Load Transfer

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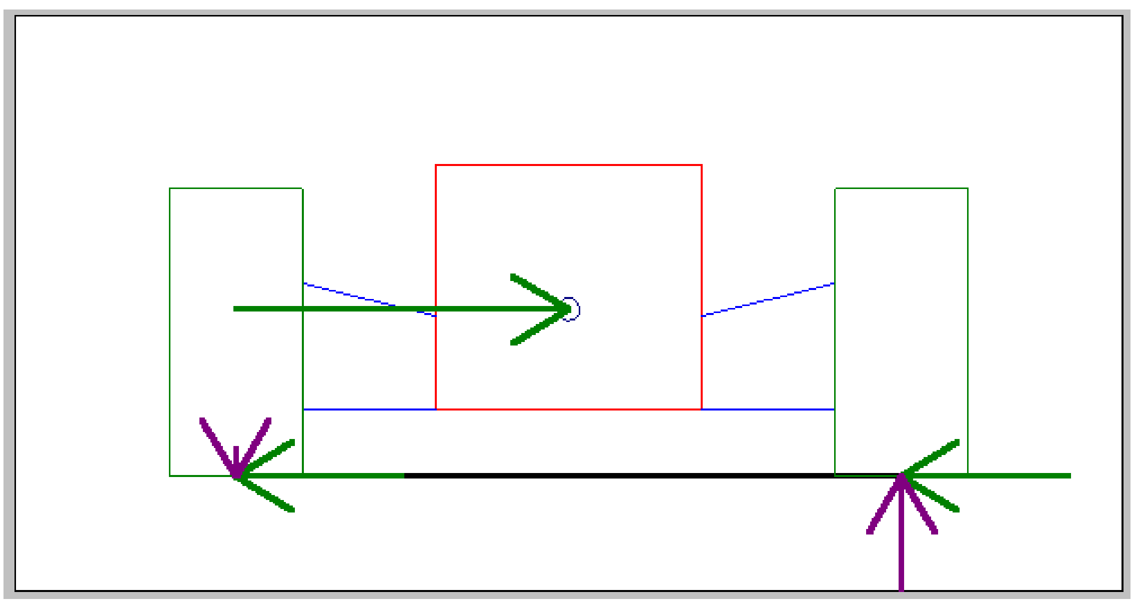
When a racing car goes around a corner it transfers load from the inside tires to the outside tires. This is simply a matter of physics and balancing the forces on a mass.

The amount of Load Transfer depends upon the cornering force, the height of the center of gravity and the track. Indeed, the formula to balance forces is simply:

Load Transfer = Cornering Power * CG_Height / Track

Lowering the CG will decrease load transfer, which is why road racing cars try to get the CG as low as possible. Widening the track will decrease load transfer, which is why road racing cars usually choose the widest track permitted by the rules. (Aerodynamics may alter this principle).

When a car corners, the lateral force is generated at the tire contact patches. The Center of Gravity is above ground. This requires the outside tire to carry more load than the inside to balance the forces on the vehicle and avoid an overturning torque.



About 80% of handling relates to load transfer. The tuning effects of spring, bars and corner weights can be explained by load transfer. Even shock absorbers and driver technique relate to load transfer. Dave Weitzenhof has listed the items controlling handling: the following items from his list depend on load transfer:

