Slip Angle is a summary of Claude Rouelle's OptimumG seminars

Skid row: analysing car balance with driver data

In part two of his analysis of a driver's key performance indicators OptimumG president Claude Rouelle looks at how the steering integral can help identify understeer and oversteer in a racecar

GOODWOOD

A key difference between oversteer and understeer is that the former is much more fun – especially in a Ferrari 250 GT SWB

Vehicle balance is commonly associated with the words *understeer*, *oversteer* and *balance* itself. Very simply, understeer happens when the front tyres of the car lose grip making the car go forward instead of turning. Oversteer causes the rear axle to snap out, making the driver reduce the amount of steering or counter steer. When a car follows the corner path and it does not oversteer nor understeer it is said that it is neutral steer. To define these in engineering terms, understeer is a lack of yaw moment and oversteer is an unnecessary over-yaw moment.

Slide rules

Contrary to an oversteer situation, an understeering car is usually less evident and more progressive, and it can be difficult for an amateur driver to know that they are understeering, and even difficult for the engineer to identify it – even more tricky to quantify it. Some specific analysis of multiple channels such as steering wheel angle, throttle, brake, yaw rate (with the gyro) or lateral acceleration could help. Let's start with a simple one.

To analyse the vehicle balance we will be looking at a key performance indicator (KPI) called 'steering wheel angle integral'. We are going to show here how you can relate it to the vehicle's balance variation throughout a track session.

To assess the vehicle balance, that is if it's oversteering or understeering, the easiest way is to set a nominal steering reference lap. A reference lap is one in which the driver makes a lap slightly slower than the fastest lap he could set, say, around 95 per cent of their normal pace. When driving 'slowly' we can assume that tyre slip angles won't go past their peak. We need a reference, even if it is not a perfect one, and this reference will be the driver's opinion – remember that with a racecar there are too many inputs to be spot on in our performance prediction, and so we work in deltas, in trends, in sensitivity and in slope.

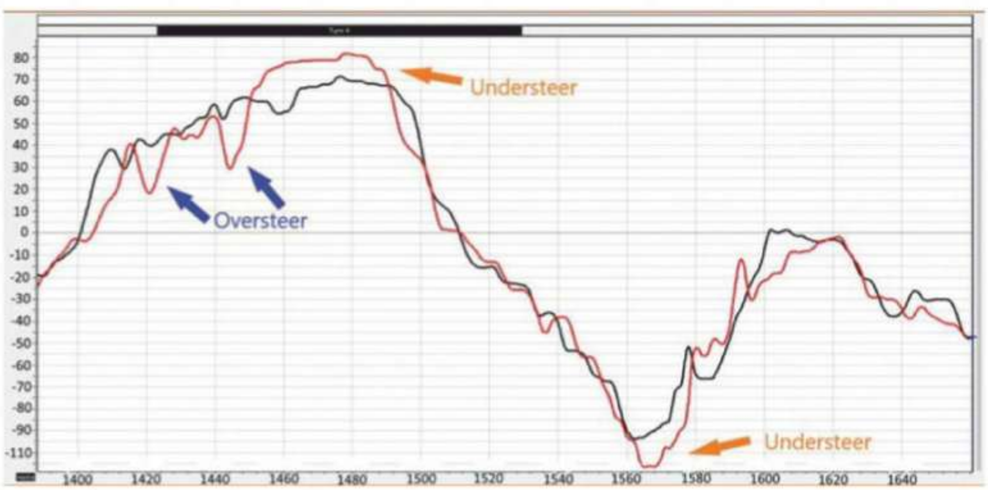

Figure 1: Steering wheel angle with reference lap (in black) and fastest lap (in red) with handling states indicated

In a relatively slow lap, with a 'happy' driver, we can consider we have no serious oversteer or understeer (at least from the driver's point of view), hence this lap is called the reference lap. By overlaying it with a normal lap, the engineer can spot oversteer and understeer. An example is shown in **Figure 1**, where the steering wheel angle of the fastest lap (in red) and the reference lap (in black) for a corner are plotted. The steering wheel angle is plotted in the *y*-axis. By looking at the red and black steering values it becomes clear the areas where the driver is fighting understeer or oversteer.

The car has difficulty in corner entry; noticeable here by the fact that the driver needs to reduce its steering at the 1420m and 1444m mark. At the apex (1450-1480m)

Overlaying the steering wheel angle channel on top of the reference steering wheel readout can be very insightful

the driver needs to steer more, indicating that they are most probably fighting understeer.

We could have plotted other channels such as yaw rate or the lateral acceleration and we would have obtained a similar conclusion. Why then would it be useful to go through the effort of setting up a reference lap and comparing the steering wheel angles? Because if objective data analysis is confirmed by the driver's subjective comments (the word subjective not taken in a pejorative way here) then we have gained a significant confidence in the data analysis that can only help the driver's communication with the race engineer.

Steering integral

Overlaying the steering wheel angle channel on top of the reference steering wheel can be very insightful. Points of interest can be quickly identified, especially if combined with the previous key performance indicator – steering smoothness, as discussed in the previous article (January issue, V29N1).

