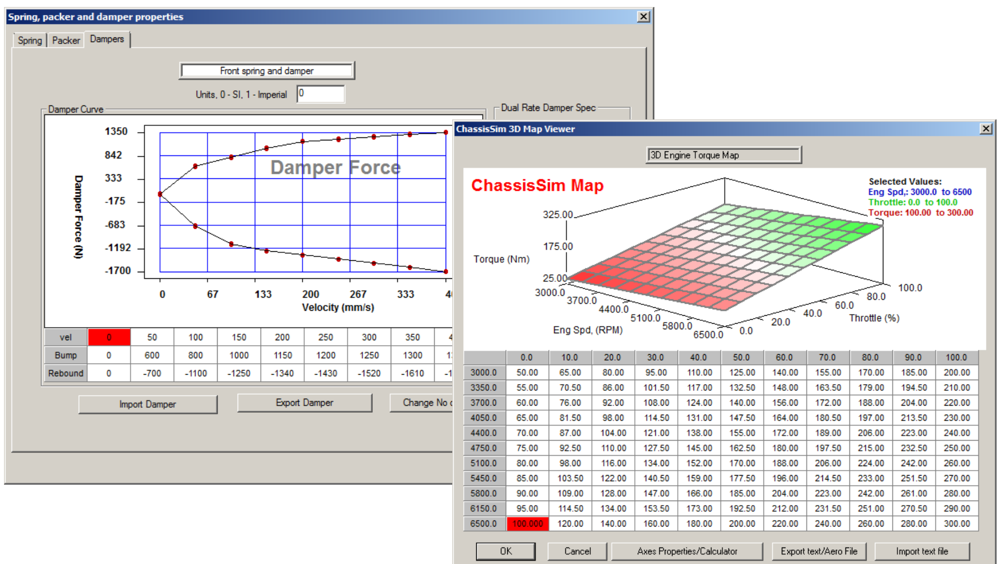
Racecar Simulation – Modern Approaches to Racecar Engineering that get Results

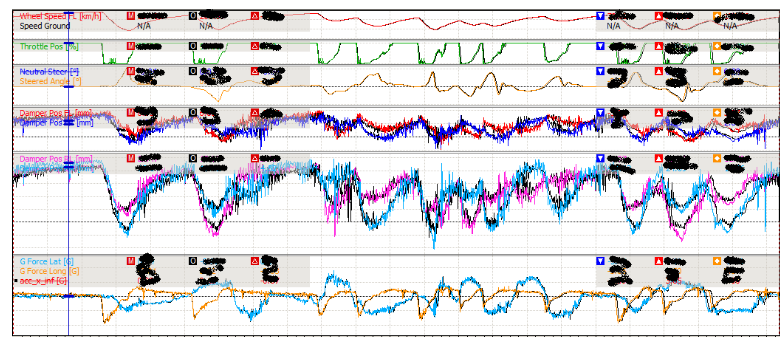
Introduction

- Racecar Simulation and Engineering are thought to be totally disconnected.
- Most Racecar Engineering is still done by trial and error.
- Yet the big point that is missed is Racecar Simulation forces you to understand your car numerically!
- Once you understand this, it drives your race engineering.

