your October column* [based on the June 2004 newsletter] *addressed a reader's question about the possibility of a roll center being deliberately placed below ground level. I've thought quite a bit about what I call "anti-jacking", and I've seen no real references to below-ground roll centers. If we put the roll center below ground, wouldn't this tend to put more force on the inside wheels than the outside wheels? Because of the non-linearity of the coefficient of friction, wouldn't this give, effectively, more total friction, and therefore more centripetal acceleration?*

Taking the last question first, if we assume that the inside and outside tires are symmetrical and identical, and are running at identical absolute camber, with the same camber direction relative to the turn (e.g. x degrees positive on the inside wheel and x degrees negative on the outside wheel), and assuming the car has 50% left weight at static, then we'd ideally like no load transfer inward or outward. If the outside tire has more favorable camber than the inside one (common in road racing), or the outside tire is larger (common in oval track racing, rules permitting), then we'd ideally like a bit more than 50% of the load on the outside tire.

As a practical matter, however, we always get more load transfer than we'd like, and we're always trying to reduce it. We don't really want more than half of the load on the inside wheels, but we're always trying to move the situation in the direction of more load to the inside.

The total load transfer for both wheel pairs, at a given lateral acceleration, depends only on the center of gravity height and the track width. The only way to get zero load transfer at both ends of the car would be to have the c.g. at ground level. The only way to get load transfer inward at both ends of the car would be to have the c.g. below ground level. This is of course impossible for a car as we would normally conceive it, running on a flat road. It would only be possible if the car could hang in a trench between two tracks, or if the wheels ran on elevated rails.

About all we can do with roll center height (or, more properly understood, with geometric anti-roll/pro-roll), springs, and anti-roll bars is to control what share of the inevitable load transfer is borne by the front wheel pair compared to the rear. We also can control the amount of roll, which has a small effect on total load transfer because the c.g. moves outward slightly as the car rolls.

We normally think of the sprung mass as a rigid body, supported on two roll-compliant support systems (the front and rear suspensions and wheel pairs). The two roll-compliant systems resist the rigid body's roll moment in parallel with each other. Each suspension system absorbs a portion of the roll moment proportional to its overall roll resistance.

That overall roll resistance has three components: geometric (from the suspension linkages), elastic (from the springs and anti-roll bars), and frictional (from the dampers and the mechanical or Coulomb friction in the system).

There is another component of load transfer as well: the unsprung mass component. This is commonly thought of as acting only through the tires, and not through the suspension. It would therefore be unaffected by suspension geometry. Actually, this is not strictly true with independent suspension, although it is correct for beam axles. A reader recently sent me some very insightful information about this, which we will take up in a future issue. The unsprung masses in an independent system do usually create some moments on the sprung mass, through the suspension linkage, which are resisted by the springs and anti-roll bars and are affected by both elastic coefficients and linkage geometry. We will ignore these effects for now, in the interest of simplicity.

If the roll center for the front or rear wheel pair – understood in the usual way, as the intersection of the front view force lines – is below ground level and between the wheels, that implies geometric pro-roll on both wheels. The outside wheel's linkage generates a downward jacking force in that wheel's suspension, and the inside wheel's linkage generates an upward jacking force. The resulting couple acts to roll the sprung mass outward, exaggerating roll. Considered in isolation, this does add load to the inside wheels, and remove load from the outside wheels.

However, if this moment were not resisted somehow, the sprung mass would accelerate outward in roll and wouldn't stop: the car would turn over. So it falls to the springs, anti-roll bars, and any frictional forces to resist the overturning moment, unassisted by any anti-roll forces from the linkage geometry. Additionally, the springs, anti-roll bars, and frictional effects must resist the pro-roll moment created by the linkages.

Therefore, if we have pro-roll geometry at both ends of the car (roll axis below ground), the elastic component of the roll resistance just gets very large, and there is still a net anti-roll moment from the suspension as a whole. Since the suspension is supported only by the tires, any moment generated in the suspension reacts through the contact patches and creates a load change there. That means there is net outward load transfer, even if the geometric moments are the "wrong" way.

Actually, it is theoretically possible to get inward load transfer, with a c.g. above ground level, at one end of the car only. I doubt that there is any real-world situation where we'd want such a setup, but it is an interesting hypothetical curiosity. If we used geometric pro-roll, combined with a wheel rate in roll of zero or nearly zero, at one end of the car only, we could achieve inward load transfer at that "soft" end. To get sufficient ride stiffness, we'd have to use a springing system that acted only in ride, such as the Z-bar at the rear of a Formula Vee or the third spring on a modern high-downforce car.

The other end of the car would then have to resist not only the overturning moment of the entire car, but also the pro-roll moment from the suspension at the "soft" end of the car. We would then get outward load transfer at the "stiff" end greater than the total outward load transfer for the car, and a small inward load transfer at the "soft" end, equal to the difference.