However, the real gain in using the steering wheel angle lies mainly through the use of the key performance indicator, the steering integral. This is a maths channel resultant from the integration of the steering wheel angle over a lap. Simply put, we are looking at the total amount of steering done by the driver in the lap. A high value means that the car has a tendency to understeer. The lower the value, the more the balance will shift towards oversteer (again, at least from the driver's perspective). By plotting this metric, we can have an idea of how the vehicle balance changes with time, as tyres wear out, the fuel is consumed, and so on.

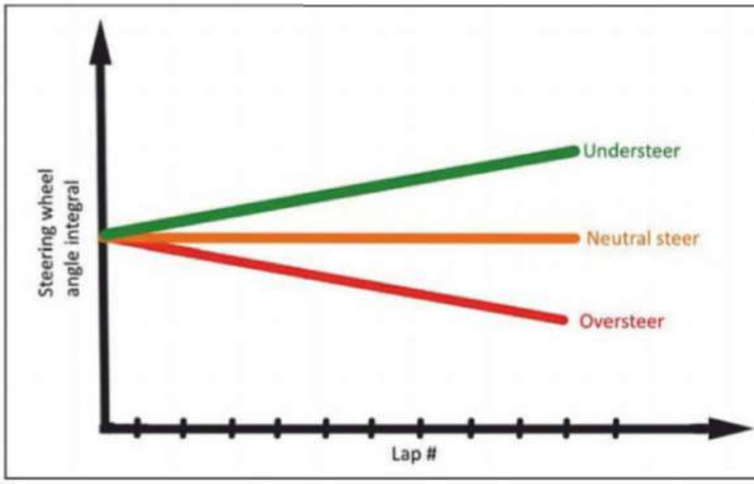

Figure 2: Theoretical steering wheel angle integral metric for a neutral steering, understeering and oversteering racecar

Table 1: Maths channel equations to create the steering wheel angle integral

Math channel name	Math channel equation
Steering Wheel Angle Integral	integrate(abs('Steering Wheel Angle' [deg]), 1, range_change("Outings:Laps"))
Steering Wheel Angle Integral KPI	stat_max('Steering Wheel Angle Integral' [deg],1,range_ change("Outings:Laps"))

If a driver is too slow they exaggerate the amount of steering angle required to negotiate a corner

Figure 2 illustrates this case. The *y*-axis represents the steering wheel angle integral metric, and the *x*-axis the lap numbers. As the session progresses, if the car is perfectly balanced, no tyre degradation, and a perfect driver, then they would always be steering the same amount, resulting in a constant steering wheel angle integral (represented by the orange colour). What actually happens is that either the driver will need to steer more (green colour) indicating a more understeered car or to steer less (red colour), which is typical of oversteer behaviour.

The steering wheel angle integral is calculated by using the Integrate function available in the analysis software MoTeC i2, and the result is displayed in **Table 1** and **Figure 3**. This function takes three arguments. The first entry is the data that we want to integrate, in this case the *abs('Steering Wheel Angle' [deg])*. Notice that we use the *abs* function for the case where the steering signal is negative, since this would even out with the positive values when calculating the integral. The next argument is to set a condition to integrate only when this condition is true, in this case we want to always integrate, so we put the number 1, which MoTeC interprets as a true condition and will integrate always. The final argument is to decide when to reset the integral, we use the *range_change ('Outings:Laps')* to specify that we want to start the integration again at the beginning of each lap. Finally we can use the function *stat_max*() to calculate the maximum value of the steering integral.

Figure 3: Red is steering wheel angle for a lap while blue is the steering wheel angle integral obtained from Table 1

Nominal steering

The trick is to do a low speed lap to get the 'nominal steering', and then compare the steering integral of this lap with the one of a normal lap: steers more (understeer tendency), steers less (oversteer tendency).

Besides comparing the nominal lap with other laps, if we use the second equation from **Table 1**, we can plot for each lap the steering integral and from there have a reference of how the steering wheel angle integral changes during a session. The results of this operation are presented in **Figure 4**, where we analyse the steering integral of four different drivers with the same car (same set-up, same tyres) during an endurance race simulation.

Head to head

From **Figure 4** we can make some conclusions and correlations with the steering integral and the number of laps. First, as the session progresses the steering integral value keeps increasing for drivers A and B, while it remains constant for drivers C and D, and between them they have pretty much the same slope as the session progresses.

Drivers C and D seem to be managing the tyres much better, because their steering integral slope varies little, unlike drivers A and B. You can see that driver A is fighting understeer. In a future article we will study why this understeer occurs for driver A and not so much for the other drivers. There are other KPIs that will explain this.

Instead of plotting the steering integral versus the lap number, another way to look at data is to plot it against the lap time, which is illustrated in **Figure 5**. In this chart, another dimension is added by applying a colour gradient to the data. The lightest, or faintest, colour represents the first lap while the darkest, or boldest, colour is the last lap for each driver. Note that the data shown in **Figure 5** is not from the same data set as **Figure 4**, they are from different tests.

