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

Hitting the brakes: is your driver aggressive enough?

The way they apply the brake is what separates the good drivers from the average, but just how do you measure their level of braking aggression? OptimumG's Claude Rouelle explains all

XPB

Top drivers brake aggressively when they need to, but the balance between getting it right and locking up is a fine one

In the last two Slip Angles we defined what key performance indicators (KPI) are, and how using the steering wheel angle signal to create KPI such as steering smoothness and steering integral will help you better understand driving style and vehicle balance.

OptimumG engineers usefully use these data analysis techniques on a day-to-day basis in racing series such as WEC and ELMS, Supercars in Australia, Brazilian Stock Car, and the Blancpain GT Series. And you can too. If you haven't read the previous articles, try to check them out (January and March issues), as they will help you get the most from this month's piece, as some of the important definitions and calculations were included in these.

Braking good

The goal of this series of articles is to highlight the benefits of a data-driven approach and provide some examples on how it can be used for getting the most performance from the car and driver. Here we will be looking at the brake signal. The brake KPI can be calculated using a range of signals including brake pressure in the master cylinders, brake pedal displacement or brake pedal force.

First, we will define what we call a braking zone. This is the zone where brake pressure is applied before a corner. It can be split into two major phases. The first phase, commonly called brake application, is defined from the point where the driver starts to brake until the point of maximum brake pressure, and the second one, brake release, from the point of maximum brake pressure until the release of the brake pedal.

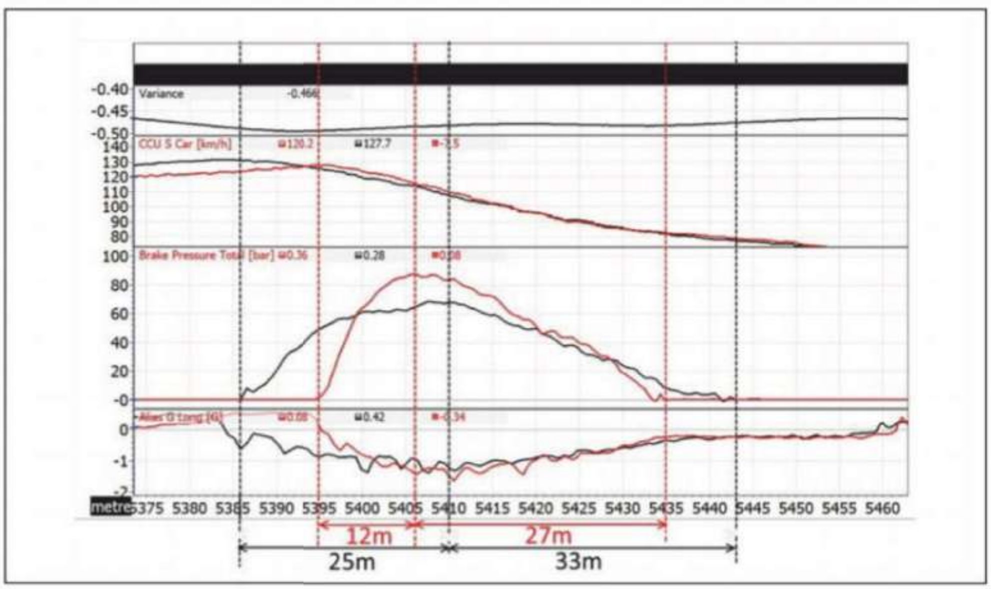

Figure 1: Analysis of the braking zone for two different race drivers heading in to Turn 10 at the Paul Ricard circuit

Both phases are highly dependent on the type of corner (speed as well as early, normal, or late apex), on the driver's driving style (aggressive/smooth at braking), vehicle type (aero car versus a non-aero car), the overall grip of the tyre, and the vehicle balance.

An overlay of the data of two drivers braking for Turn 10 at the Paul Ricard circuit is shown in **Figure 1**. The chart is composed

Most driver inputs really should be smooth, except in the hard braking zones such as the end of the long straight at Le Mans

of four traces: variance, vehicle speed, total brake pressure (defined as the sum of the front and rear brake pressure, see **Table 1**), and longitudinal acceleration.