ChassisSim Background

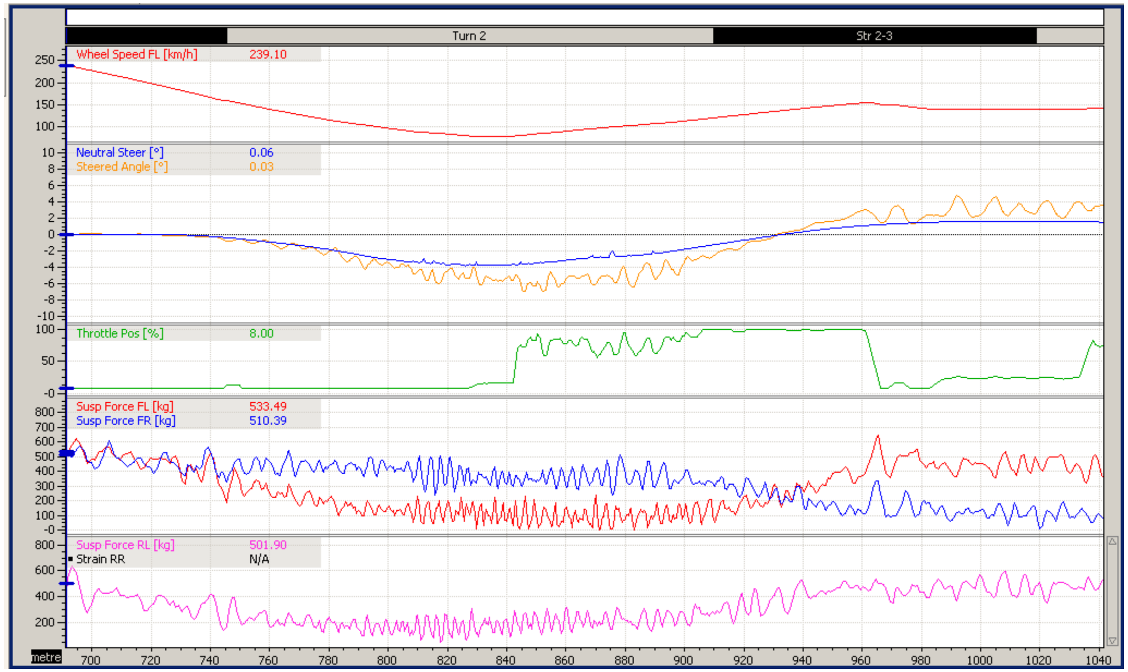
- Large No of simulation toolboxes, such as Lap time simulation, shaker rig and track replay.
- In use in Formulas as diverse as LMP1,P2, IndyCar, GP2, NASCAR, V8 Supercars and DTM
- Can reverse engineer tyre and aero models from race data.
- At it’s core is a full 21 state MBD model