This would work up to the point where the "stiff" end lifted a wheel. The car would then immediately flop over onto the bump stops at the "soft" end. The "soft" end would then no longer be soft, and we would start getting outward load transfer at both ends of the car.

As for net downward jacking, in most cases if the front view force line intersection is below ground and between the wheels, we will get some net downward jacking. However, it is possible we could get net upward jacking if the inside wheel has a substantially steeper force line slope than the outside wheel. That might create an upward force from the inside wheel's linkage greater than the downward force from the outside wheel's linkage, despite the smaller contact patch force at the inside wheel.

This would imply a force line intersection off-center toward the inside wheel, though still within the track width. That is not necessarily an unrealistic case. We could easily encounter it in a lowered production car strut suspension, in a rolled condition. This is an interesting case, because it illustrates that there are situations where the car does not roll about the force line intersection, or even do anything close to that. If it did, it would have to move downward rather than upward with roll – and if the upward jacking on the inside wheel exceeds the downward jacking on the outside wheel, the car clearly doesn't do that at all.

## ROLL MOMENTS FROM LONGITUDINAL ANTI

*Some people tell me that anti-dive and anti-squat act to stiffen the suspension when forward or rearward forces are present at the wheels. Does that mean these effects add roll resistance? How does this really work?*

Anti-dive at the front wheels does impose a bit of a roadholding penalty, because it requires the contact patch to move forward as the suspension compresses, at least if we imagine the imagine the wheel as locked. Or, we might view this effect as requiring an increase in wheel rotational speed with respect to the caliper, as the suspension yields to a bump. The effect varies somewhat with the abruptness and height of the bump, the outside diameter of the tire, whether the hub moves forward in compression or not, and how hard we're braking. However, anti-dive, even in an amount that completely eliminates dive (100% anti-dive), does not completely lock up the suspension as some authors have suggested. It merely acts counter to our desire to have the wheel move backward relative to the car, as well as upward, when the wheel hits a bump.

At the rear of the car, things are a bit different. Anti-lift in braking and anti-squat in forward acceleration cause the contact patch to move rearward in compression rather than forward, while of course the bumps still come at the wheel from the front. So rear longitudinal anti actually improves the system's ability to yield to a bump.

Jacking forces, whether lateral or longitudinal, do not in themselves add to wheel rate or subtract from it, provided that the jacking forces do not change with wheel movement. The jacking force simply acts in parallel with the wheel rate or elastic forces, which are displacement-dependent. That doesn't mean the jacking forces can't create roll moments or affect wheel loads. They definitely can.

While anti effects do not necessarily vary as the suspension moves, it is very common for both longitudinal and lateral anti effects to vary with suspension displacement. Most often, both lateral and longitudinal anti diminish as the suspension compresses, and increase as the suspension extends. This is not so in all cases, however. A counter-example would be the trailing arm front suspension on a VW beetle. The arms are equal-length and parallel to each other, and at static condition they slope down a bit toward the rear. As the suspension compresses, the arms quickly reach horizontal, then begin to slope upward to the rear. The suspension goes from decreasing pro-dive to increasing anti-dive. The direction of change is consistently toward anti-dive as compression increases.

A NASCAR front end is an extreme case of the opposite, and more common, tendency. It changes rapidly toward pro-dive with compression, because the lower control arm is a semi-leading arm (pivot axis angled dramatically outward at the rear in plan view) while the upper control arm is almost a purely transverse arm (pivot axis close to longitudinal in plan view).

If the slope of the suspension's longitudinal force line varies with suspension displacement, then assuming a constant longitudinal force at the contact patch, the jacking effect can act in a manner analogous to a spring force: it may increase or decrease according to displacement. It won't necessarily increase with compression, however. If it does increase with compression, as in the case of the VW, it can loosely be thought of as adding wheel rate. If it decreases with compression, as with the NASCAR suspension, it can be similarly thought of as subtracting wheel rate.

On the face of it, we might suppose that if the front wheels have the same amount of anti-dive – that is, the same longitudinal force line slope – then their longitudinal-force-induced jacking forces will lift both the right front and the left front corners of the car with the same force, and this will not create any roll moment, although it will create a pitch moment. Therefore the anti will neither wedge nor de-wedge the car.

This is true, but we must remember that the longitudinal forces at the two contact patches may not be equal. In fact, if we are cornering, they are unlikely to be equal.

The longitudinal forces at the front contact patches actually come from two sources. One is braking, which may or may not be present. The other is the induced drag that a tire produces when running at a slip angle, which is present any time we're cornering. That induced drag varies with the amount of load on the tire, and it is also affected to some degree by camber and toe. Generally, though, it is safe to say that the induced tire drag is greater on the outside wheel. Therefore, the jacking force on the outside wheel will be greater for a given force line slope than on the inside wheel. That will tend to wedge the car (add diagonal percentage, i.e. outside front tire load plus inside rear, as a percentage of the whole), and tighten it (add understeer).

