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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. Topics and questions are also drawn from my posts on the tech forum at www.racecartech.com , where readers can see chassis consulting done for free. Readers are invited to subscribe to this newsletter by e-mail.

WEIGHT TRANSFER IN WINGED-OVER SPRINT CARS

I see winged sprint cars rolling to the left in left turns when cornering on dirt. How does this happen? What is going on with the wheel loads when the car does this? How does this behavior impact the car's response to spring or torsion bar changes?

Roll and load transfer in winged sprint cars make a very interesting analysis exercise, and a very good lesson in the distinction between roll and wheel load transfer ("weight transfer"). When equipped with a high wing with big side plates, a sprint car can transfer wheel load rightward while rolling leftward. Or, on a very slippery surface, the car theoretically could actually transfer wheel load leftward, though this would be unusual.

Disregarding aerodynamic forces for the moment, total wheel load transfer in any car is simply the car's weight, times lateral acceleration in g's, times its overall CG height, divided by track. This is the number of pounds by which the inside wheel pair loading is reduced, and the identical number of pounds by which the outside wheel pair loading is increased.

To estimate front and rear wheel load changes, this total load transfer is customarily broken down into the following components:

1) **Load transfer of the front and rear unsprung masses.** These act independently at the front and rear, and act through the tires but not through the suspension. The rear unsprung mass load transfer is substantial when the car has a live axle. Each of the two unsprung masses has its own center of mass, or center of gravity, approximately at hub height.

2) **Geometric load transfer** (sprung mass load transfer through the suspension members). For the front or rear wheel pair, this component is equal to the pounds of sprung weight at that end of the car, times lateral acceleration in g's, times roll center height at that end of the car, divided by track width at that end of the car.

For a car with high roll centers, such as a sprint car, this component is the largest one. For a car with low roll centers at both ends, such as a car with four-wheel independent suspension, this component is small. For a stock car or IMCA-style modified or dirt Late Model, with independent front suspension and a live axle in back, this component is small at the front and large at the rear. For a roll center below ground level, this component is negative (leftward, in a left turn).

3) **Elastic load transfer** (sprung mass load transfer through the springs, including anti-roll bars or other roll-resisting interconnective springs if present). To calculate this component, we need to know the wheel rate in roll for each wheel, and the wheel's distance, laterally, from the sprung mass CG plane (the longitudinal, vertical, plane containing the sprung mass CG). Using these wheel rates and moment arms, we calculate the elastic (spring-derived) roll resistance, or angular anti-roll rate, for each end of the car, in lb-in per degree of roll. Adding the front and rear angular anti-roll rates, we have the angular anti-roll rate for the whole car.

That angular anti-roll rate resists the sprung mass roll moment about the roll axis. This roll moment is equal to the sprung weight, times lateral acceleration in g's, times the moment arm of the sprung mass CG about the roll axis. (This is measured perpendicular to the roll axis in side view, not vertically in side view or diagonally in three dimensions.)

If we divide the roll moment (lb-in) by the overall elastic anti-roll rate (lb-in/deg), we get the amount of roll (deg). Working backwards, we divide the front and rear elastic anti-roll rates (lb-in/deg) by the roll (deg) to get the elastic anti-roll moments for the front and rear wheel pairs (lb-in). We then divide the wheel pair elastic anti-roll moment (lb-in) by the wheel pair track (in) and we have the elastic component of the load transfer (lb) at each wheel of the pair.

Sprint cars have a soft wheel rate in roll, and a small moment arm from sprung mass CG to roll axis. Therefore, their elastic load transfer is a fairly small component. Their roll angles can be considerable, despite the high roll axis, due to the soft springing. Any force acting at a large distance from the roll axis can roll a sprint car a lot, without creating a lot of wheel load change. If you have a sprint car on wheel scales, and you push laterally on the roll cage, you can easily rock the car, while the wheel scale readings change relatively little, compared to rocking a stock car or a road racing car the same amount (which would also take a much stronger push).

In a car with a low roll axis, elastic load transfer is the largest component. In a stock car, elastic load transfer is the largest component at the front, and relatively small at the rear.

4) **Load transfer due to lateral CG movement.** This component is very small in cars, but can be highly significant in heavy trucks and other tall vehicles, especially when the cargo can shift or slosh.

These four components comprise the factors in lateral load transfer, assuming a flat (unbanked) turn, constant speed, constant turn radius, and rigid tires – and ignoring aerodynamic influences. This is of course a simplified model – complex enough already though, right?

