Calculated Brake Channel

Why?

For driver development - to complement the throttle channel.

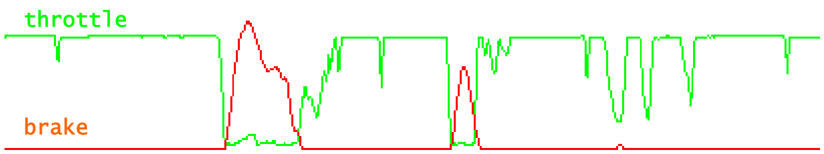

Figure 1 – Brake and throttle trace

A calculated brake channel can help you figure out whether the driver is getting the most from the brakes, and allows for comparison between brake and throttle application.

If your system can measure brake pressure, you probably don't need this channel.

How?

When traveling in a straight line, a vehicle will accelerate or decelerate as a result of these factors:

- Engine power output or engine braking
- Braking force
- Aerodynamic drag
- Rolling resistance
- Track inclination

The overall effect of all these forces on the vehicle is measured by the logger's longitudinal G channel. When there is no longitudinal accelerometer, this channel can be derived from vehicle speed.

At racing speed with the throttle closed, by far the biggest contributors to longitudinal G are brake forces and aerodynamic drag.

We can get a handy channel that approximates to the braking force by subtracting the deceleration caused by aerodynamic drag and by showing data only when the vehicle is slowing down.

Simple Equation

```
max((-1*LongG)-((Speed^2)/50000),0)
```

`LongG` is longitudinal acceleration in g. By SAE convention, forward acceleration is a positive value; hence deceleration from braking must be a negative value.

`Speed` is the vehicle speed in miles per hour.

`max(m,n)` is a function which returns whichever value of m or n is closest to positive infinity.

The 'magic number' of 50000 can be tuned up or down to get to a point where a throttle-lift with no brake on a level track shows up as a tiny bump on the trace.

If vehicle deceleration shows as a positive value in your system, the Longitudinal G trace must be adjusted:

```
max(LongG-((Speed^2)/50000),0)
```

James Hakewill – james@jameshakewill.com

If speed is measured in Km/h, start with 135000 as your ‘magic number’.

Interpreting brake data

It is possible to see how much the driver is braking by looking at the speed channel or a longitudinal G trace. The brake channel makes it easier to figure out “did I brake or lift?” and “how hard do I brake?”

The trace below shows parts of two laps (red and green) in the same session at Laguna Seca. We’ll look at the use of the brakes in a slow corner – turn 2.

The first and biggest brake application in the trace is for turn 2, slowing from 110 mph to 50 mph. The second is a little dab on the brakes for turn 3. The third deceleration is a lift on entry to turn 4.

The red trace shows the brakes being applied later and harder than in the green trace.

The shape of the green brake trace suggests that the driver started by braking hard, felt that it was too early and reduced brake pressure to arrive at the turn at the correct speed. Braking too early in this case appears to have cost around 0.2s.

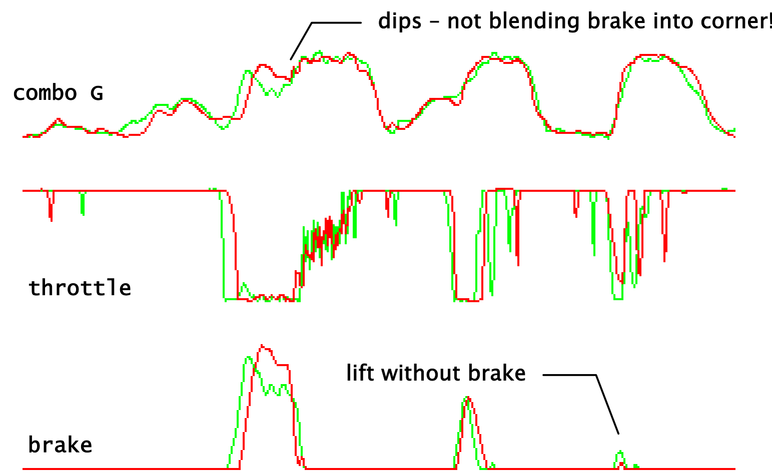

Figure 2 – Comparing overlaid brake traces

When looking at a single lap, it is useful to overlay throttle and brake channels as in the trace below. This allows the relative timing of brake and throttle application to be examined.

The trace below shows a very early brake – given away by the dip between braking and cornering on the combined G trace. The sharp initial brake followed by release on the brake trace also gives the criminal away.

$$ComboG = \sqrt{LatG^2 + LongG^2}$$

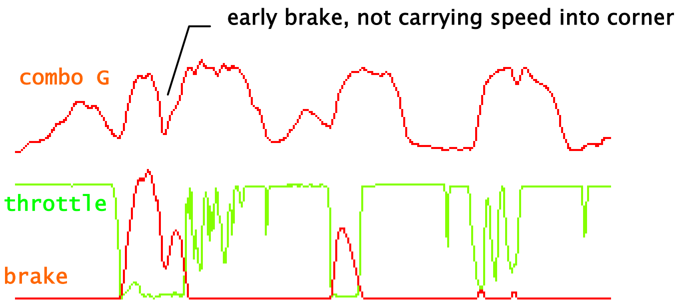

Figure 3 – 'Early brake' signature

In a straight-line braking area, the braking G figure should be able to reach the same level as the steady-state cornering G. Check for a step in the combo G channel to find where the driver is not pressing the brakes hard enough.