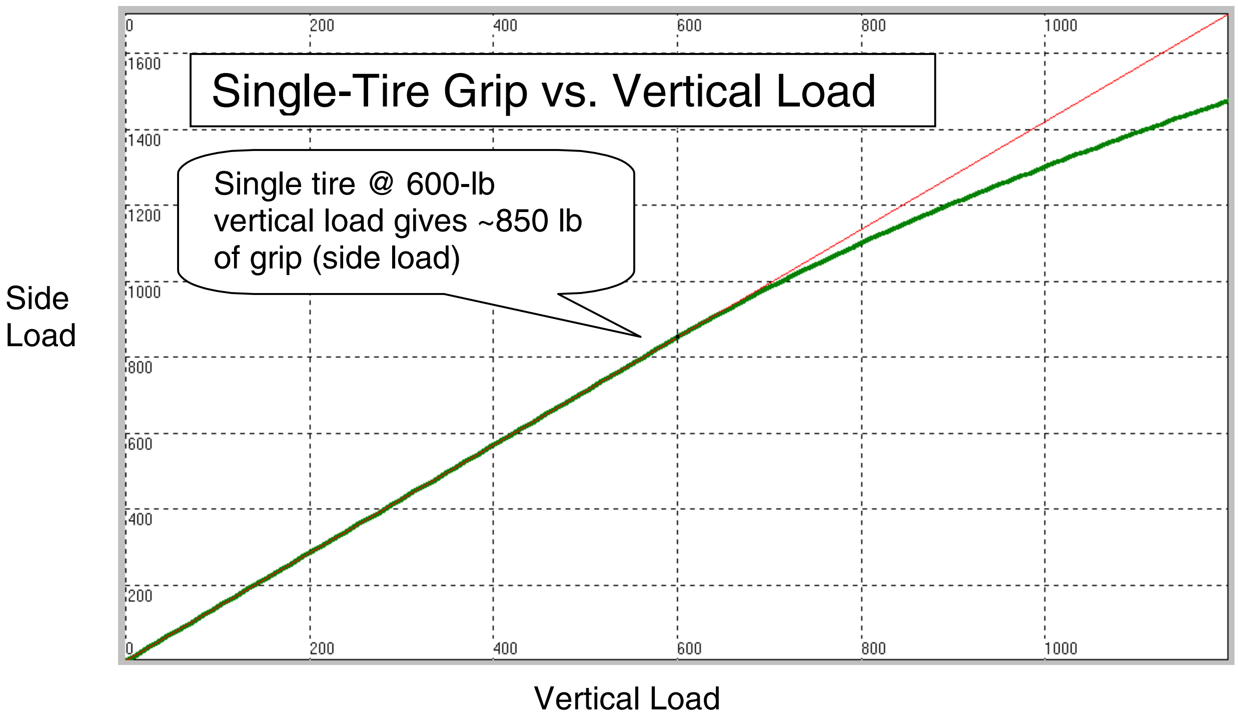
Items Controlling Cornering Power and Handling: Suspension

- ***Spring rates***
- ***Swaybars***
- ***Shocks***
- ***Ride height, roll center height***

Weight Distribution

- ***Front to rear***
- ***CG height***

The reason for the effect on handling is the tire's sensitivity to load. The lateral grip as a function of load looks something like this:



The important characteristics of this curve are as follows:

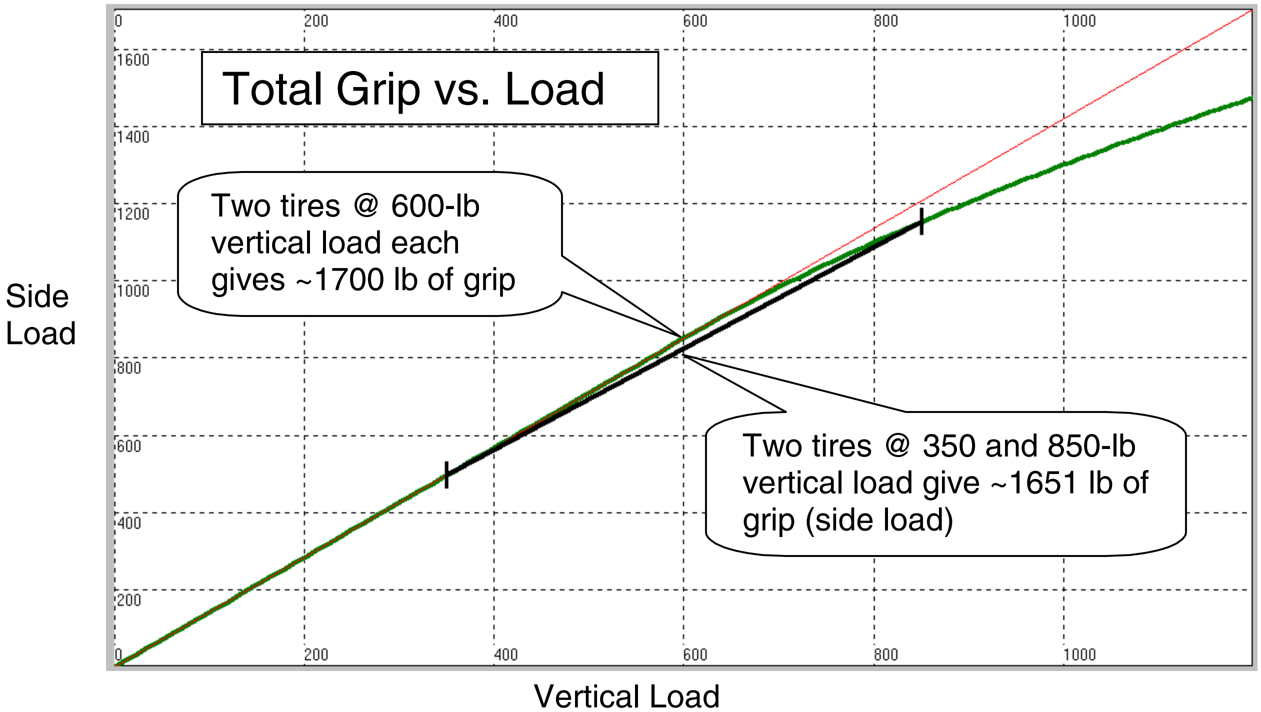
A. Increasing the Load increases the Grip.
B. The amount of grip gained DECREASES as the load increases.