When the car is not in steady state cornering, there are additional factors. Actual cornering involves longitudinal accelerations as well as lateral ones. These effects are highly significant, especially in oval track racing. But for simplicity, let's just consider the effect of lateral acceleration increasing on entry and decreasing on exit.

When the lateral acceleration is changing, the car's roll angle will be changing. That is, the car has a roll velocity, not just a roll position. The suspension is in motion. This is called a transient condition. In transient cornering, we have additional load transfer factors:

5) **Frictional load transfer.** This includes forces generated by the shocks and also any other friction in the suspension. These frictions create front or rear frictional moments that act in parallel with the elastic moments, and may either add to the elastic moments or subtract from them. In general, frictional moments add to elastic moments any time the suspension is moving away from static position, and subtract from elastic moments when the suspension is moving toward static position. Hydraulic forces are velocity dependent. Dry friction forces are more or less independent of velocity.

6) **Minor inertial effects.** These arise from accelerations (changes of velocity) of the various elements of the car, particularly the sprung mass in roll. Properly understood, the centrifugal force and all other forces the tires have to overcome when cornering are also inertial effects. Roll inertia is minor compared to these. However, it can have significant effects in cars that roll a lot, in sudden maneuvers. Roll inertia explains why a vehicle may corner in a stable slide on a skidpad, yet overturn in a lane change or slalom test.

Breaking down the components of roll resistance like this allows us to predict the effects of changes to the various design and tuning factors that govern these components, in a sprint car or any other.

Now let's look at the forces from the wings. On a sprint car, we actually have two wings, but the rear one generates the most significant forces; it's big, and it's far enough from the bodywork to get ample airflow. It's also up high, and has big side plates. These are the factors that allow it to roll the car leftward, when the car is passing through the air at an angle (i.e., is in aerodynamic yaw).

Each wing generates a downward force. This acts approximately in the CG plane, or a little more strongly on the left wheels than the rights. It loads all four wheels. This increases the longitudinal and lateral forces available from all the tires, which of course is why people use wings. This, in turn, increases all accelerations generated by tire forces.

The downward forces from the wings, in themselves, have little effect on roll or amount of lateral load transfer. The added tire forces affect roll, but if anything they increase the tendency to roll rightward.

The wings also generate a rearward drag force. This unloads the front tires and loads the rears, and causes some rearward pitch.

Finally, the wings, especially the side plates on the main one, generate a leftward drag force when the car is in aerodynamic yaw. That's what rolls the car left. This force is small compared to the leftward force from the tires or the rightward inertia force (centrifugal force) at the sprung mass CG, but it acts on a huge moment arm about the roll axis. It's like your hand on the roll cage in the earlier example of easily rocking a sprint car on wheel scales without affecting the scale readings a great deal, compared to other kinds of cars.

In round numbers, a sprint car's roll axis is about a foot above the ground, the overall and sprung mass CG's are about a foot and a half above the ground, and the wing is about 6 feet up.

So the car sees a net leftward load transfer if the side force at the wing is more than ¼ as great as the centrifugal inertia force at the CG. This means the wing has to make ¼ of the lateral force. It has to make 1/3 as much force from air as the tires make with four sticky rubber footprints on the ground, aided by downforce. That's not impossible, but it takes a lot of air speed and a very slippery track.

However, the car will roll leftward if the side force at the wing is more than about 1/10 as great as the centrifugal inertia *of the sprung mass only*. This is a much easier condition to achieve.

In this state, the elastic component of the load transfer is negative (leftward), but the geometric load transfer is still positive (rightward) and is greater than the elastic load transfer. The unsprung mass load transfer is still positive (rightward). The load transfer due to sprung mass CG movement is negative (leftward), but very small. Thus, the big components of the load transfer are not reversed, just the small ones. The car is transfering wheel load rightward despite rolling leftward.

Since the elastic load transfer is reversed, the usual effect of spring changes is also reversed. More rear spring adds wedge when cornering and tightens the car.

Effect of roll center height is as usual. Raising the front roll center tightens the car; raising the rear roll center makes it looser.

Effect of static cross (diagonal percentage) is as usual. More load on the right front and left rear tightens the car, except perhaps on entry when slowing mainly with the rear wheels .

Shock tuning, assuming the track is smooth enough for low speed damping of roll motion to matter, works backwards. To add wedge on entry, add RR rebound damping or LR compression damping, or reduce RF rebound or LF compression. To add wedge on exit, add RF compression or LF rebound, or reduce RR compression or LR rebound.

Bump rubbers on the RF or LR tighten the car, when the car is leaning on the rubber.