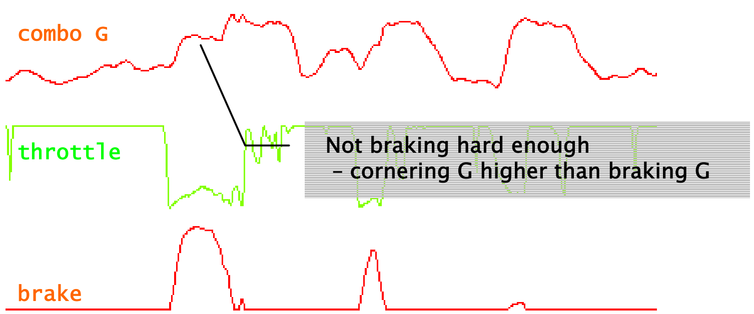

Figure 4 – 'Weak brake' signature

Check with the driver to see if a harder brake is possible. If not, find out why – could it be due to instability under braking, poor brake balance or just weak thigh muscles?

What will mess up the data?

Most systems get vehicle speed from a sensor on one of the wheels. If that wheel is locked during braking, the speed channel will not show a correct value.

If your system has a longitudinal accelerometer, the brake channel should not be affected much by locked wheels. The contribution of aero drag at the speeds at which wheels tend to lock up is pretty small.

If your system doesn't have a longitudinal accelerometer and calculates longitudinal acceleration from a wheel speed input, then the brake channel will spike when the wheels lock.

Left-foot braking whilst on full or part throttle may not show up on the calculated brake channel, as the assumption is that the engine is off during braking.

Arriving at the corner with the brakes at one end locked will result in a reduction in longitudinal G – which also looks as if the driver isn't pressing the brakes hard enough.

Complicated Equations

We combine Newton's Second Law with equations for aerodynamic drag. See *Fundamentals of Vehicle Dynamics* especially Chapter 3 p45 and Chapter 4 p97.

Newton's Second Law (NSL):
Force = mass * acceleration

NSL used to represent the total sum of forces F_{xt} acting on a vehicle of mass M with acceleration in the X direction of a_x:

$F_{xt} = M.a_x$

Using SAE symbols D_X for linear deceleration ($D_x = -a_x$):

$F_{xt} = -MD_x$

We can also write this to show the effect of total braking force F_b, aerodynamic drag D_A and track uphill grade θ. Rolling resistance is included in the braking force F_b. Note that D_X is an acceleration and D_A is a force, just to confuse you even more. Gravitational acceleration is g.

$F_{xt} = -MD_x = -F_b - D_A - Mg \sin\theta$

The rotating masses of the engine and drivetrain help and hinder braking simultaneously as a result of drag and inertial effects respectively. This sounds complicated so we won't worry about it.

We're also not going to worry about track grade since it's not practically possible to include in the math channel without a detailed track map – so we'll assume θ = 0, hence sin θ = 0. The effect of grade will have to be considered by whoever is analyzing the data.

$F_{xt} = -MD_x = -F_b - D_A$

We can rearrange to get the braking force F_b:

$F_b = MD_x - D_A$

We would like to know the deceleration D_{Xb} attributable to braking, so rearrange again to get acceleration:

$$D_{Xb} = \frac{Fb}{M} = Dx - \frac{D_A}{M}$$

Data logging systems tend to represent accelerations not as ft/sec^2 or ms^{-2} but in 'g' (9.8086 ms^{-2}). We must convert between the two systems:

$D_X = g.LongG$ and $BrakeG = \frac{D_{XB}}{g}$

So:

$$BrakeG = \frac{D_{XB}}{g} = LongG - \frac{D_A}{Mg}$$

Calculated Brake Channel

The aerodynamic drag force D_A on the vehicle varies with the square of speed v, and is affected by the air density ρ (rho), coefficent of drag of the vehicle C_D and the frontal area A:

$$D_A = ½\, \rho\, v^2\, A\, C_D$$

We can plug this into the latest equation to get:

$$BrakeG = LongG - \frac{½\, v^2 \rho\, A\, C_D}{Mg}$$

Where:

v – velocity (ms^{-1})	from Speed channel
ρ (rho) – Air Density	1.19 kg/m^3
g – gravitational acceleration	9.80865 ms^{-2}

For a typical late 70's Formula Ford:

A – frontal area	1.11 m^2
C_D – Coefficent of drag	0.71
M – mass	500 kg

Using the logger's *Speed* (mph) channel and a mph to ms^{-1} conversion (0.447039):

$$BrakeG = LongG - \frac{½\, (\text{mph2ms}.Speed)^2 \rho\, A\, C_D}{Mg}$$

By bundling up these constants into one 'magic' number we end up with a value of 1/52323 – call it 1/50000 for convenience!

$$magic\ number = \frac{½\, \text{mph2ms}^2 \rho\, A\, C_D}{Mg}$$

$$BrakeG = LongG - (Speed^2.magicnumber)$$

For a car other than a Formula Ford (e.g. a saloon), the mass, frontal area and drag coefficent will change, so have a go at working out a new starting point – or just play with the magic number until a straight-and-level throttle-lift shows up as a little bump on the trace.

Using the following figures found on the web, we get a magic number of 1/117000 for a Mazda Miata MX-5, with speed measured in MPH.
Frontal area – $2.1m^2$ ($22.3ft^2$), C_D = 0.37, M = 1091kg (2400lbs).

If speed is measured in Km/H, change the speed conversion factor from 0.447039 to 0.277778.

If you're a real pro and are measuring speed in ms^{-1}, then change the speed conversion factor from 0.447039 to 1.0.