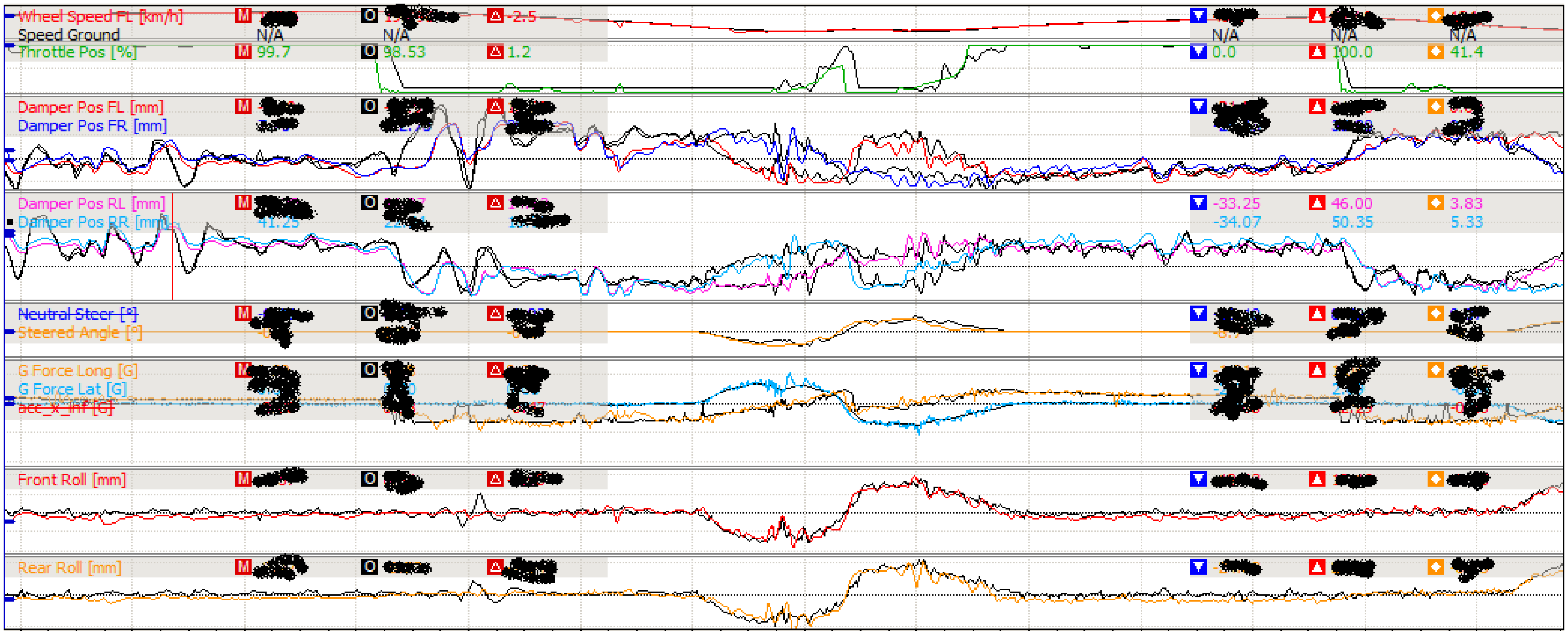
What Makes ChassisSim unique

- ChassisSim is fully transient simulation.
- It can deal with situations like this,



What ChassisSim delivers

- When you have done your job right you should expect this,



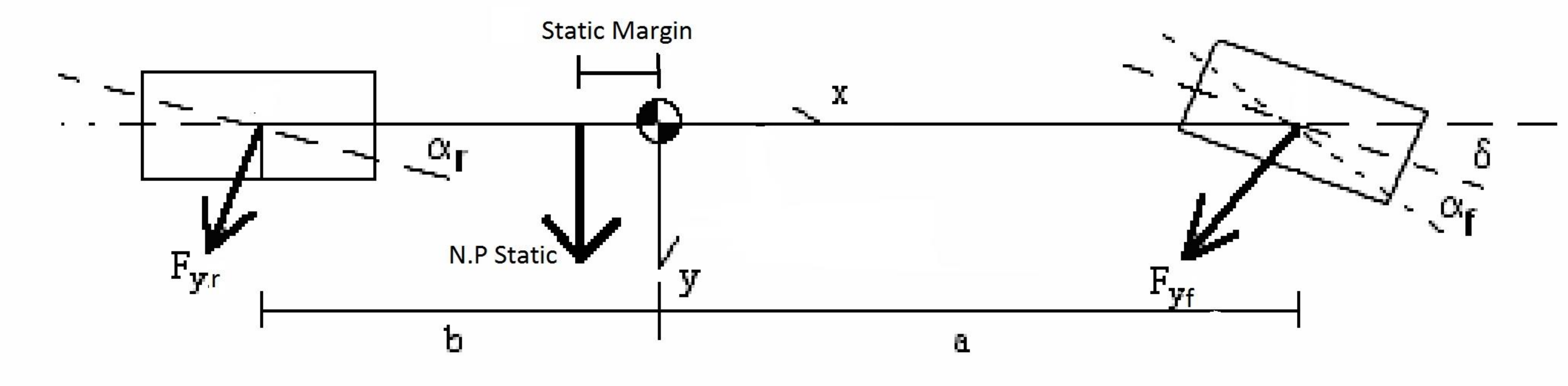
- The results of lap time simulation

The two main currencies of a race engineer

- All car performance boils down to grip and stability.
- The following is a perfect case in point,

