My Big T.O.E. on Dirt

I have been a dirt track racer for life, attending races since I was 3. I am also a fan of theoretical physics. There are proven formulas for Newtonian physics (basic understanding of how things move) and there are formulas for quantum physics (how atoms and particles move). But the two fields of study have great contradictions among them, things seem to work differently on an atomic level than they do at our level. Ever since Albert Einstein's theory of general relativity, physicist have been trying to tie the two fields together, to devise a theory that fully explains all known physical phenomena into a Theory Of Everything (T.O.E.). Einstein himself died trying to develop a big T.O.E. Theoretical physics is the field of cutting edge theory in this area.

Dirt track racing needs a big T.O.E. A theory to explain why the adjustments we make on our race car have the effects they do. Although we may know how adjustments affect the car, we do not always know why the adjustments do what they do. Oh we may think we know or we may develop some theory of why they do what they do, but do we really understand? It has been my life long search to understand all that I can about dirt track chassis setup. Not until after reading tons of books, talking to hundreds of racers, thinking obsessively about it, meditating on it, collecting/analyzing gobs of data, and racing for 34 years that I think I may have a big T.O.E for dirt track racing. Although I think I have it clear in my head, writing it down is another issue. I also must warn you, I got a D in college English grammar.

Side Bite? Where did that term come from?

On asphalt, without wings, there are lots of books written based on the laws of physics, with tons of skid pad testing to back them up. Dirt track racers have never paid attention to these formulas and principles because when you take a car that handles well on asphalt, it does not do to well on dirt, many changes need to be made to get it to work to the best of its potential when sliding on dirt. It was discovered that the right side tires needed to be moved in and the center of gravity needed to be moved up. The idea of side bite, the tires digging into the dirt when sliding, then became someone's reason of why these changes needed to be made. Makes sense and explains why the adjustments work.

To the typical dirt racer **Side bite** then is the idea that the car is rolling to the right, forcing the tires to dig into the dirt providing more traction. Kind of like a paddle in the water, the further you push the paddle down into the water, the more force you can put through the paddle to propel the boat.

However, the only time this understanding of side bite really applies is when the tire grooves (paddles) can work into the dirt (water), which is when the track is wet or slightly wet, in this condition traction is not a problem. Wouldn’t you agree? After warm ups, or maybe into the heat races, the tire's grooves can no longer work into the dirt, at least not much because the dirt is harder than the rubber. So this idea of side bite and trying to make the grooves work into the dirt by applying more weight to the right rear for traction doesn't make much sense.

I have proven this to myself in years past by loading the right rear tire more and more trying to achieve more traction. While at times it would work, many times it did not. I could not put my finger on why this was the case.

Fundamentals

Please keep in mind that these are not my ideas; this stuff I am about to show you has been proven and is documented in many books. In physics there is a whole branch of study called **vehicle dynamics**, which is where all the language and facts come from. The automotive industry has invested billions in dollars and time to document, research and test. Again, all of the study is on asphalt, not dirt, which is why it has gotten misrepresented and **misapplied.** Dirt is a whole lot more complicated and inconsistent than its *prissy* sister! But the laws of physics remain the same.

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There are two basic formulas used in the vehicle dynamics world, one used for longitudinal weight transfer (front to back), and one used for lateral weight transfer (side to side). They look like this:

Lateral Weight Transfer = (Weight x CGH / TW) x G(lateral)

Longitudinal Weight Transfer = (Weight x CGH / WB) x G(longitudinal)

Where Center of gravity height = CGH, Tire offsets = Track Width or TW, Wheel Base = WB, G-force = G, and Weight of the car = Weight

Don't over complicate this, just understand that to change the amount of weight transfer we need to change the CGH or change the tread width or wheel base. The other variables are not relevant. We are also not going to slow down (decrease G's). We are not going to add weight to the car, we need to keep the car light for acceleration. We do need to keep in mind that a heavier driver will very quickly change the way a car handles. He will change both the weight and the CGH.