Large differences can be seen in the braking application and brake release of the two drivers. The driver with the red trace applies force on the pedal later, more rapidly and ultimately with a higher force. This will cause the car to decelerate quicker and allow the driver to release the brake sooner.

If we look at the variance, which is the difference in lap time between both drivers (a positive value means that the red trace is faster than the black one and a negative means the opposite), the red driver was able to gain 0.016s in this corner.

Hard and fast

Brake aggression is the ability of the driver to apply a braking force rapidly. The higher the brake force speed (the slope of the brake force during the brake application phase) the more aggressive the driver is.

Most driver inputs to the car should be smooth, except in hard braking zones, such as the end of the long straight at Le Mans, where speeds can reach well above 300km/h and where braking aggression will make a massive difference in braking distance, which translates into faster lap times, or the ability to defend a position or make a pass. This is especially important in aerodynamic cars, the higher speeds mean more downforce and more load on the tyres. This means that at higher speeds, the car is capable of larger braking accelerations. In order to make use of this, a driver needs to achieve the peak braking pressure very quickly, but then release the pressure as the car slows and the downforce decreases.

The process

Here we will firstly show you how to calculate the brake pressure speed during the brake application and create a KPI to characterise brake aggression. Secondly, we will give you a few examples on how you can analyse brake aggression with other variables such as wheel locking, brake wear, vehicle balance, etc.

In this first example we will be using the brake pressure signal, but the same calculations can be

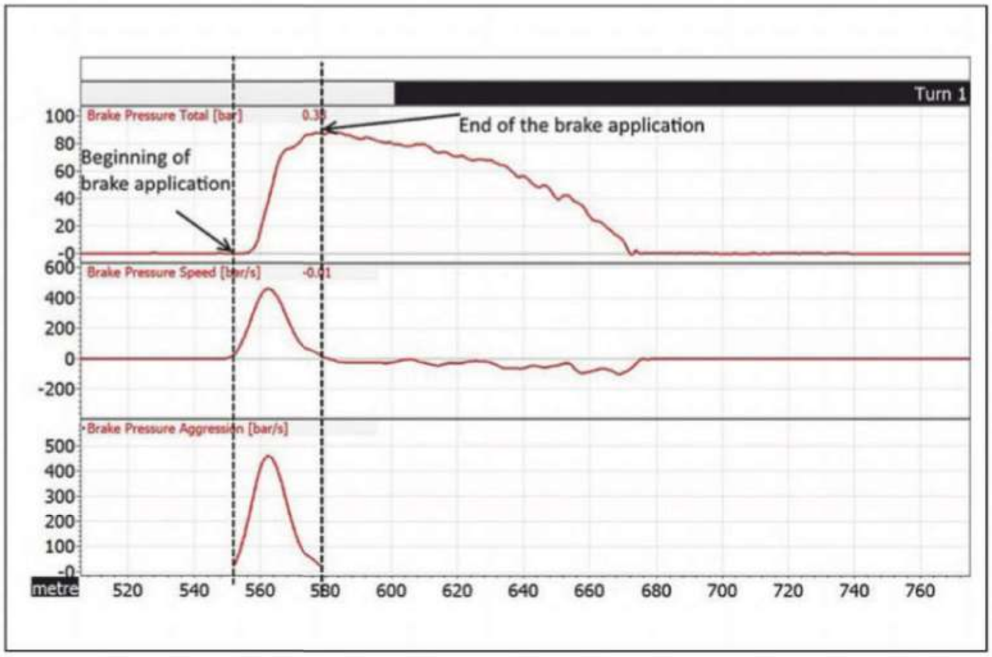

Figure 2: The results of the Table 1 math channels are applied. Calculating brake pressure speed correctly is key

Table 1: Math channel equations in MoTeC i2 to create the brake pressure aggression KPI

Math channel name	Math channel equation
Total brake pressure	'Brake Front' [bar] + 'Brake Rear' [bar]
Brake pressure speed	derivative('Brake Pressure Total' [bar], 0.2)
Brake pressure aggression	choose('Brake Pressure Speed' [bar/s] > 20, 'Brake Pressure Speed', 1/0)
Brake pressure aggression KPI	state_mean('Brake Pressure Aggression' [bar],1,range_change("Outings:Laps")

'Brake aggression' refers to the ability of the racing driver to apply a braking force rapidly

performed using the brake pedal displacement or force. First, we create a math channel called 'Total Brake Pressure'. To obtain this math channel, the first thing we need to create is the total brake pressure sum of the front and rear brake pressure. Note that this is optional and the KPI can be calculated either with the front or rear brake pressure.

