

## Using Tire Data On Track

Tires are complex – and vitally important – parts of a race car. The way that they behave depends on a number of parameters, and also on the interaction between these parameters. To further complicate matters, there are often multiple changes to the tire operating conditions that will result in the same change to vehicle behavior. If a car is understeering in the middle of the corner, you can increase the front grip by softening the front ARB to have less load variation on the front tires; you can change the toe or Ackermann to change the front tire slip angle; you can change the front camber angles or caster angle. The list goes on and on. You can make changes to the car setup either through experience or by using data – and preferably both.

OptimumT, the tire data modeling and visualization software from OptimumG, can be used to help set up a car. OptimumT includes an "Add-in" that allows tire models to be easily incorporated into Excel, Matlab or a programming language like C++, VB or C#.

In order to put the add-in to work on the race track, we'll need some data acquisition in the car, some information about the car and the tires and we'll also have to create an excel spreadsheet or do a bit of programing. Fortunately, once this is done, we should not need to touch it again. We can set everything in the comfort of the office and then use it on the race track with relative ease.

The technique described here, which indicates the relative effectiveness of possible setup changes, is particularly useful when setting up a car on an oval because the car is in nearly steady-state corners for a large portion of the lap, and these corners are similar (same direction and similar radii). Throughout this tech tip, we're going to use the example of a generic medium downforce car running at Indy.

This generic car runs on the same tire on all corners. The lateral force – slip angle curve for this tire is shown in Figure 1.

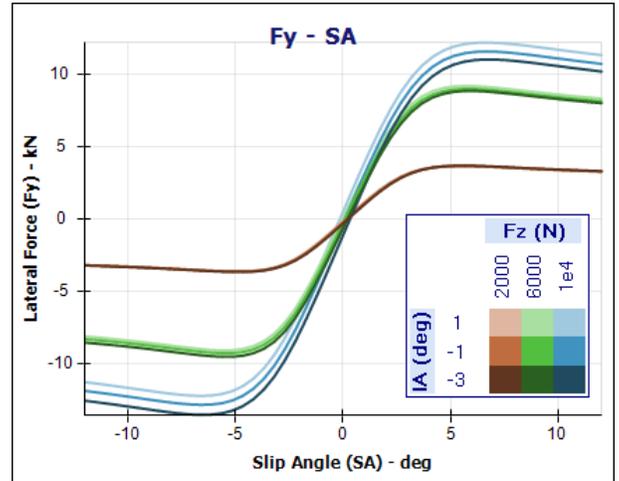


Figure 1: Lateral force characteristics for the tire used in this example

| fx =CalculateFy(F3,F1,0,F2,10,10,A10) |                   |   |          |     |
|---------------------------------------|-------------------|---|----------|-----|
| C                                     | D                 | E | F        | G   |
|                                       | Slip Angle        |   | 4        | deg |
|                                       | Inclination Angle |   | 0        | deg |
|                                       | Vertical Load     |   | 1000     | N   |
|                                       | Lateral Force=    |   | -1802.61 | N   |

Figure 2: Example of OptimumT Add-In in Excel

## Creating the Calculation

The OptimumT Add-in can be used in Excel, Matlab, or most programming languages just like any

of the built-in functions. Figure 2 shows an example of its use in Excel. In Matlab and programming languages, it is implemented as a COM component.

The required inputs of the calculation sheet will be the information about the condition of each tire. We'll need to know the slip angle, the inclination angle (camber), the slip ratio and the vertical load. This is best obtained from data acquisition, but some quantities can be calculated if they cannot be directly measured.

The vertical loads can be estimated from push-rod load cells. If you do this, remember that the push-rods don't see the geometric weight transfer or the non-suspended weight transfer. Both of these need to be calculated and added to the measured loads. Alternatively, damper linear pots, load transfer calculations or wheel force transducers can be used

To estimate the inclination angle of the four tires, an instrument like the Corrsys-Datron Dynamic Camber Angle sensor can be used. Alternatively, it can be calculated using three ride height sensors on the chassis and damper linear pots with knowledge of the kinematics. Whatever method is used, make sure that it takes tire deflection into account, particularly for high downforce cars with stiff suspensions.

The slip angle can be measured in two ways: with an optical sensor, or with an inertial sensor. An optical sensor like the Corrsys-Datron SF-II or SHR sensor works by measuring the longitudinal and lateral speed of the ground moving past the sensor. An inertial sensor like the GeneSys ADMA or Oxford Technical Solutions RT3000 works by integrating acceleration and angular rate data and correcting it with GPS information.

