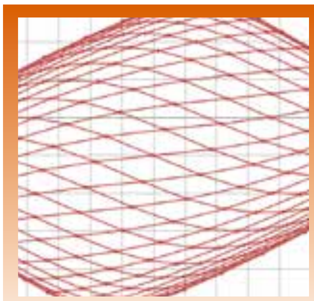

Slip Angle provides a summary of OptimumG's seminars

The four secrets for chassis happiness

Claude Rouelle explores the possibilities of qualifying and quantifying a racecar design or set-up through grip, balance, control and stability

In the racing industry, I often find engineers that perform simulations in the same way barmen create cocktails: by (sometimes randomly) mixing ingredients and varying quantities until they eventually find something that matches their taste. From weight distribution to springs and aerodynamic balance, everything is changed to, after numerous consecutive approximations, find the best possible outputs, the most important one being the lap time.

The barman approach has two main problems. First, simply varying inputs and observing the changes in outputs without understanding the real reason behind those changes can be very time consuming, since it involves lots of trial and error. There must be other methods that allow us to walk less in the dark. Second, an engineer may spend hours and hours to find a set-up that works perfectly in his computer, only to be told later by the driver that the car is undriveable. A set-up that exploits 75 per cent of the car performance can be, on the track, quicker than a set-up that exploits the performance at 95 per cent. We need a set of criteria to link the perspectives of the driver and the engineer. That is why the concepts of grip, balance, control, and stability are useful. To define these concepts, we need to look at the yaw moment diagram.

The metrics

Figure 1 shows a typical constant-speed yaw moment diagram. As explained in previous articles in this series, the yaw moment diagram is a representation of all the possible states of the vehicle during a corner at a given speed. Even though we simulate all the combinations of steering wheel angle (δ) and chassis slip angle (β) within a range, most of the time we are interested in only a few points of the diagram. Point 2, for example, represents the maximum lateral acceleration of the car while having zero yaw moment. It corresponds to a situation where the vehicle is at the apex of a corner. The overall maximum acceleration that the car can reach at a given speed is represented by Point 3. Notice that, at this point, the vehicle has a positive resultant yaw moment. In other words, when the vehicle is at the limit of its performance, the tyre forces and moments result in too much yaw moment. As mentioned in previous articles, this is what we defined as an oversteer behaviour. We give the name of grip and balance to, respectively, the lateral acceleration and the yaw moment of Point 3. The grip is a rather obvious performance metric of the car; as you maximise the lateral grip of your car, it can drive faster in corners. The balance is a good indicator of how oversteer or understeer will exhibit at the limit of the car's lateral performance: the more positive the value is, the more oversteer the vehicle will have; the more negative the value is, the more understeer the car will have.

Take a look now at Point 1 of **Figure 1.** This point is the intersection of the isolines of zero steering wheel angle and zero chassis slip angle. It represents the car going in a straight line, where both lateral