Then we create the math channel for the 'Brake Pressure Speed', which is the differentiation of the previous created math channel 'Total Brake Pressure'. The derivative function is simply called *derivative* in MoTeC. This function measures the rate of change for a given number of points or a time frame. Thus we want to calculate the variation of the total brake pressure in a time frame of 0.2s. The chosen value of 0.2s is based on the delta time from brake application until reaching the maximum brake pressure. By selecting this value, we are naturally filtering the signal by not taking into account the small variations from, for example, small vibrations that occur when the brakes are applied. We only calculate the variation from initial to the maximum braking pressure.

Brake away

The next step is to extract the braking speed only of the brake application phase, which we achieve by using the MoTeC *choose* function. What characterises the braking application phase is a positive braking speed, all values below a certain threshold are ignored. In our case we used 20 bar/s but this is a reference value and it will have to be adapted depending on the racecar concerned: typical values are normally between 20-40 bar/s. We use this value in order to remove any small braking that could occur during the trail braking phase, by the driver modulating the brake.

Finally, we then calculate the 'Brake Pressure Aggression KPI' by calculating the average of the brake pressure aggression during the braking phase for each lap. The total brake pressure, brake pressure speed and brake aggression are shown in **Figure 2**.

For a more detailed explanation of how to use the *choose* or the *'state_mean'* function please refer to our March edition (V29N3).

Figure 3 shows the braking aggression over a stint. Plotting the KPI over a stint or the duration of a race gives a good overview of what is actually happening and allows you to detect any variation/deviation from a nominal value rapidly. It also enables you to see the progression of the brake aggression during the stint. This can be very useful, to see the evolution over the weekend during practice, qualification, or during the whole race.

By looking at the data we can see that Driver A is the most aggressive compared with their peers, but after lap 10 we can see that the braking aggression decreased significantly.

The goal of the race driver is to apply the maximum braking pressure at the fastest rate possible without locking up

To better understand why Driver A started to brake less aggressively we could look at the amount of time that the driver is locking the wheels (**Figure 4**). Wheel locking is the total amount of time that the racecar spent with its wheels locked, a high value means that the driver locks the wheels a lot, and a low value means that the driver doesn't lock-up that much. The wheel locking can be calculated based on comparing the speed of the car with the speed of each wheel, if the difference between the car's speed and wheel speed is higher than a predefined threshold then it's considered wheel locking.

Table 2 summarises the creation of this math channel for the front left wheel, the same methodology can be applied to calculate for the remaining wheels. To simplify the creation of the wheel locking math channel we use an intermediate step. The *'IsFLWheelLock'* returns 1 if the front left wheel is locking and 0 if not. We then create the math channel *'WheelLockFL'*, which will integrate (sum) every time that the *'isFLWheelLock'* returned a 1, giving the total amount that the wheel locked per lap.