The slip ratio can be calculated if the true vehicle speed, the wheel rotational speeds and the effective radius of the tires are known. The effective radius needs to be determined from tire testing. If it is unavailable, an estimate can be made from the loaded radius of the tire.

Once we have the condition at which each tire is operating at a given point on the track, we can use the Add-in to find the partial derivatives of the lateral force (and possibly longitudinal as well) with respect to a number of variables.

For those readers who have forgotten their calculus classes, a partial derivative is a measure of how fast on variable changes when another is varied. For example,  $\partial F_y / \partial \alpha$  – read as "the partial derivative of lateral force with respect to slip angle" – indicates how quickly the lateral force changes when the slip angle is varied and all other variables are held constant. For example,  $\partial F_y / \partial \alpha = 100N/^\circ$ , would indicate that the lateral force increases by 100N when the slip angle is changed by 1° and everything else (camber, vertical load, etc) is kept constant<sup>1</sup>.

We find the relative sensitivity of the lateral force to changes to the tire conditions using the following Using the following functions of the Add-in:

|  |  |
|--|--|
| $\frac{\partial F_y}{\partial \alpha}$ | CalculateInstantaneousCorneringStiffness() |
| $\frac{\partial F_y}{\partial \gamma}$ | CalculateInstantaneousCamberStiffness()    |
| $\frac{\partial F_y}{\partial F_z}$    | CalculateFyLoadSensitivity()               |

Using these functions, we've created the example spreadsheet shown in Figure 3.

These three partial derivatives will tell us about what changes will be most effective. The simplest of these to look at are the camber and slip angle response. An example of this is shown in Figure 4. This example shows our generic racecar in the middle of turn 2 at Indy. In our example, the driver was complaining that the car was too loose (oversteering) in the corners. This means that we need to do one of two things: reduce the front grip or increase the rear grip. Since we want to maximize the speed in the corners, we prefer to increase the rear grip, but it may be necessary to do the reverse to fix the balance.

Taking a look at the graphs in Figure 4, the best thing that we can do is to increase the rear grip by changing the right-rear slip angle. From the slip angle sensitivity graph, this tire has a slip angle sensitivity of about  $-1550N/^\circ$ . This means that by changing the slip angle by 1°, we will get a change of approximately 1550N of lateral force.

In this case, we're using an ISO coordinate system: the slip angles have a negative sign and the lateral force has a positive sign. Therefore, we need

<sup>1</sup>More precisely, the partial derivative indicates how quickly the quantity changes when a variable is varied an *infinitesimal* amount.