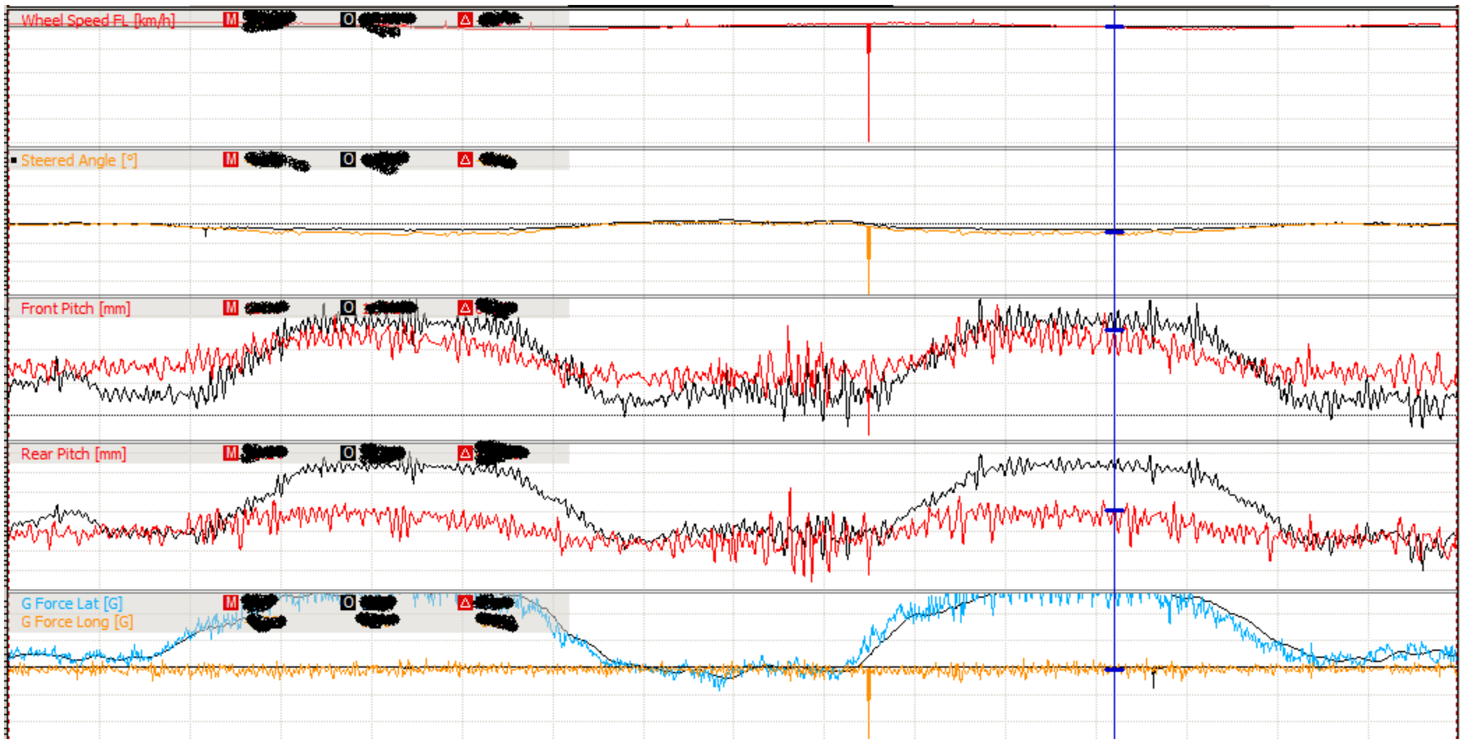
Primer - The Stability Index – A true measure of racecar stability

- The Neutral steer line is a good measure of stability If the car is being driven hard
- To get an absolute measure we need something else
- We will adapt the concept of static margin used in the aerospace industry



What racecar simulation tells you

- The following correlation between simulated and actual is very revealing,



- This illustrates a hole in the aeromap.