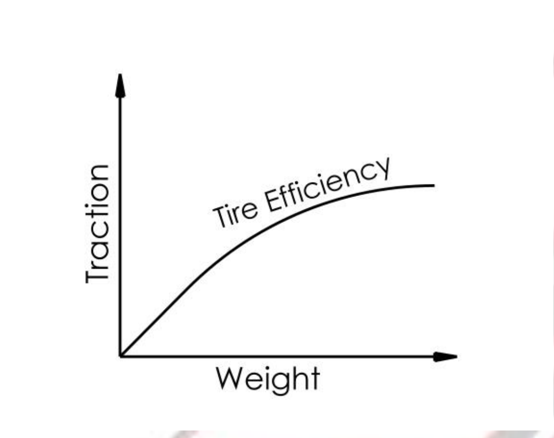
I would like to change that term side bite to **lateral traction**, lateral means side to side. I want to redefine the idea of side bite, lateral traction, and why dirt chassis need to be setup different than asphalt cars.

Forward bite is what dirt track racers use to describe available traction to propel the chassis forward. It makes sense, but in vehicle dynamics the term is **longitudinal (**front to back**) traction**.

These two formulas contain the only variables that affect weight transfer. Everything that you adjust on your car will change the way your car handles because it changed one of these variables or it change tire efficiency.

Tire Efficiency

So how do we achieve maximum traction? When we add weight to a tire the traction goes up, but not linearly (in a straight line), according to skid pad tests, it drops off pretty quick, traction does not increase in proportion to the weight that is added.



As weight is added to the right rear tire, it will get more traction than it did with less weight on it, this much is true. But here is the catch, to gain that traction, weight had to come from somewhere, some other tire needs to loose weight and therefore loose traction. Since we are only considering lateral weight transfer here, we didn't take the weight from the front tires, it had to come from the left rear tire. So now, by definition of the above graph, the left rear tire lost more traction than what the right rear gained.

Fundamental truth: *Maximum traction in the rear of the car is achieved when both rear tires have the same amount of weight on them, and as much as weight as possible is transferred to the rear.*

Actually, due to the larger foot print or contact patch of the right rear tire, its efficiency curve is different than the left rear tire (it can handle more weight before the traction falls off), as a result, about **30%** more right rear weight is needed to maximize the traction. Likewise, maximum traction in the front is achieved when the two front tires are equally loaded.

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The weight on a race car is constantly shifting around, it is **dynamic**, it is not **static** (constant, still, not changing). We know that weight is going to transfer from the left to the right, then we can assume that we will need to start out with, in the static state, more weight on the left rear and less on the right than what we want to end up with in the middle of a turn. The question is how much.

Maximum Traction Achieved

Now let's go back and look at the formulas again, consider **lateral traction** first. How do we achieve maximum lateral traction?

- Keep the CGH low, although some of this is controlled by the design of the car, we can raise and lower the CGH. By lowering the car we transfer less weight and keep the rear tires more equally loaded providing more lateral traction.
- Increase tire offset (TW) by offsetting the tires. Based on the formula, a bigger TW number will yield less weight transfer.
- Make the car as **light weight** as possible. Less weight means less transfer.

We will talk about track width (tire offsets) later.

Our 600cc sprints will pull between 0.8 and 2.5 g's in the middle of a turn depending on track conditions, size, and shape. The net result then is that with a normally designed car, it will be transferring a total of 190 pounds on a slick track where the lateral g force is low and about 80 pounds of that is in the rear depending on roll couple (more on that in a minute) and many other factors. That means, in this example, we need to start out with 35 pounds heavy on the left rear to end up with 30% more right rear weight in the middle of the turn. (530lbs in the rear 283lbs LR/247lbs RR static, after weight transfer 203LR/327RR). You can calculate this stuff out. It is actually easy, until you add a wing on top of the car, more on that later.

Now let's look at forward drive or **longitudinal traction**. Although tire efficiency does not increase as much as we add more weight, it still goes up. For more longitudinal traction, we need to increase weight transfer to the rear. How do we do that?

- **Raise** the center of gravity CGH
- Shorten the wheel base WB
- Increase the horse power to increase the longitudinal

Yes, all that talk we just did above about lowering the CGH works great for lateral traction, but for longitudinal traction, or whenever we are spinning our wheels from lack of drive, the opposite is true. So that is why there has never been a clear advantage to raising or lowering your car, you will help one type of traction and hurt another.