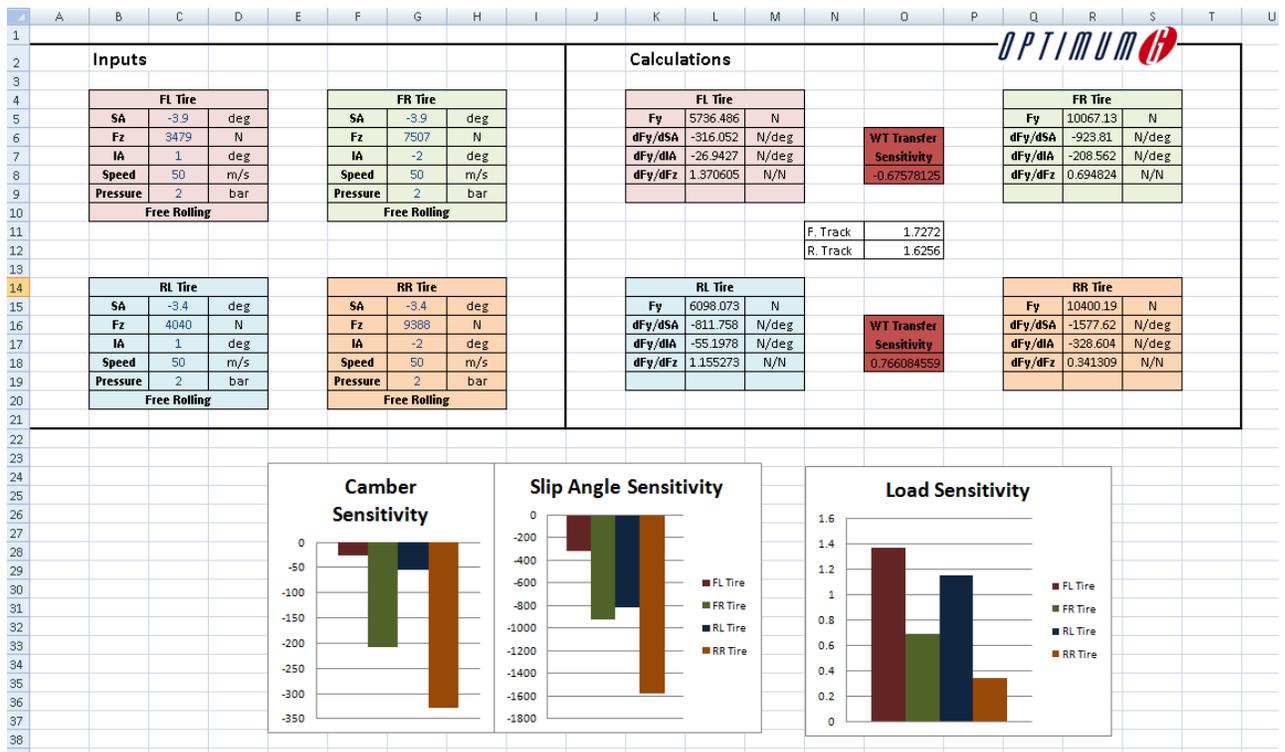


Figure 3: The spreadsheet using the OptimumT Add-in

to make the slip angle *more negative* to increase the lateral force. For the right side of the car, this means adding toe-in. We can achieve this either by adding static toe-in or by changing the bump steer.

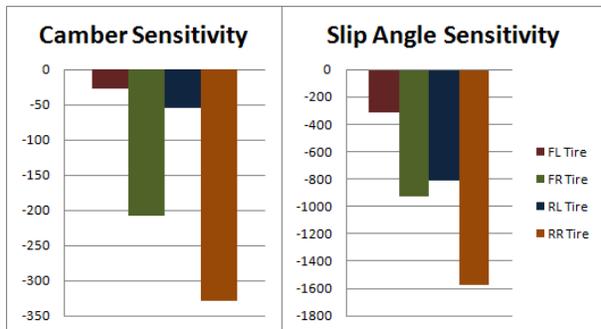


Figure 4: Camber sensitivity and slip angle sensitivity of lateral force for all four tires at the apex of a corner

This decision whether to change the static toe or bump steer comes from looking at how the car is handling on other parts of the track. It may be preferable to change the bump steer to minimize the additional induced-drag on the straights, or it be unwise to add bump steer if the track is bumpy. It may also be impossible to easily add bump steer, depending on the suspension design.

If changing the slip angle is not an option for some reason, Figure 4 tells us that the right-rear camber is the next best thing to change. To be precise, we are actually talking about inclination angle, which is slightly different from camber. The sign of inclination angle depends on whether the top of the tire is leaning right or left, while the sign of camber depends on if the top of the tire is leaning towards or away from the centerline of the car. This is shown in Figure 5. In this case, the right-rear tire has a neg-

ative inclination angle, so Figure 4 is telling us that it needs a *more negative* inclination angle. In this coordinate system, negative inclination angle means negative camber on the right side of the car.

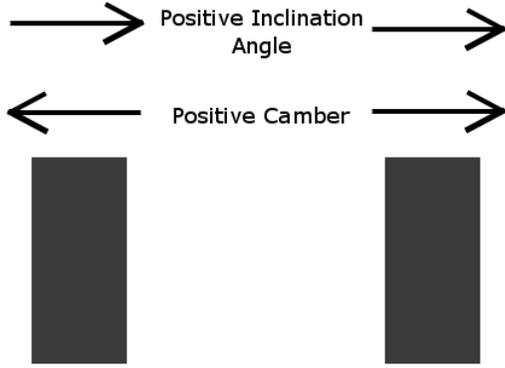


Figure 5: Rear view of car showing camber and inclination angle for the ISO tire coordinate system.

So far, we have looked at how the angles of the tires affect the forces. Now, we will look at how the vertical load affects the tire forces. This is more complicated because the four vertical loads are not independent. When we change the anti-roll stiffness of one axle, all four vertical loads are affected.

To investigate this, we'll need a bit of math. The total roll-torque is given by Equation 1:

$$M = \Delta F_{zF} \cdot t_F + \Delta F_{zR} \cdot t_R \quad (1)$$

Where  $\Delta F_{zF}$  and  $\Delta F_{zR}$  represent the front and rear load transfer respectively and  $t_F$  and  $t_R$  represent the front and rear tracks.