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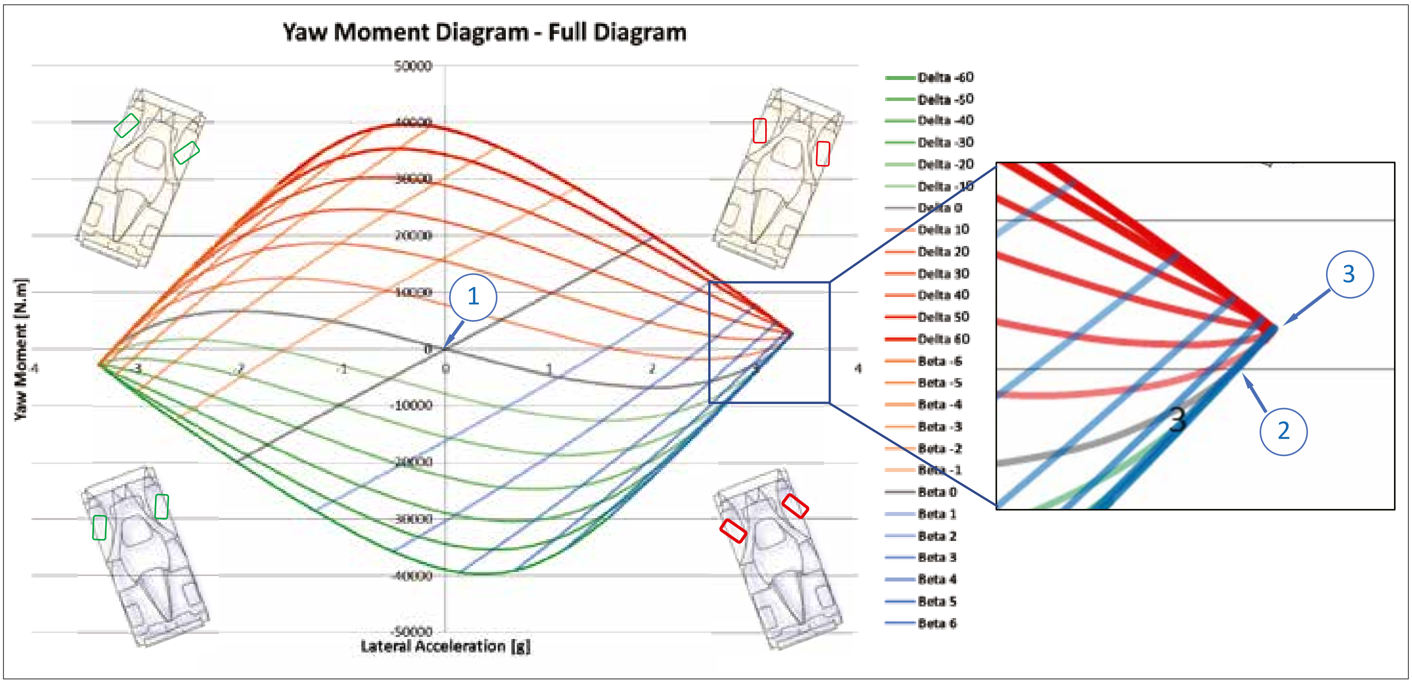

Figure 1: Yaw moment diagram at constant speed with CG slip angle (β) and steering (δ) isolines. We are usually interested in only a few points on the diagram

acceleration and yaw moment are zero (if the car is symmetric, of course). When the driver turns the steering wheel to enter a corner, he creates slip angles in the front tyres, which will generate lateral forces and aligning moments. These forces and moments will then result in a yaw moment in the car, which will be different than zero. This is where the definition of vehicle control comes from; it is the change in resultant yaw moment as you vary the steering wheel angle by one degree. The control can be calculated in the yaw moment diagram as illustrated in **Figure 2a**. By following a line of constant chassis slip angle (in this case, β = 0), we can calculate the variation of yaw moment as we travel between the lines of steering wheel angle δ = 0 and δ = 1. Here resultant control is equal to 24.7N/deg.

Degrees of stability

The concept of stability is derived in an analogous way. We start off again with the vehicle going in a straight line (Point 1 of **Figure 1**), then we give it an increase in one degree of chassis slip angle (β). This increase come from a disturbance such as a bump on the track, a gust of wind or, worse, another car hitting it. Wherever the disturbance comes from, we always want the vehicle to go back to its trajectory instead of spinning. In other words, the tyres must generate forces and moments which will result in a negative yaw moment, and rotate the car back to its original slip angle. The stability is defined as the change in yaw moment as you vary the chassis slip angle by one degree. Therefore, it represents the capability of the vehicle to return to its trajectory after a disturbance in its orientation. In the yaw moment diagram, this situation is represented by **Figure 2b.** The stability is calculated as the variation of yaw moment as between two lines of constant chassis slip angle (β) as you go along a line of constant steering wheel angle (in this case, δ = 0). In the given example, the stability is equal to -3156Nm/deg. The vehicle is more stable when the stability value is lower (i.e. more negative).

It is important to mention that the notions of control and stability can be applied not only to the centre, but to any point of the yaw moment diagram. **Figure 3**, for example, shows the calculation of control for a steering wheel angle of 60-degree and a chassis slip angle of four degrees, which can represent an instant when the vehicle is approaching the apex of the corner.

Once we have very clear notions of vehicle balance, grip, control, and stability, we can start associating these calculations to data and comments from the driver.