Data analysis

In this test, we can conclude that driver A was the quickest driver, and the fastest lap times were achieved when the steering integral was lowest. The data of all drivers show a trend where around a certain steering integral value they have their fastest laps. Comparing all drivers, it seems that driver A (blue) needs less steering integral (less understeered vehicle) compared with driver B (red), a more understeered vehicle. The colour gradient allows the engineer to see that as the session progresses all drivers steering integral, as well as their lap times, increased, possibly due to tyre wear. The colour gradient highlights that driver B (red) and driver C (green) have a much smoother understeer gain when compared to driver A (blue), who did some fast laps consistently but then was slower with more understeer during the last laps.

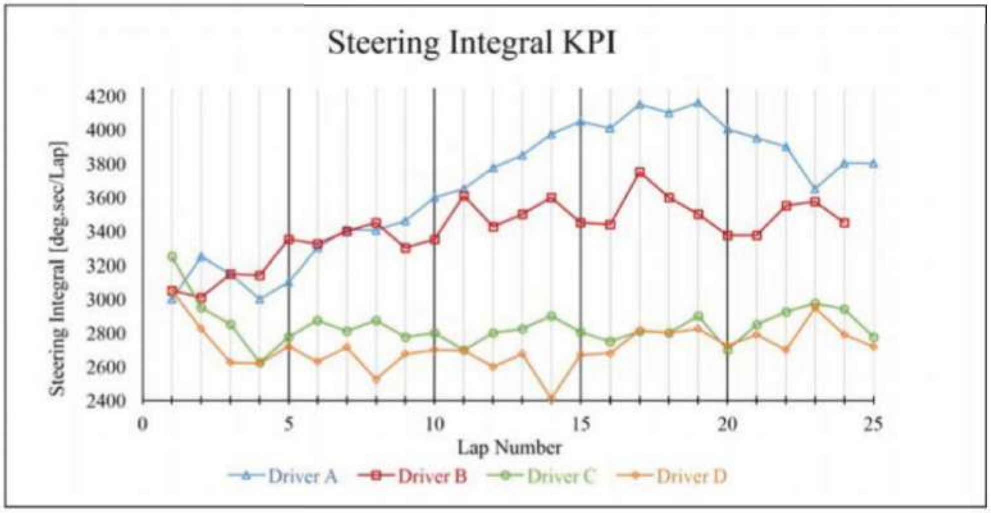

Figure 4: Steering integral KPI versus lap number for four drivers. Drivers C and D seem to manage their tyres well

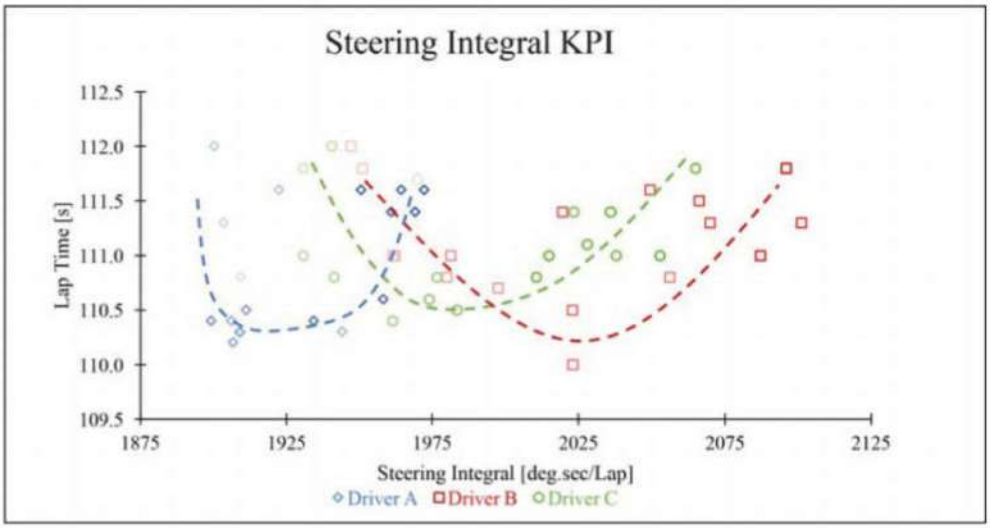

Figure 5: Steering wheel angle integral KPI versus lap time – faintest colour is first lap while boldest is the final lap

Their steering integral as well as their lap times increased, and this was possibly due to tyre wear

In conclusion, when looking at the steering integral special attention should be paid so that we are only examining the large deviations. Small changes that are within a certain margin of error should be neglected.

When setting the reference lap, if the driver is too slow, they will exaggerate the necessary amount of steering angle required to negotiate a corner due to the larger steering angles required at slower speed. The car should be driven just slow enough to prevent any unbalance from tyre slip angles.

The steering integral can give the engineer a very good idea about the balance variation of the car over time. It is useful to investigate set-up changes, compare different tyres, evaluate trends in vehicle balance as tyres wear more, as fuel load gets lower, and assess differences in driving style and differences in track conditions.

Note that different vehicle set-up is often required for different driving styles, as shown in **Figure 5**, where the lap time as a function of the steering integral is illustrated.