By changing the anti-roll stiffness (through ARB changes, springs, etc.) we change the load transfer on the front and rear axles, but if the lateral acceleration remains the same, the total roll moment will remain constant. By doing a bit of rearranging and also introducing some new quantities denoted by a prime (') to indicate the new values of load transfer, we obtain:

$$M = \Delta F'_{zF} \cdot t_F + \Delta F'_{zR} \cdot t_R \quad (2)$$

$$\left( \Delta F'_{zF} - \Delta F_{zF} \right) = \frac{t_R}{t_F} \left( \Delta F_{zR} - \Delta F'_{zR} \right) \quad (3)$$

This means that as you increase the load transfer on one axle, the load transfer on the other will decrease in proportion to the ratio of the two track widths. We can use the load sensitivity to look at how this change in load transfer affects the lateral force of each axle. We'll define the *change* in the load transfer on the front axle as  $D$ .

$$D = \Delta F'_{zF} - \Delta F_{zF} \quad (4)$$

$$\Delta F_{yF} = D \left[ \left( \frac{\partial F_y}{\partial F_z} \right)_{FR} - \left( \frac{\partial F_y}{\partial F_z} \right)_{FL} \right] \quad (5)$$

$$\Delta F_{yR} = D \frac{t_F}{t_R} \left[ - \left( \frac{\partial F_y}{\partial F_z} \right)_{RR} + \left( \frac{\partial F_y}{\partial F_z} \right)_{RL} \right] \quad (6)$$

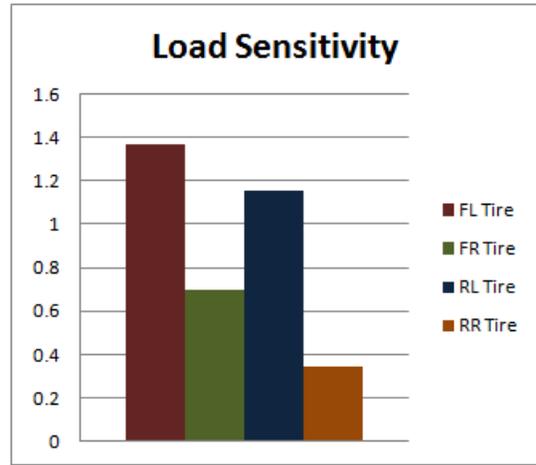


Figure 6: Load sensitivity of the four tires at the apex of a corner

The load sensitivities for our example car is shown in Figure 6. If we apply Equations 5 and 6 to our example, we find that by increasing the load transfer on the front axle by 1N (setting  $D = 1N$ ), then the front lateral force is reduced by 0.676N and the rear lateral force is increased by 0.766N.

To determine how this change will affect the balance, we need to look at the yaw moment,  $M_{yaw}$ . This can be found by using the distance from the front and rear axles to the CG ( $a$  and  $b$  respectively) and the increases in the lateral forces. The change in the yaw moment can be calculated as:

$$\Delta M_{yaw} = a \cdot \Delta F_{yF} - b \cdot \Delta F_{yR} \quad (7)$$

When we evaluate Equation 7 using our example, we find that we get a decrease of  $0.04Nm$  in yaw moment for every Newton the front load transfer is increased. This will reduce the oversteer. Since we're gaining more grip on the rear than we are losing on the front, this change will also tend to increase the total lateral acceleration. The opposite can be true in some situations as well. Depending on the condition that the front and rear tires are experiencing, changing the anti-roll stiffness could reduce the lateral acceleration.

## Improving the Accuracy

To be more accurate, these calculations should be corrected for the steered angles and toe angles because the lateral force found from the tire models is perpendicular to the plane of the wheel and not the center line of the car.

## Extending the Calculation

You can keep extending this calculation as much as you want. It could be expanded to also find the change in induced drag in the straights so that a trade off between cornering performance and straight line speed can be made. If the tire model used includes pressure effects, the additional partial derivatives can be used to help optimize the inflation pressures of the four tires.

With the ability to include tire models in calculations, you are limited only by your imagination. Add any feature to the calculation that will help you set up the car more efficiently.

*If you have any questions about OptimumT or any of OptimumG's other products and services, please email [engineering@optimung.com](mailto:engineering@optimung.com). Also, don't forget to visit [www.optimung.com](http://www.optimung.com)*