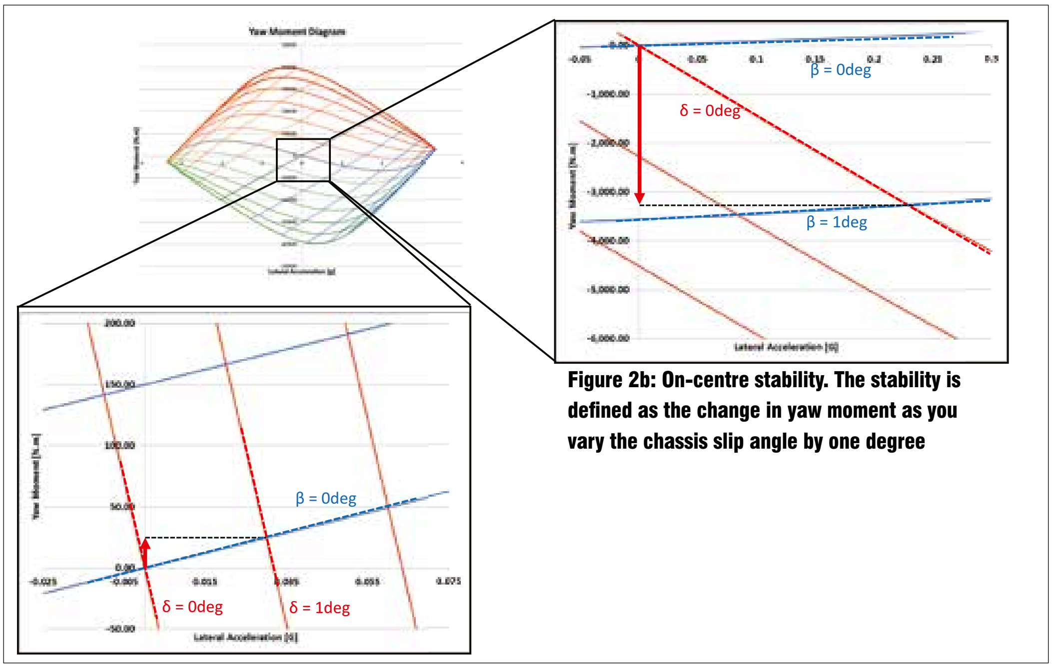

Figure 2b: On-centre stability. The stability is defined as the change in yaw moment as you vary the chassis slip angle by one degree

Figure 2a: On-centre control. Control is the change in resultant yaw moment as you vary steering angle by one degree

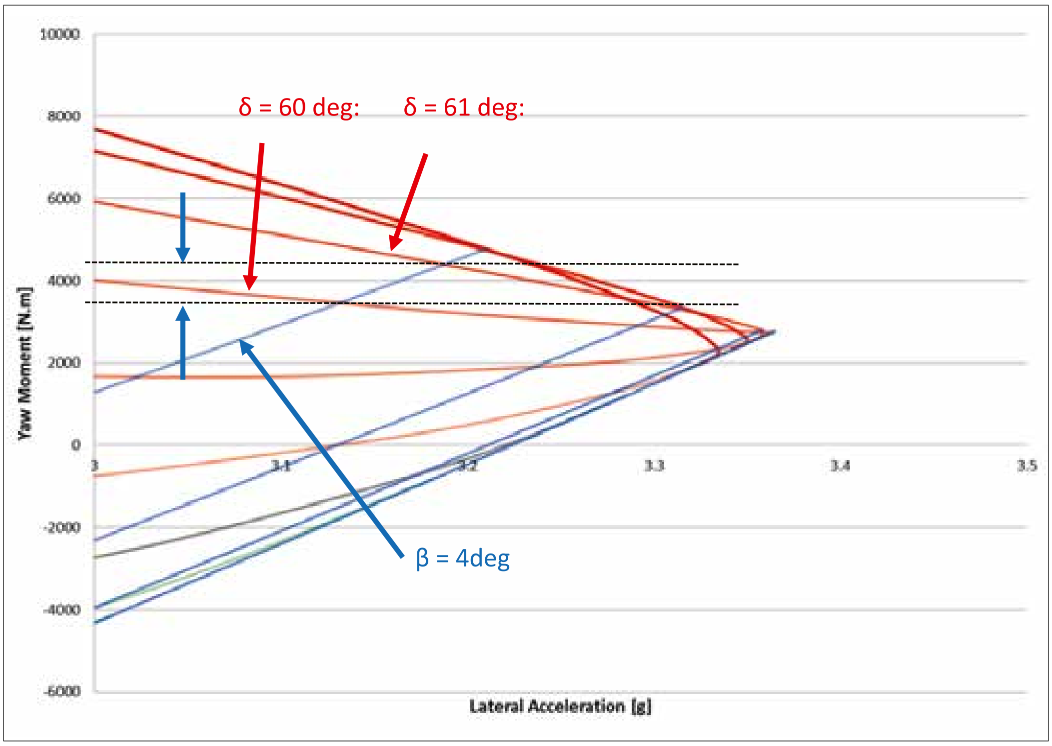

Figure 3: Control and stability can be applied at any point of the yaw moment diagram. This shows 400Nm of yaw moment variation at four degrees of CG slip angle (β) with a steering angle variation (δ) from 60 to 61 degrees