C_LA, C_DA, and aero balance – The metrics of Aerodynamics

- Downforce - C_LA, Drag – C_DA and aero balance can be defined as,

$$C_L A = C_Z = \frac{F_{AeroF} + F_{AeroR}}{\frac{1}{2} \cdot \rho \cdot V^2}$$

$$C_D A = C_x = \frac{Drag}{\frac{1}{2} \cdot \rho \cdot V^2}$$

$$awf = \frac{F_{AeroF}}{F_{AeroF} + F_{AeroR}}$$

- Keep this in strict SI Units. Forces are in N, speed in m/s, and density kg/m^3 .

C_LA, C_DA, and aero balance – Calculating from race data – Your dampers are load cells

- The first thing to do is to calculate the spring forces.

$$F_S = \left(k\left(x_s\right) + c\left(\dot{x}_s\right)\right) \cdot MR$$

- From here the aero coefficients are given by,

$$C_L A = \frac{\sum_{i=1}^{4} F_{s_i}}{1/2 \cdot \rho \cdot V^2}$$

$$C_D A = \frac{T(rpm) \cdot gr / r_t - m_t a_x}{1/2 \cdot \rho \cdot V^2}$$

$$awf = \frac{\sum_{i=1}^{2} F_{s_i} + \frac{m_t a_x h}{wb}}{\sum_{i=1}^{4} F_{s_i}}$$

- A really good place to take this from is the end of the longest straight on the circuit.

C_LA, C_DA, and aero balance – Example calculation

- Let's consider some typical F3 numbers

Item	Quantity
Front Motion Ratio	0.9
Rear Motion Ratio	0.8
FL Damper/FR Damper	10mm/10mm
RL Damper/RR Damper	15mm/15mm
Front spring	140.1 N/mm (800 lbf/in)
Rear spring	140.1 N/mm (800 lbf/in)
Torque at RPM	200 Nm
Rolling tyre radius	0.28m
a_x	0g
Vx	220km/h
Gear ratio value	3
m_t	500kg
h	0.3m
wb	2.6m

C_LA, C_DA, and aero balance – Example calculation – Crunching the numbers

- Doing the calculations it is seen.

$$
\begin{aligned}
FtDownforce &= MR_f \cdot k_f \cdot (FL\_Damp + FR\_Damp) \\
&= 0.9 * 140.1 * (10 + 10) \\
&= 2521.8N \\
RearDownforce &= MR_r \cdot k_r \cdot (RL\_Damp + RR\_Damp) \\
&= 0.8 * 140.1 * (15 + 15) \\
&= 3362.4N \\
C_L A &= \frac{FtDownforce + RearDownforce}{0.5 * 1.225 * (220/3.6)^2} \\
&= 2.57 \\
AeroBal &= 100 \cdot \left(\frac{FtDownforce + \frac{mt \cdot g \cdot a_x \cdot h}{wb}}{FtDownforce + RearDownforce} \right) \\
&= 100 \cdot \left(\frac{2521.8 + \frac{500 \cdot 9.8 \cdot 0 \cdot 0.3}{2.6}}{2521.8 + 3362.4} \right) \\
&= 42.9\% \\
C_D A &= \frac{gr * T / r_t - m_t \cdot g \cdot a_x}{0.5 * 1.225 * (220/3.6)^2} \\
&= \frac{3 * 200 / 0.28 - 550 \cdot 9.8 \cdot 0}{0.5 * 1.225 * (220/3.6)^2} \\
&= 0.937
\end{aligned}
$$