How Rubber and Tire Properties Affect Handling

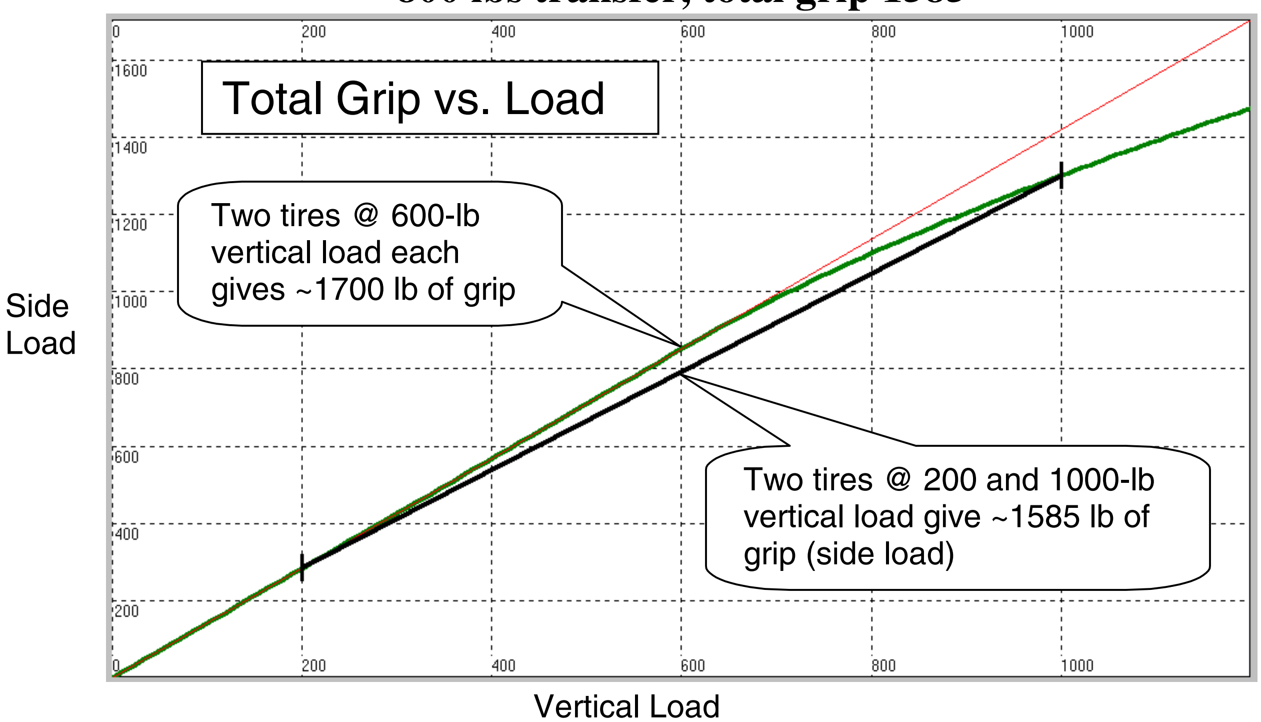
- ***Tire friction coefficient decreases as tire load increases***
- ***More weight transfer produces less grip***

Now, the total load on the front tires remains the same (ignoring longitudinal acceleration for the moment). The total grip is the sum of grip from the unloaded tire and the loaded tire. The total grip is greatest when the tires have equal load. As the disparity in load grows with load transfer the total grip declines.

Tire Grip with load transfer: 500 lbs transfer, total grip 1651



800 lbs transfer, total grip 1585



Thinking About Load Transfer

When thinking of load transfer it may help to consider body roll. As the body rolls the outside springs are compressed and place more load on the outside tires. In reality, body roll is a result of cornering force, not a cause of load transfer. If you double the spring rate you will NOT significantly change the load transfer, but you will reduce body roll.

It can be helpful to think about load transfer as you drive your street car. As you accelerate, stop or corner think about the forces acting on the car and the resulting loads on each tire. Think about which shocks are compressing and which are rebounding. Think how you (as driver) can minimize the forces acting on the car. Eliminate the nose of the car popping up when you complete a stop by rolling off the brakes as the car comes to a total stop.

Total Load Transfer

So far we have analyzed two tires. But most of us drive four-wheeled vehicles. Four tires give us four loads to satisfy three equations. This gives us a degree of freedom within valid solutions. There are many different solutions to each situation.

But there is one additional restraint. The front of the vehicle is attached to the rear of the vehicle. If the front rolls 1.2 degrees then the rear should also roll 1.2 degrees. If the front and rear roll different amounts than you have a “fifth-spring” car (certain Lola formula fords) and this is not good. If the chassis is insufficiently stiff then it will twist in the middle and will not respond to tuning.