Driver input

During a free practice session, an engineer usually gets many comments from the driver about the vehicle and various parts of the track. The job of the engineer is to be able to gather all these comments (as well as vehicle data) and quickly make decisions about which parameters of the car will be changed. In the consulting projects that OptimumG performs at the racetrack, we always ask the race drivers to rate the performance of the vehicle, at each corner (or even at each section of each of the corners), in three criteria:

1. Control. How well, for a given amount of steering input, the

We ask drivers to rate the performance of the car at each corner

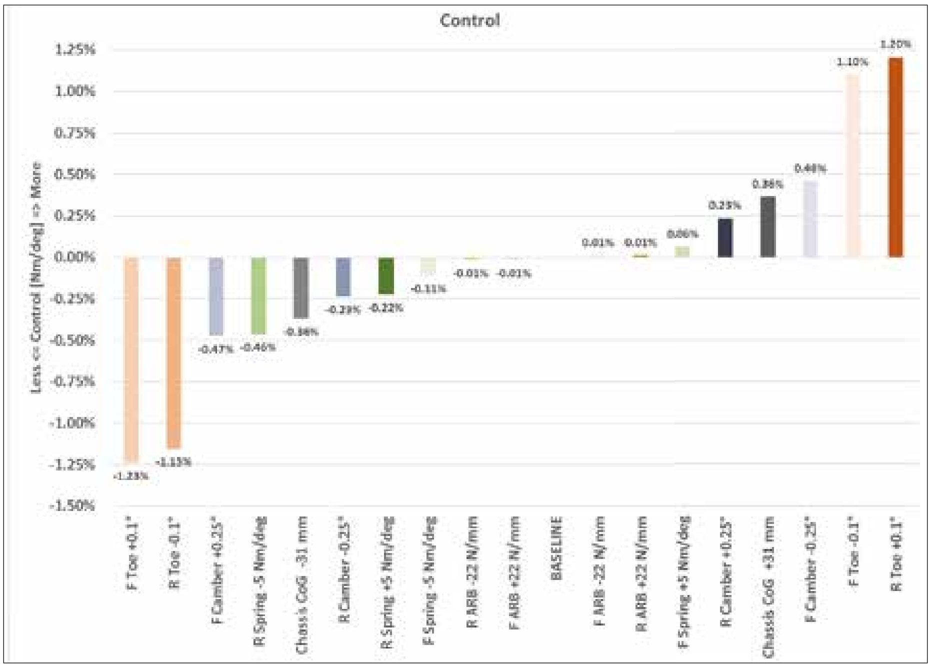

Figure 4: Accessing simulation data. This shows the effect of various set-up parameters on entry control

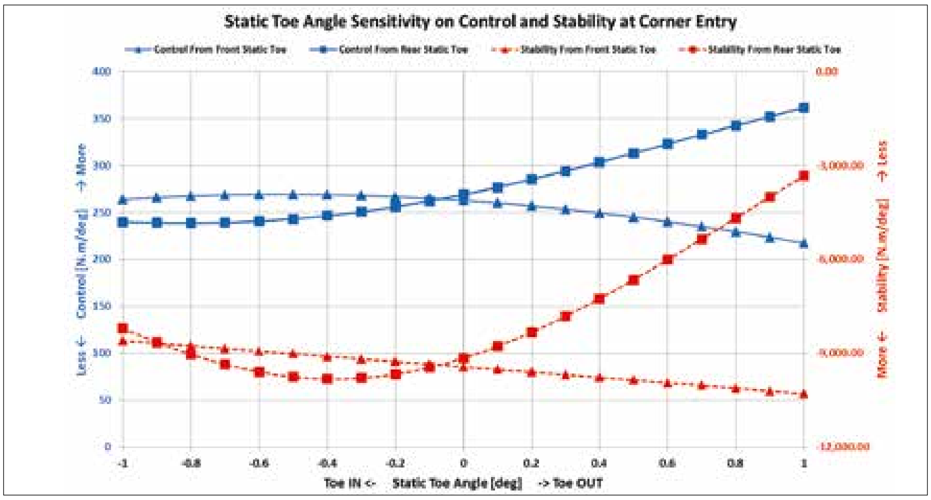

Figure 5: Varying parameters. The effect of front and rear toe control and stability on corner entry