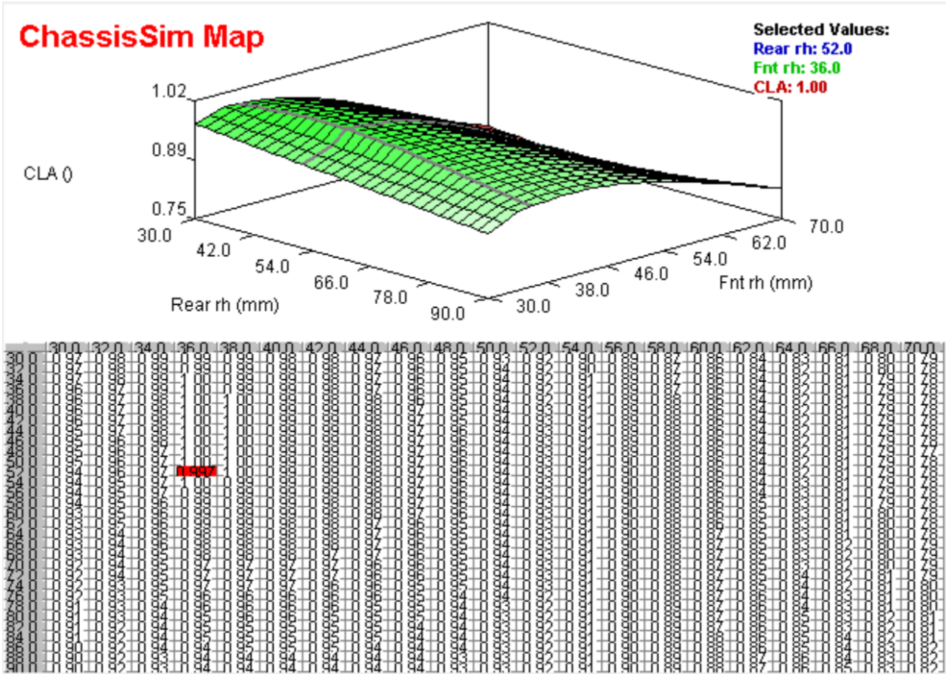
C_LA, C_DA, and aero balance – Typical values

- Some typical values for C_LA and C_DA are shown below

Car	C_LA	C_DA
Touring car	0.5 – 1.4	0.9 – 1.3
FIA GT3 – GT2	1.7 – 2 (configuration dependant)	0.9 – 1.3
F3 or equivalent	1.5 – 2.7 (configuration dependant)	0.7 – 1.1
F3000	2.4 – 2.7 (configuration dependant)	1.2 – 1.3
IndyCar	3 – 4.5	1.4 – 1.7
LMP2	3.7-5	0.9-1.2

The payoff of all this – generating and reading an aeromap

- Consider this downforce map from an LMP2 car,



- This tells you where you need to be in high speed corners,

Tyre Modelling – Why you don't leave home without it.

- In tyre modelling getting the TC radius vs Load characteristic right is key.
- Fortunately there is a simple way of getting started.

$$TC_{RAD} = k_a (1 - k_b \cdot F_z) \cdot F_z$$

- Here we have,

TC_{rad} = Traction Circle radius (N)

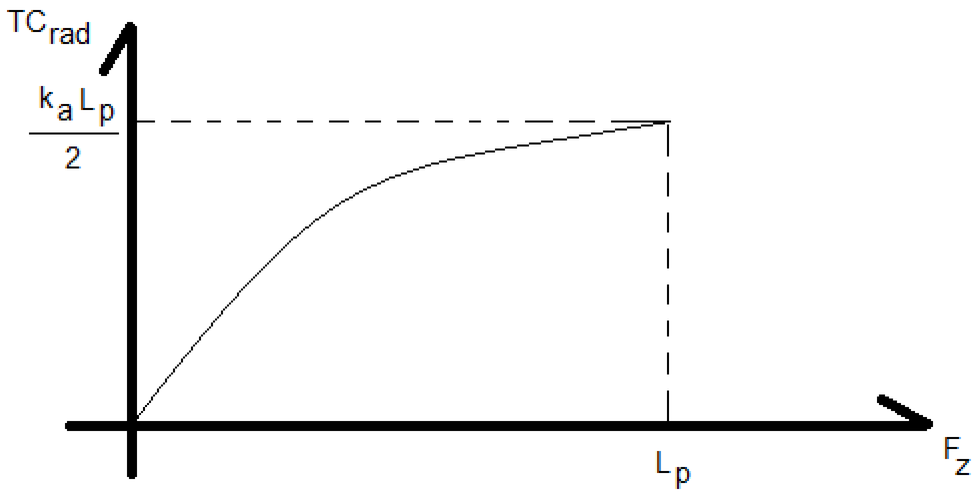
k_a = initial coefficient of friction

k_b = drop off of coefficient with load

F_z = load on the tyre (N)

We can express the tyre curve as a function of Peak Load

- The second order curve fit gives us this shortcut.