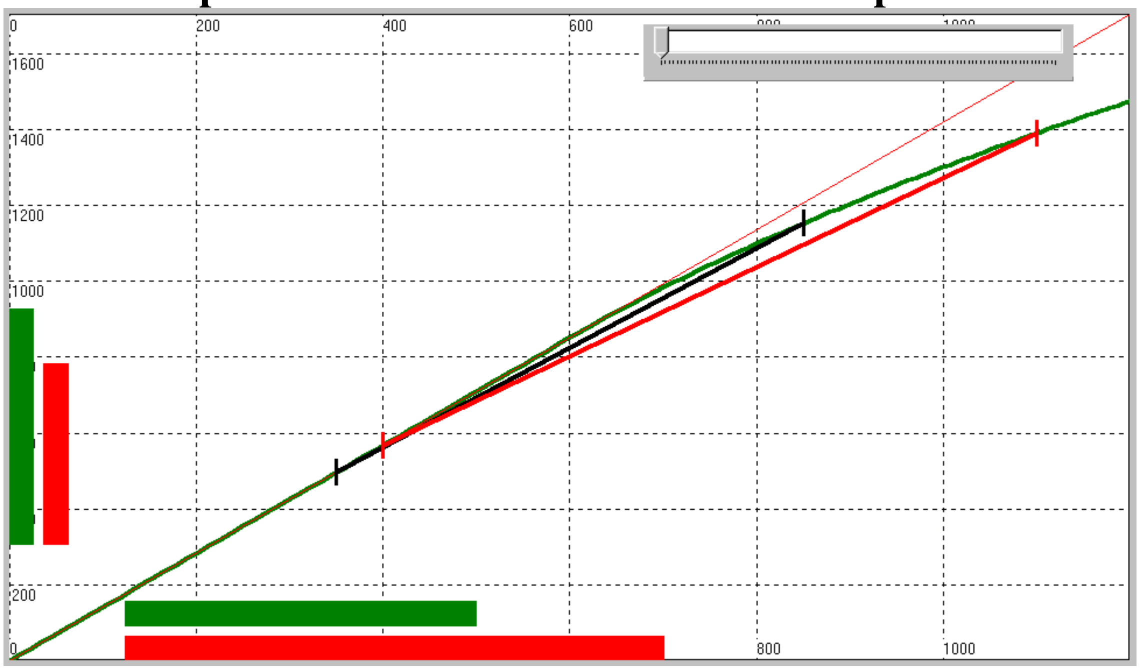
If the front wants to roll more than the rear then chassis stiffness will reduce roll at the front and increase roll at the rear. This will decrease load transfer at the front and increase load transfer at the rear.

If the front wants to roll less than the rear then chassis stiffness will increase roll at the front and decrease roll at the rear. This will increase load transfer at the front and decrease load transfer at the rear.

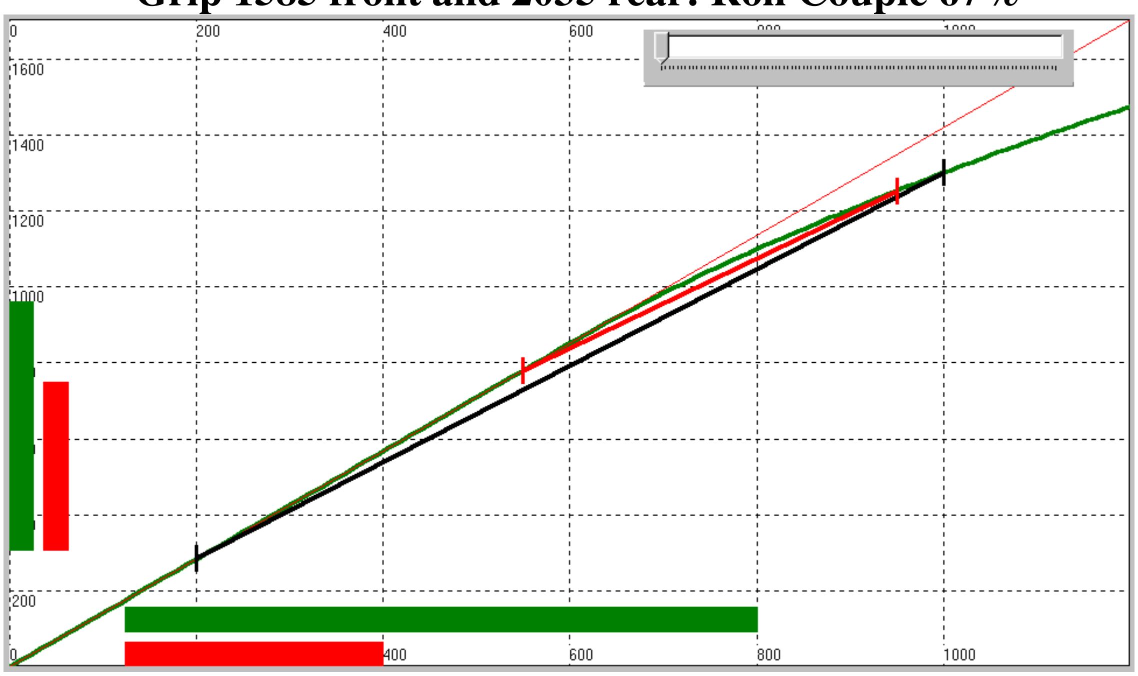
When a car goes around a corner it WILL transfer load. The total amount of load transfer depends on CG height, track and cornering force. The CG height should be as low as possible, so that is not something we can tune at the track. The track is usually set by the rules or aerodynamic considerations, so that is not really a tuning trick. Finally, the more cornering force we have the more load transfer we will produce. We can reduce load transfer by generating less cornering force, but other than choosing a line to minimize cornering force, this is not a help.