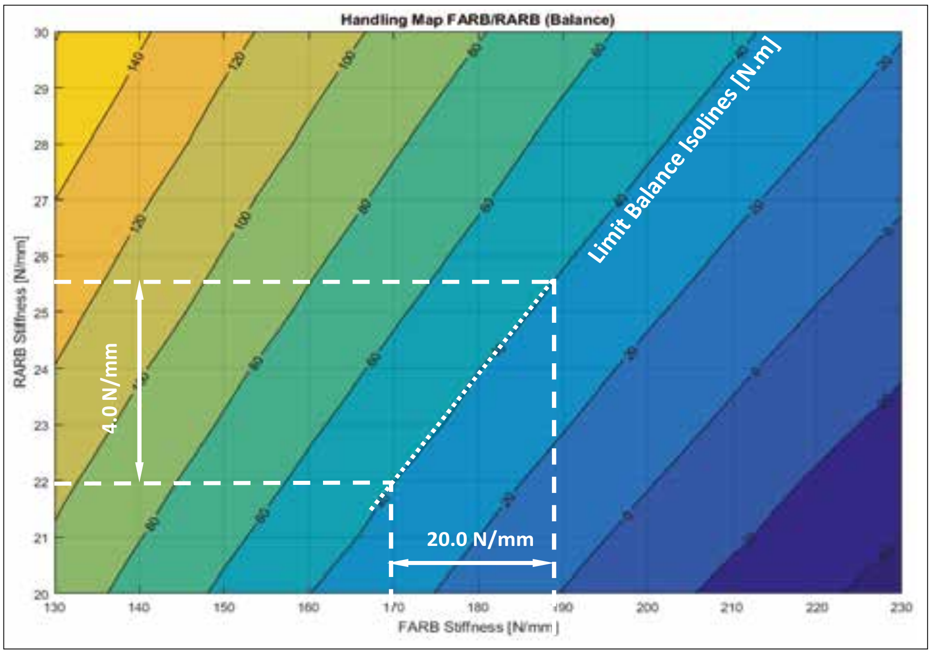

Figure 6: If the race engineer wants to change the front anti-roll bar (ARB) stiffness by 20N/mm while still keeping the same balance in the racecar, then a change of 4N/mm is required in the front ARB

racecar goes where you want it to go. This is rated from 0 to 10.

2. Stability: How well the vehicle is capable of staying in its trajectory during the corner. Rated from 0 to 10.
3. Balance: Does the vehicle understeer or does it oversteer? Rate it from -5 (understeer) to 5 (oversteer).

Organising the driver feedback according to this set of criteria helps the engineer to decide the changes he will make in the set-up. Of course, he must have done simulations prior to going to the race track.

Target values

Let's imagine a situation where the driver rates the car control as 4/10 and the engineer knows that, according to simulations, the current vehicle set-up has a control of 150Nm/deg. By accessing the history of previous testing sessions, the engineer finds out that the driver had given a rating of 9/10 for a set-up that had a control of 220Nm/deg, so he knows what his target value is. The question now is; which changes will he have to make to reach the target value? This is where simulation data becomes crucial.

Being able to access and visualise simulation data is as important as performing the simulation itself. A chart such as **Figure 4**, for example, can help the engineer not only decide which parameter to change, but also the amount of the change. Since much of the behaviour of the car is often very non-linear, it is also interesting to calculate metrics as you vary certain parameters within a range, as shown in **Figure 5**. If you want to observe the interaction between two parameters and one of the metrics, a chart like that shown in **Figure 6** can be very useful. It displays the value of balance as you very the stiffness of the front and rear anti-roll bars.

Useful tool

As I've been saying during this series of articles about the yaw moment diagram, this simulation method is not perfect for many reasons (for example, the fact that the calculation is steady-state based). In fact, with so many parameters involved, all simulation that you try won't be perfect. However, some of simulations can be useful, and I can say that the yaw moment *vs* lateral acceleration method is one of them. OptimumG's successful experience in many championships has proven it.

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