- All we need to know is what peak tyre loads we are expecting and the forces we need to produce.

The first thing you need is peak tyre loads

- The first thing we need to know is the peak tyre loads.
- We can get these from hand calcs or simulation,

- As a rough rule of thumb I add 30% for the peak load.

The 2nd thing is what forces you need

- This is where a pseudo static force balance is of great help,

$$F_{yf} = wdf \cdot m_t \cdot iR \cdot V_x{}^2$$

$$F_{yr} = (1 - wdf) \cdot m_t \cdot iR \cdot V_x{}^2$$

- The terms are,

F_{yf}	= Front lateral force
F_{yr}	= Rear lateral force
wdf	= Front weight distribution (%/100)
m_t	= Total car mass in kg
iR	= Peak corner curvature in 1/m
Vx	= Cornering speed (m/s)

This can be all combined in an excel sheet

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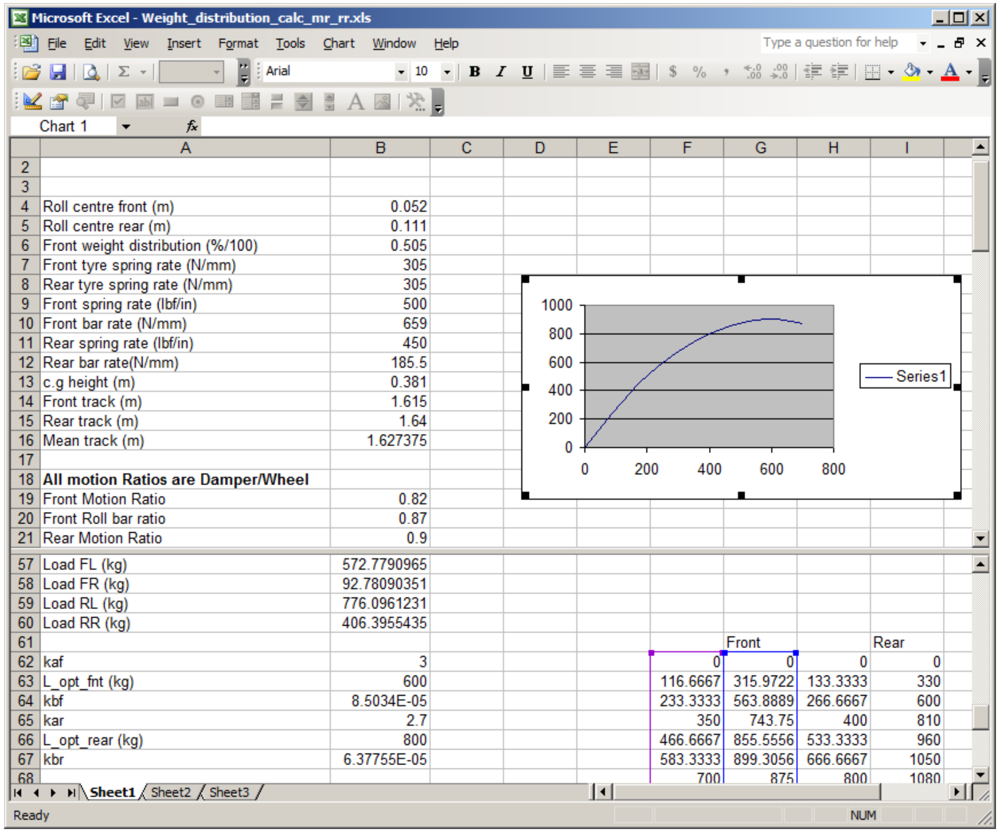
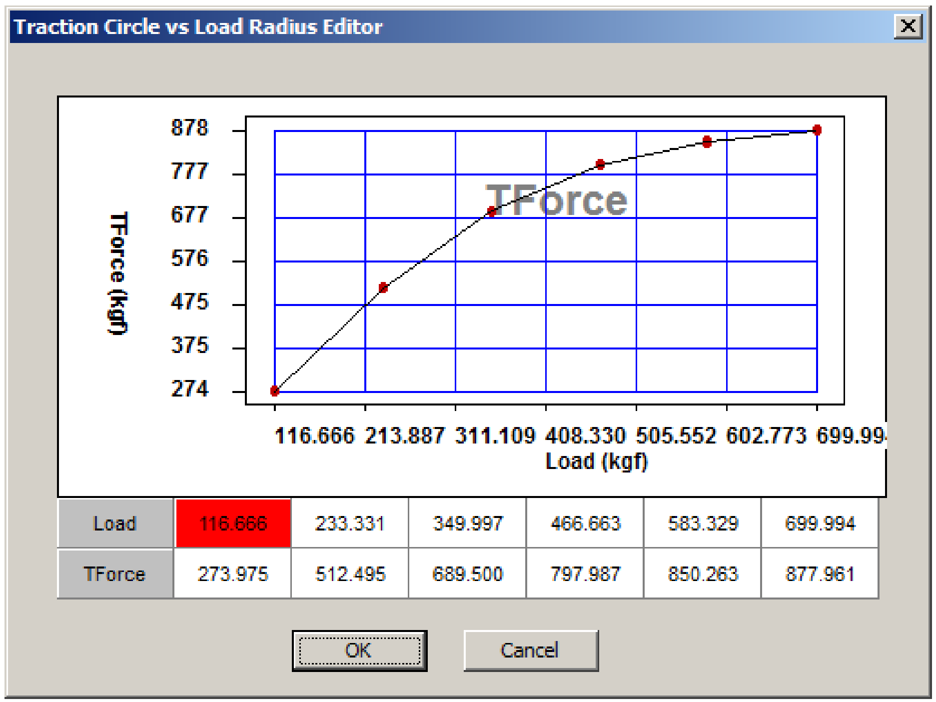