We do have four tires and we can apportion the total load transfer between the front and rear tires. This is the primary tuning tool for all four-wheeled vehicles.

500 lbs transfer at front (green): 700 at rear (red)
Grip 1651 front and 1959 rear: Roll Couple 42%



800 lbs transfer front (green); 400 at rear (red)
Grip 1585 front and 2035 rear: Roll Couple 67%



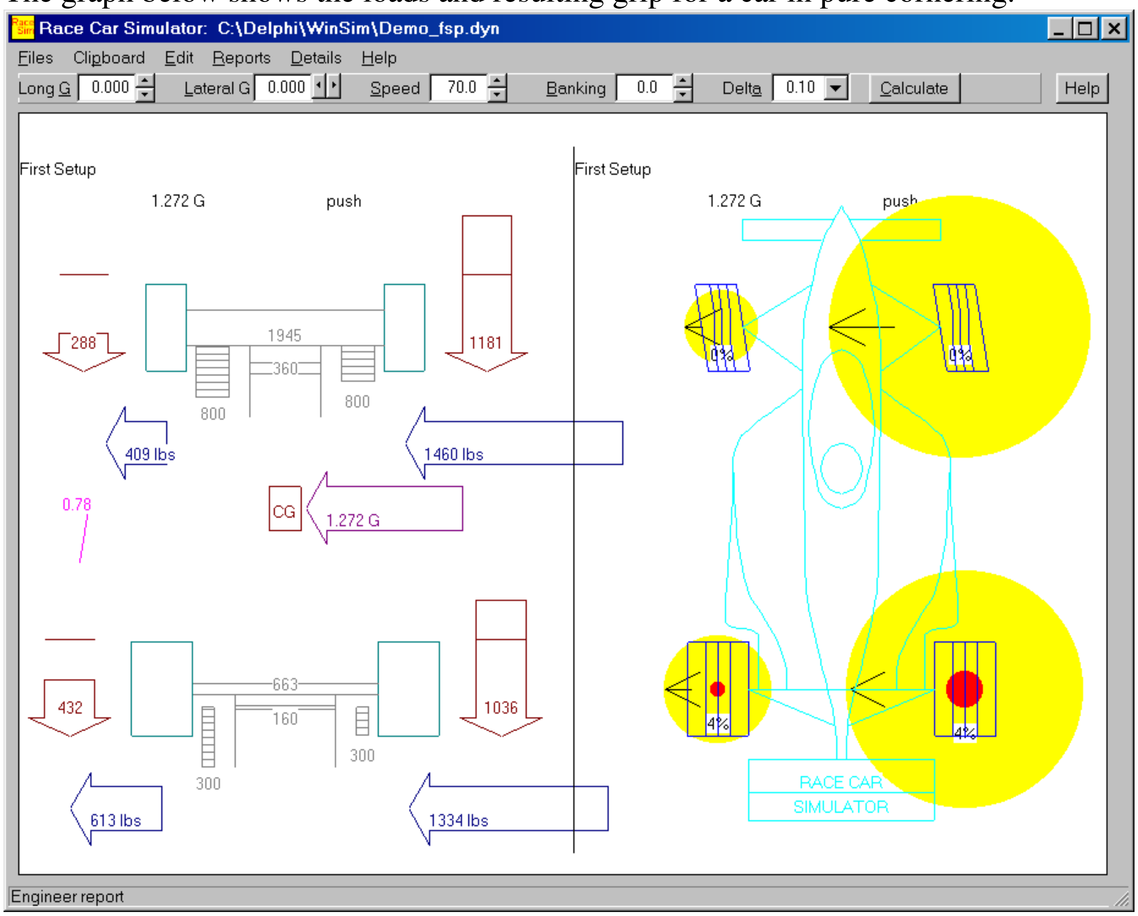
How to Tune Your Handling
To get more understeer (to get more oversteer)