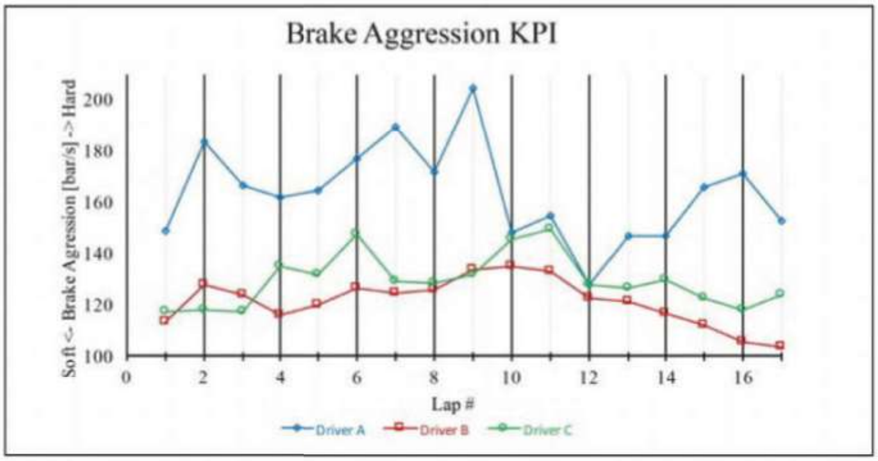

Figure 3: Braking aggression evolution during a stint. Driver A is the most aggressive of the three racers

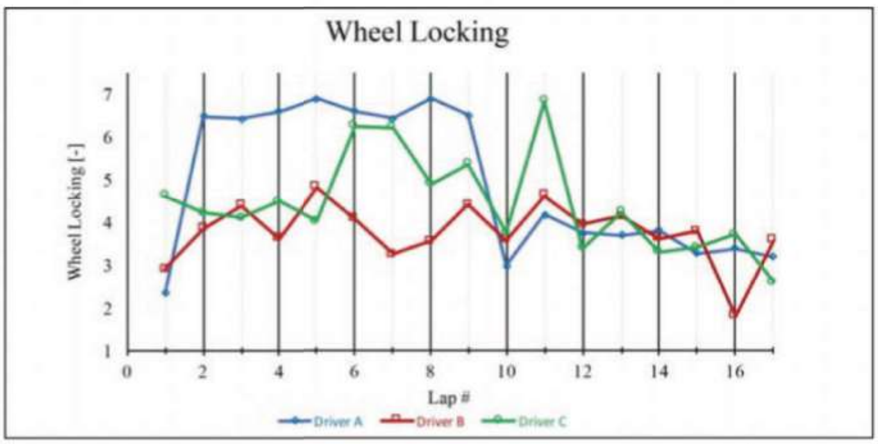

Figure 4: Wheel locking over the same stint. It's no surprise that Driver A locks up more than the others

Table 2: Equations in MoTeC i2 to create the wheel locking math channel

Math channel name	Math channel equation
IsFLWheelLock	choose(('Car Velocity' [km/h] - 'Wheel Speed FL' [km/h])>5,1,0)
WheelLockFL	integrate('isFLWheelLock',1,range_change("Outings:Laps"))

Wholly smoke

What we can expect is if a driver locks their wheels a great deal then maybe they are being too aggressive on the brakes. This can cause overheating of the tyres/ brakes which can led to premature tyre wear. This is most likely what happened to Driver A; being too aggressive and therefore then needing to ease off to avoid continuing to lock up too much, in order to manage the tyres.

Another way to look at the data is to correlate brake aggression and brake stability. Braking stability is defined as how stable the car is under braking. This is estimated by studying the amount of steering wheel angle correction applied during the braking. With both Driver B and Driver C the braking aggression decreased towards the end of the stint. The reason why both drivers become less aggressive under braking was to react to the lack of rear stability that became more significant with rear tyre wear. With the rear tyre wear greater than the front tyre wear, the grip balance shifted forwards, meaning the car was more likely to spin under braking if the rear wheels locked.

Braking good

Braking technique is one of the most important of race driver skills, as often braking is what conditions how quickly you can go around a corner. Simply put, being able to brake later while accelerating sooner will result in faster lap times.

Braking data can be looked at in many ways: brake application point, maximum braking pressure, brake lock-up, brake aggression, brake release smoothness, and braking stability, to name but a few. But more important, understanding how they relate to each other can help extract the most performance from the racecar and the driver.

Applying the correct amount and pressure of braking is necessary to provide good retardation. The goal of a driver is to apply the maximum braking pressure at the fastest rate possible without locking the wheels.

By braking too hard and fast, there is a risk of locking the wheels, creating flat spots which could compromise vehicle handling and performance, forcing the car to pit, and thus losing more time.