Adjustments

You have to think about what you are adjusting and what you want to achieve. Think about the size of the track and/or the type of car to which we are applying these principles. A key concept is that if the horsepower is not high enough to break the tires loose in the forward direction, then the longitudinal traction is not an issue and we need to focus on lateral traction. If we can break the wheels loose anytime we want, then we need to focus on gaining longitudinal traction.

Of course for a given car, due to gear ratio changes, it is much more likely to spin tires due to lack of longitudinal traction on a small track than a large one. As far as micro sprints go, on tracks about 1/3 mile and bigger, longitudinal traction is generally not much of a problem. Track shape comes into play too as paper clip shaped tracks (tight turns long straights) tend to need more longitudinal traction than tracks that are more round shaped.

Sometimes you can look at the angle of the feathers on the tires and determine if you are spinning more in the longitudinal or lateral direction and make your adjustments accordingly.

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Wheel Base

Some of you caught the part about wheel base. You get more weight transfer from the front to the rear with a shorter wheel base, but the disadvantage to a short wheel base is you lose rear weight percentage in the static state. With a long wheel base car, at least if it is designed correctly, will have more rear weight percentage in the static state, so much so that even with the decrease in weight transfer due to the longer WB, the end result is that it still has more rear weight under acceleration, think top fuel drag racing car. You can run the numbers and check me.

Front and rear roll couple (roll stiffness) and Spring Rates

Looking at the lateral weight transfer formula, spring rates have nothing to do with how much weight transfers aside from their input on CGH. For lateral traction, weight transfer is bad due to cause's unequal tire loading in the rear. What springs do control though is where the weight goes when it is transferred. If it goes to the front, the car is tighter because it is transferring the weight from the left front to the right front keeping the rear tires more equal. If we only increase the right front spring rate, more weight transfers up front resulting in a tighter car.

Fundamental truth 2: *A softer spring will transfer less weight to that corner of the car than a stiffer spring.*

A stiffer spring on one corner = more weight transfer to that corner, that is why a stiffer right rear spring makes the car looser. The fact about this concept is when you put a softer right rear bar in, the car rolls more to the right rear but it is actually transferring **less** weight that is why it gets tighter. Although the same amount of overall weight is being transferred, the weight is being transferred up front and less in the rear. Imagine if you took the bar out of the right rear, the car would roll a ton to the right rear but would transfer no weight there; all the weight would be transferred up front. Again, this is a fundamental law of vehicle dynamics; I am not making this up.

Dirt track racers have botched this stuff up so bad, it took me 27 years to flush it all out of my head and rethink it all.

Things are not always as they appear. It may look like the car is transferring a ton of weight to the right rear and the car really is tighter than it was before, and the old idea of side bite seems to be true**, it is not**. Forget the old idea of side bite, it is wrong.

Bottom line: when you see a car rolling on the right rear, the car is tight because it is transferring less weight, not more weight. It is keeping more weight on the left rear resulting in a tighter car. It is <u>**not**</u> rolling more weight on the right rear pushing it into the dirt more making the car tight.

Adjustments: To give the car more lateral traction, go to a softer right rear bar or a stiffer right front spring. A stiffer left rear bar will have two effects, raising the car (higher CGH), and it will add static left rear weight. This will tighten the car in the lateral and the longitudinal directions depending of course on the size and shape of the track.

In the automotive world this concept of front and back spring stiffness is called ***front and rear roll couple*** or roll stiffness. An increase in front roll couple makes the car tighter and a decrease in rear roll couple makes the car tighter. As we stiffen front roll couple, more weight transfers up front and less transfers in the rear. The rear tires stay more equally loaded and the car gets tighter.

Right side springs affect the cars roll couple when negotiating a left hand turn and the car is rolling to the right. Because we do not turn right, the left side springs do not play much of a role except for static weight and ride height considerations. Unless of course, you race with a wing.