- ***More weight in front (rear)*** **–** `more mass means less tire grip`
- ***Soften or lower rear (front) springs, shocks, swaybars*** **–** `roll couple`
- ***Wider rear (front) or narrower front (rear) tires*** **–** `load pressure`
- ***Wider rear (front) or narrower front (rear) tires*** – `load pressure`
- ***Change tire pressures***
- ***Diagonal weight jacking***

The Race Car Simulator

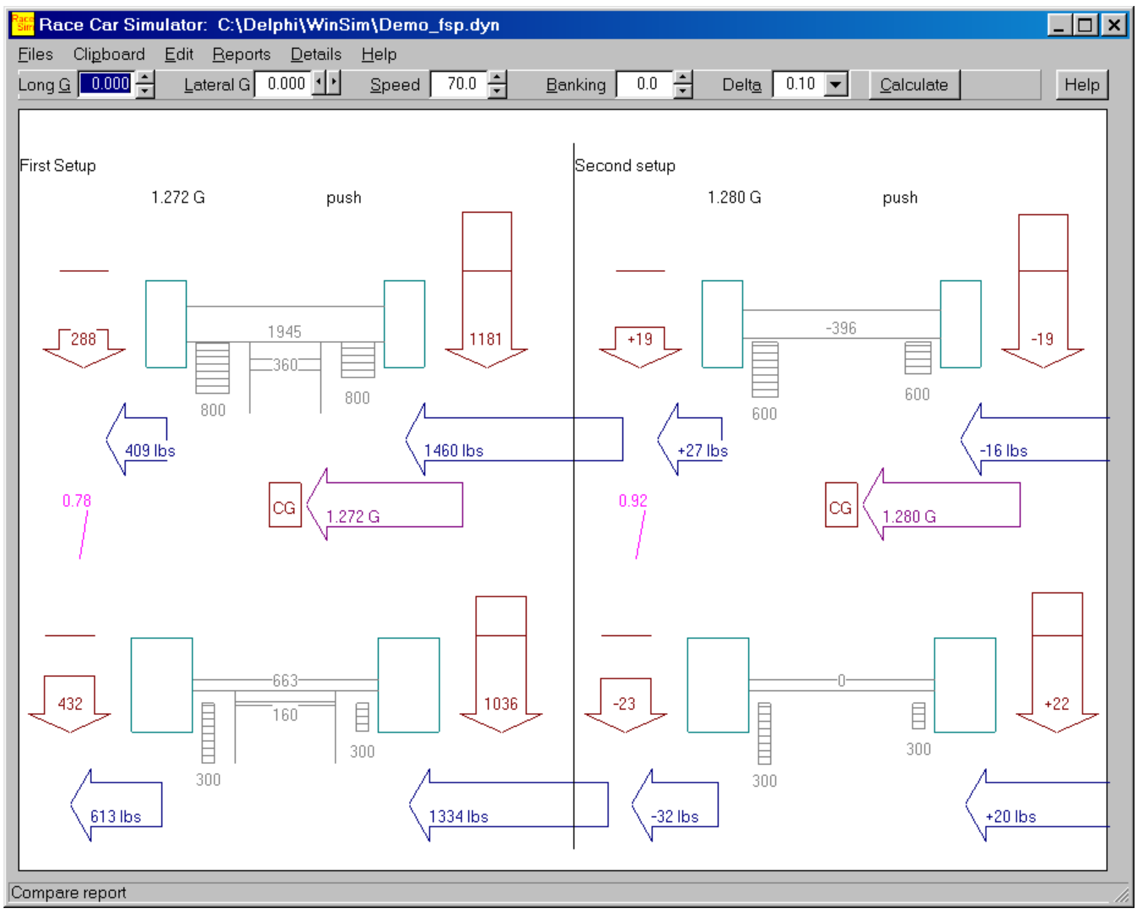
When I was struggling to understand vehicle dynamics two decades ago I wrote a computer program to implement the concepts we have been talking about. This program calculates load transfer and applies the same tire grip formulas used above. This helped me understand load transfer and vehicle handling.

The graph below shows the loads and resulting grip for a car in pure cornering.