Braking forces, on the other hand, tend to be more nearly equal. Theoretically, if we are short of the point of lockup, with no front tire stagger, and the brakes are as identical as we can make them, the braking forces will be identical at the two front wheels. Actually, with no tire stagger, the outside tire will act slightly smaller if we are braking while cornering, because it will deflect more vertically and therefore have a reduced loaded radius. Reducing the loaded radius reduces the effective radius (increasing the revs/mile), though not by the full amount of the deflection change. This effect will make the braking force slightly larger on the outside wheel.

If we are braking and cornering at the same time, we will have both a drag component and a braking component. If we are braking hard and cornering gently, the rearward forces at the front contact patches may be fairly equal, especially if the car has some toe-out. If we are braking gently and cornering hard, the rearward force may be substantially greater on the outside wheel, especially if there is some toe-in.

When we are off the brakes entirely, and cornering hard, we can say fairly confidently that the rearward force will be greater on the outside front.

Can we say, then, that adding anti-dive makes the car tighter? Well, we almost can. If we add anti-dive only on the outside wheel (right front, for oval track), that will tighten the car. It will do this even when we're not braking. If we add anti-dive evenly on both front wheels, that may also tighten the car, due to the greater rearward force on the more heavily loaded tire. Any such effect will tend to be more pronounced in hard cornering than in hard braking.

However, if we increase anti-dive only on the inside wheel (left front, for oval track), that will loosen the car (add oversteer) instead. This effect will be present whether we are braking or just cornering. So this would be a situation where we'd be increasing overall anti-dive yet adding oversteer.

One might suppose that adding anti-dive on just the inside or outside wheel is impossible for road racing, but as we have noted, suspension layouts vary as regards how anti-dive changes with suspension movement, and such effects can be used to control the left/right balance of anti-dive when the car is in a rolled condition, even when the car has to turn both ways. Such effects are often hard to manipulate on an existing car, but they deserve consideration in the design phase.

All of the above is based on the principle that adding diagonal percentage tightens the car and reducing diagonal percentage loosens it. When applying these principles, it is also important to bear aerodynamics in mind. More anti-dive will cause the front of the car to ride slightly higher through the turns, particularly with soft front springs. If static ride height or valance height are not adjusted for this, the greater ride height when cornering may add understeer purely by reducing front downforce.

Now, what about anti-lift and anti-squat at the rear? As at the front, the jacking forces will depend on both the force line slopes and the magnitude of the forces at the contact patches. And, as at the front, any roll moments created will depend on the difference in jacking forces at the right and left sides. Two things are different at the rear: we can have forces forward or rearward (this whole discussion assumes rear wheel drive), and we have various kinds of differentials (or lack of) that can influence the relative magnitude of the longitudinal forces, and in some cases even their relative direction.

Like the front tires, the rears generate drag when running at a slip angle. However, it is unusual for that to be the only longitudinal force. The rear tires are almost always either propelling the car or retarding it. Even in roughly constant-speed cornering, the rear tires are making enough forward force to overcome the front tire drag and the aerodynamic drag.

The rearward forces at the rear contact patches when braking or trailing the throttle will tend to be fairly equal if we have an open differential. If we have a spool or a limited-slip, however, any rearward force will be greater on the faster (usually the outside) wheel. When under power, again the forces will be fairly equal with an open diff, but any locking effect will result in more force at the slower (usually the inside) wheel. At least, that holds true up to the point of inside wheelspin. Then the outside wheel may make more forward force than the inside.

All of this makes it fairly complex to predict the distribution of longitudinal force at the rear. However, we can say this much: in braking, more anti-lift or less pro-lift on the inside rear loosens the car (adds oversteer); more anti-lift or less pro-lift on the outside rear tightens the car (adds understeer). Under power, more anti-squat or less pro-squat on the inside rear tightens the car (adds understeer); more anti-squat or less pro-squat on the outside rear loosens the car (adds oversteer). Effect of more anti-lift or anti-squat geometry added evenly on both sides depends on the distribution of longitudinal force between the two rear contact patches.

Distribution of longitudinal force also affects handling balance because it creates yaw moments. In general, we can state that more longitudinal anti of any type intensifies these effects. For example, more induced drag at the outside front creates a yaw moment promoting understeer. If there is more anti-dive, there is also an increase in diagonal percentage, which intensifies the tightening. If there is more forward force at the inside rear, that creates an understeer-adding yaw moment. If there is ample anti-squat, again we get an increase in diagonal percentage, intensifying the effect. More rearward force at the inside rear creates a yaw moment that adds oversteer. More anti-lift there reduces diagonal percentage, again intensifying the effect. So we may say that, in general, increased longitudinal anti geometry makes a car more sensitive to its tires' load and force distribution.