Winged Down

This is where none of the asphalt formulas or vehicle dynamics concepts were ever devised. The huge **wings** and side boards that we run are unique in the racing world. No where else is there a wing that has such huge side boards to cause such a drastic side force. This is the thing that throws things astray, the top wing with huge side boards; they actually cause weight to transfer to the **inside** of the car for a portion of the turn. This happens because when we enter the turn with such high speed and then we all of a sudden turn the car and make our wing panels face a huge wind. The wind pushes so hard on the side boards that it **overcomes** the weight transfer caused by the side g-force. Imagine going 90 MPH in your car and trying to hold a sheet of plywood up, can you imaging the force?



Here you can see in these three pictures the cars are all winged left and transferring weight to the left side of the car in corner entry.

We need to start looking at the corner in two distinct phases; these phases will change from track to track. It is what I will call **winged left**, or winged down. The first part of the turn when the car is winged (rolled) left due to the wing side boards, and **roll right**, which occurs when the car slows enough that the g-force is greater than the side force generated by the wing panels. The bigger the track the longer the winged left stage will be. As a driver you need to pay attention to how the car is working when it is winged left and rolled right and make your changes accordingly. The period of the winged down or roll left phase of the turn is different for each size and shape track, and it also changes at the track during the night as the track goes **slicker**. A track with tighter turns relative to the length of the straight will have more winged left effect; tracks that are larger will also have more winged left effect.


You can see in the above pictures that the cars are now transferring weight to the right side of the car in the rolled right phase on corner exit. Interesting too you can see in Robie's 55 car, the left front shock is topped out and just about off the ground, all the weight that was on the left front has now mostly transferred to the right rear and right front, He can still steer off the right front, so this is not a bad thing.

Up until now, most of what we were using to set the balance of our car was the right side springs. Now that we recognize that weight transfers to the inside or the left side of our car for a portion of the turn we need to look at the **left side** springs and offsets. Everything we applied to the phase of our car when it was rolling right needs to be applied on the left side because it is transferring weight to the left.

Big Concept: Left side springs and offsets control the handling during the winged down phase, right side springs and offsets control the roll right phase.

Increasing the left rear spring rate will loosen the car while winged down because it will increase the roll left rear roll couple stiffness and keep the weight on the front tires more equally loaded. Softening the left rear spring will tighten the car during roll left or winged down. Of course when our car hits the ground, the spring rate not only becomes infinite, but the weight is now transferred through the frame rail to the track and not the tire to the track. The tire gets a whole lot better traction than the frame rail. Bottom line, don't let the car bottom out**.**

ARS has just developed an amazing shock that helps the problem of the left rear bottoming out during corner entry, they call it the WX shock. It acts like a three stage shock that really stiffens up when the shock sees high velocities like that of winging left on entry. They make a WX version for the right rear as well that helps running the cushion and taking bumps. This stiffening affect will keep the left rear from bottoming out. If you do not have one of these shocks, a bump rubber is a good fix and allows us to run a softer left rear torsion bar to help tighten up on entry. Keep in mind that when the car gets into the bump rubber on the left rear shock, the spring rates also climbs very high, this will also make the car loose on entry, but is a whole lot better than bottoming out.

This picture shows the proper use of a left rear bump rubber. Use the shims to adjust exactly when the car gets into the bump rubber. Try to get the shock to hit the bump rubber about ¾" before the frame hits the ground.

Winged down Corner weights

During the winged down phase of the turn, when weight is rolling from the right rear to the left rear. More static right rear-left front weight will make the car tighter. Reason is that starting out with more right rear weight, when the car transfers to the left the end result will be the two rear tires will be more equal in weight.

The opposite is true during the roll right phase; more initial left rear-right front weight will result in a tighter car. Got it? When we add left rear\right front weight or what some might call cross bite, yes the car will get tighter during roll right, but looser during roll left.

Again, think about the size of the track you are on and how long the winged down phase is, and where you are trying to tighten the car when determining where to put your turns.

Tire offsets

Same theory applies; moving the right rear in will add more static right rear weight and will cause more weight transfer. These effects are good for tightening up the car when winged down, but opposite for roll right.