Compare different front springs. One car (left) has 800 lbs/inch front springs. The other (right) has 600 lbs/inch spring. This results in more load transfer at the rear. The right rear tire has 19 lbs less load; the left front has 19 lbs more. This is 38 lbs less load transfer. The rear has 22 lbs more on the right rear and 23 less on the left. This is 45 lbs more transfer. (The 23 vs. 22 discrepancy is due to rounding error). The difference in total load transfer is because the second car can corner at 1.280 G and the first at only 1.272 G)

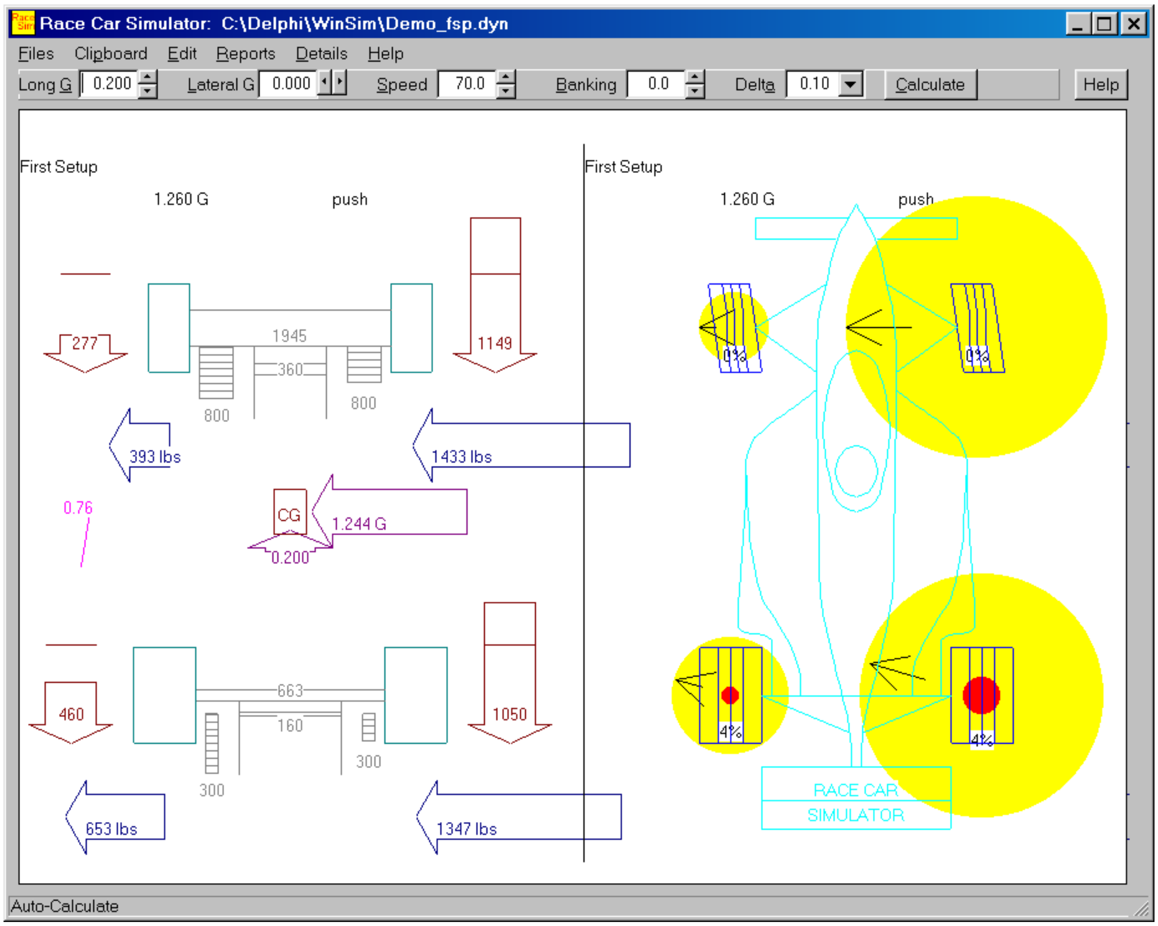
This spring change, and roll couple change, increases front grip (27 – 16 = 11 lbs) and decreases rear grip (20 – 32 = -12) lbs. Added grip at the front and reduced grip at the rear will decrease understeer or increase oversteer.