More wing speed means we need to keep the right rear in further to get the car tighter, a slicker track means less weight is transferring to the right rear during roll right, but generally our winged down phase is just as long as it was on a tacky track, so the right rear can be moved in. However there is a point of no return where you can go to far and have too much weight on the right rear. Also, remember in our lateral weight transfer formula, a larger TW number will decrease weight transfer which will increase our rolled right traction. So there is a balance. The exact numbers vary from car to car, track to track, and surface to surface.

There is also a jacking affect that takes place when the right rear is moved in. It causes the car to lift up on the left rear raising the CGH creating a lot of drive. This can be very beneficial on a small track. On a big track, we can't move the right rear out because ti will loosen the car on entry due to the loss of right rear weight.

The left rear tire can be moved out to tighten up when winged down. This is a result of the weight transfer formula being applied to roll left, a wider TW or more offset will result in less weight transfer. However, moving the LR out will decrease LR static weight which will hurt rolled right traction.

Summing it Up

If you are loose when the car is winged left, generally change left side springs and/or left side offsets and/or add right rear\left front weight. A stiffer left front spring or softer left rear spring will tighten the car in this phase. Move left rear out to tighten or move left front in to tighten.

If you are loose when the car is rolled right, stiffer right front spring and softer right rear spring will tighten car. Static weight thoughts while in this stage are add more right front-left rear weight (crank turns into the left rear).

It is a fine line and exactly where that line is on every track for every track condition, well, experience is your best friend.

Generally, softer rear springs or torsion bars will make the car tighter, although you need to raise the rear to get the CGH back to where it was before to keep the longitudinal traction up. Stiffer front springs or torsion bars will make the car tighter. However, too stiff of front springs will cause it to be inconsistent as it will push when it sees a small bump. On a slick smooth track it can be ok to go pretty stiff on the front, but don't try it on a track that has some imperfections in it.

For longitudinal traction (forward drive) keep the car high, just know that this may loosen the car where the car is needing lateral traction. I found on small tracks that are slick, generally, raising the car more is the way to go (within reason). This is because the winged down phase is real short and the car will start spinning the tires quicker because of the gear ratio allowing for greater torque on the tires. On bigger tracks, 1/3 or bigger, it is better to keep the car lower to the ground. There are optimum points where balance is achieved, just pay attention to what you car is doing, and now you know the proper adjustments to make.

Wingless

Wingless racing is a little easier to understand as we only need to look at the roll right factors. Of course with less overall traction available due to the air foil being gone (free down force), spinning the tires from lack of longitudinal traction becomes more of an issue. A higher center of gravity and more right side offset is advantageous. As mentioned earlier, when moving the right rear out, the jacking effect of raising the CGH will be gone, so you will need to statically raise the CGH to compensate.

Horsepower has a lot to do with which factors you want to focus on, other classes of sprint cars will need to focus on different parts of the adjustments than 600cc sprints do.

Roll Centers

The roll center of your chassis is the pivot point around which your chassis rolls. The roll center is controlled by the lateral linkage; this linkage controls the location of the axles under the chassis in the side to side or lateral direction. The roll center axis is an imaginary line drawn from the front RC (roll center) to the rear RC. The amount of chassis roll is a function of the distance between the roll center axis height and the center of gravity height. The longer this measurement, the more roll, shorter measurement or higher RC the less roll of the chassis.

Although roll centers play an important part in how your car handles, it does **not** control **how much** total weight transfers, only where and how it transfers. We can control the weight transfer to the front or to the rear through the difference in RC heights between the front and the rear. It works just like roll couple or roll stiffness that we talked about earlier.

Adjustments

A higher RC on one end of the car will result in a stiffer roll stiffness on that end of the car causing more of the total weight to transfer at that end of the car. Raising the rear RC will increase rear roll stiffness causing more of the weigh to transfer in the rear creating a looser race car due to the left rear/right rear tires loading being unequal.