Dynamic Handling

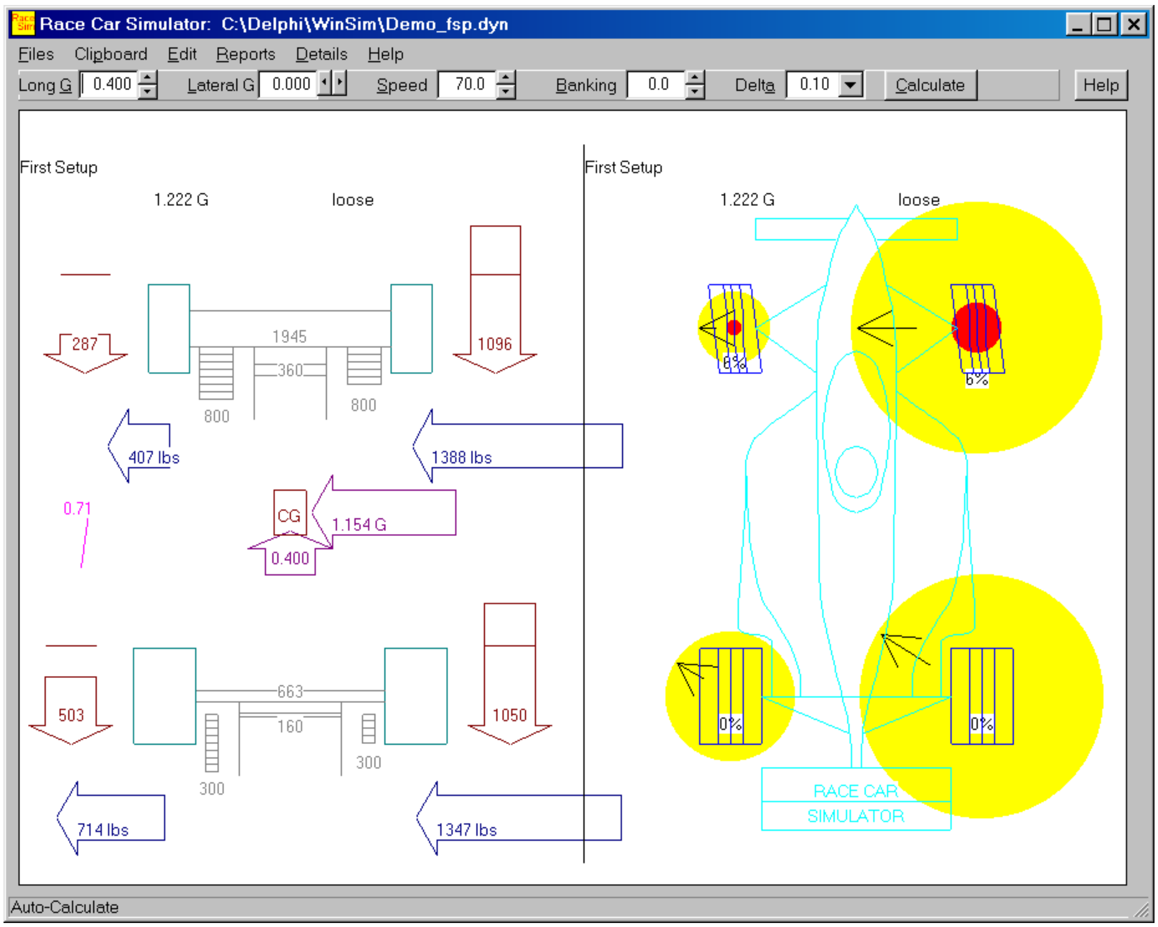
At this point you must be thinking handling is simple. Get the proper roll couple for a given vehicle and tires and you have a perfect handling car. Solve a little math and cruise to victory. But it isn't as simple as that. Rarely is a car in pure cornering mode. Usually it is accelerating or decelerating. The amount of pure cornering is very brief, unless you are at Daytona or Talladega. Even at big ovals the car is braking to the apex and then immediately beginning to accelerate out of the turn. The duration of the "roll around" or pure cornering period is very brief if nonexistent.

Now we have longitudinal acceleration to deal with. This transfers load from the front to the rear tires. Consider what happens with 0.2g acceleration. This transfers more load to the rear tires. (1050 + 460 = 1510 lbs) vs. (1036 + 432 = 1468 lbs). We are asking more of the rear tires (acceleration plus cornering) but the added load transferred to the rear produces more grip and the car still understeers.



Now increase to four-tenths g acceleration. Now we are asking even more of the rear tires. We are transferring more load (1050 + 503 = 1553 lbs) but this added load does not produce additional grip to satisfy the need for cornering and more acceleration. Now we are traction-limited at the rear and the car is oversteering.

This simply demonstrates that if we add enough throttle we can make any rear-drive vehicle oversteer. The trick to effective handling is to balance the load and grip under a variety of conditions, ranging from braking into the corner to rolling though the middle of the turn and then accelerating out of the turn. This must be done for a variety of corners and different driving styles. This is what makes vehicle tuning difficult.



Shocks

The next part of vehicle handling is damping or shock behavior. Shocks resist suspension movement and add or subtract load from a tire. If the car is braking then the front of the car is dropping and the front shocks are compressing and adding load to the front tires. What happens as the driver rolls off the brakes and begins to substitute cornering for braking? Does the outside front suspension compress or rebound? The reduced braking suggests rebound but the cornering means compression. Which effect is stronger?

The inside front tire will rebound and the outside rear tire will compress but what about the inside rear? Anti-dive/anti-squat factors also come into play.

The rear car is very complex. Load transfer provides the a way to think of vehicle handling. The devil is in the details.

The end