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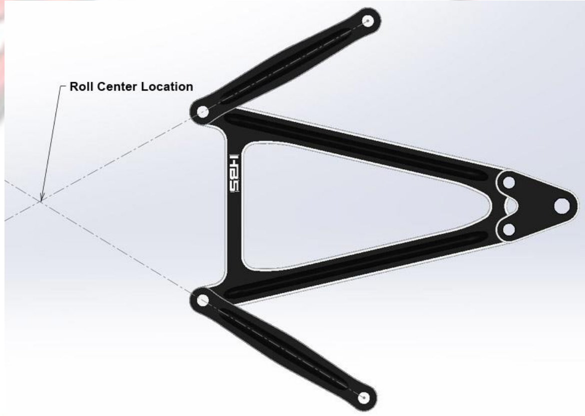
Although we don't usually change this at the track we must consider the roll center location left to right. As we move the roll center to the right the roll stiffness increases because the lever arm between the CG and the RC increases. It also changes the angle of this lever arm, we need to take the cosine of the angle multiplied by the distance of the arm.

Finding the Roll Center

The roll center of a panhard bar linkage is located directly in the center of the bar. Very easy to find.

The roll center of a Jacob's ladder is located where the two center lines created by the straps pivot points intersect. When you change the hole locations where the straps mount, it changes the RC height and/or the RC side to side location. One major difference between the two designs, the Jacob's ladder's RC goes up when the car rolls right, the panhard bar's RC moves down when the car rolls right.



Elastic and Geometric Weight Transfer

We can control if the weight transfers through the springs or the lateral linkage by controlling the height of the roll centers. As we raise the RC more of the weight is transferred through the linkage, as we lower the RC more of the weight is transferred through the springs. If we made the RC axis higher than the center of gravity of the car, the car would actually roll to the inside of the turn, like a boat, but the same amount of weight would be transferred to the right side of the car, it's just that all of the weight would be transferred through the linkage.

The weight that is transferred through the linkage is call geometric weight transfer. The weight that is transferred through the springs is called elastic weight transfer.

Although drivers generally feel more comfortable with a car that does not roll much, resist the idea to increase geometric weight transfer too much as it leads to a car that does not absorb bumps as well.

Anti squat

Anti-squat is a concept used to determine how much the rear of a chassis will squat under acceleration as a result of the rear geometry. 4-link, wishbone, z-link or trailing arm type design are examples of geometry that affects Anti-squat. Conversely anti-dive is used to describe how much a chassis nose dives under braking. Anti-dive is not something we need to concern ourselves with much on dirt as the braking force is not real high and wheel hop or chatter under braking never occurs.

Again, we already know what factors affect how much weight transfers to the rear under acceleration. Anti-squat or how much the rear squats from rear geometry is not one of them. Looking at that formula, to get max weight transfer to the rear, we need to raise the CGH, knowing this fundamental truth, designing the rear geometry to make the rear squat actually hurts our cause. Yes we do want the rear to squat, but not because of the rear geometry, but because the weight is transferring to the back. We want the rear geometry to drive the rear of the car up (a lot of anti-squat), raising the center of gravity, when the CGH is raised, more weight will transfer. As more weight transfers, the rear will squat.

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Calculating anti squat: this is not so straight forward and I will not go into the numbers, just know that as you raise you linkage points in the front (wishbone, 4-link, and the top rod on a z-link) the anti squat will be increased, it will resist squatting resulting in better forward , it will keep the CGH higher.

If you calculate the anti-squat on a typical wishbone, it is much more than the typical z-link design used on common Jacob's ladder cars.

Chain Tension

As the pivot point of the rear axle is moved to achieve different anti squat percentages, it changes how loose and how tight the chain gets as the chassis rolls. If we can achieve a pivot point (instant center is what engineers call it) real close to the front sprocket center, the result will be a chain that does not change tension as the chassis rolls, this is how the Hyper chassis wishbone cars are designed. If the instant centers are drastically moved the result may be a chain that will not stay on. Also know that the chain force will cause the left rear of the car to lift up or squat down depending on exactly where the instant center (IC) is. If the IC is below the front sprocket, the car will squat, if it is above the front sprocket it will lift up. A car that lifts up on the LR under load is a little hard to drive.

I am Humbled

Even after 34 years of racing micro sprints and mini sprints, I am still learning, and I hope it never stops. Test these ideas, develop your own conclusions, and watch my website as new truths unfold. I hope this paper inspires you and makes you want to learn more, there is a lot of information available online, just search for some of the terms I used and you can learn a lot.