	A	B	F	G	H	I
2						
3						
4	Roll centre front (m)	0.052				
5	Roll centre rear (m)	0.111				
6	Front weight distribution (%/100)	0.505				
7	Front tyre spring rate (N/mm)	305				
8	Rear tyre spring rate (N/mm)	305				
9	Front spring rate (lbf/in)	500				
10	Front bar rate (N/mm)	659				
11	Rear spring rate (lbf/in)	450				
12	Rear bar rate(N/mm)	185.5				
13	c.g height (m)	0.381				
14	Front track (m)	1.615				
15	Rear track (m)	1.64				
16	Mean track (m)	1.627375				
17						
18	**All motion Ratios are Damper/Wheel**					
19	Front Motion Ratio	0.82				
20	Front Roll bar ratio	0.87				
21	Rear Motion Ratio	0.9				
57	Load FL (kg)	572.7790965				
58	Load FR (kg)	92.78090351				
59	Load RL (kg)	776.0961231				
60	Load RR (kg)	406.3955435				
61				Front		Rear
62	kaf	3	0	0	0	0
63	L_opt_fnt (kg)	600	116.6667	315.9722	133.3333	330
64	kbf	8.5034E-05	233.3333	563.8889	266.6667	600
65	kar	2.7	350	743.75	400	810
66	L_opt_rear (kg)	800	466.6667	855.5556	533.3333	960
67	kbr	6.37755E-05	583.3333	899.3056	666.6667	1050
68			700	875	800	1080

- You put in basic setup data, a tyre curve and you tune k_a to approximate corner speeds.

Once you have a tyre curve plug it into ChassisSim

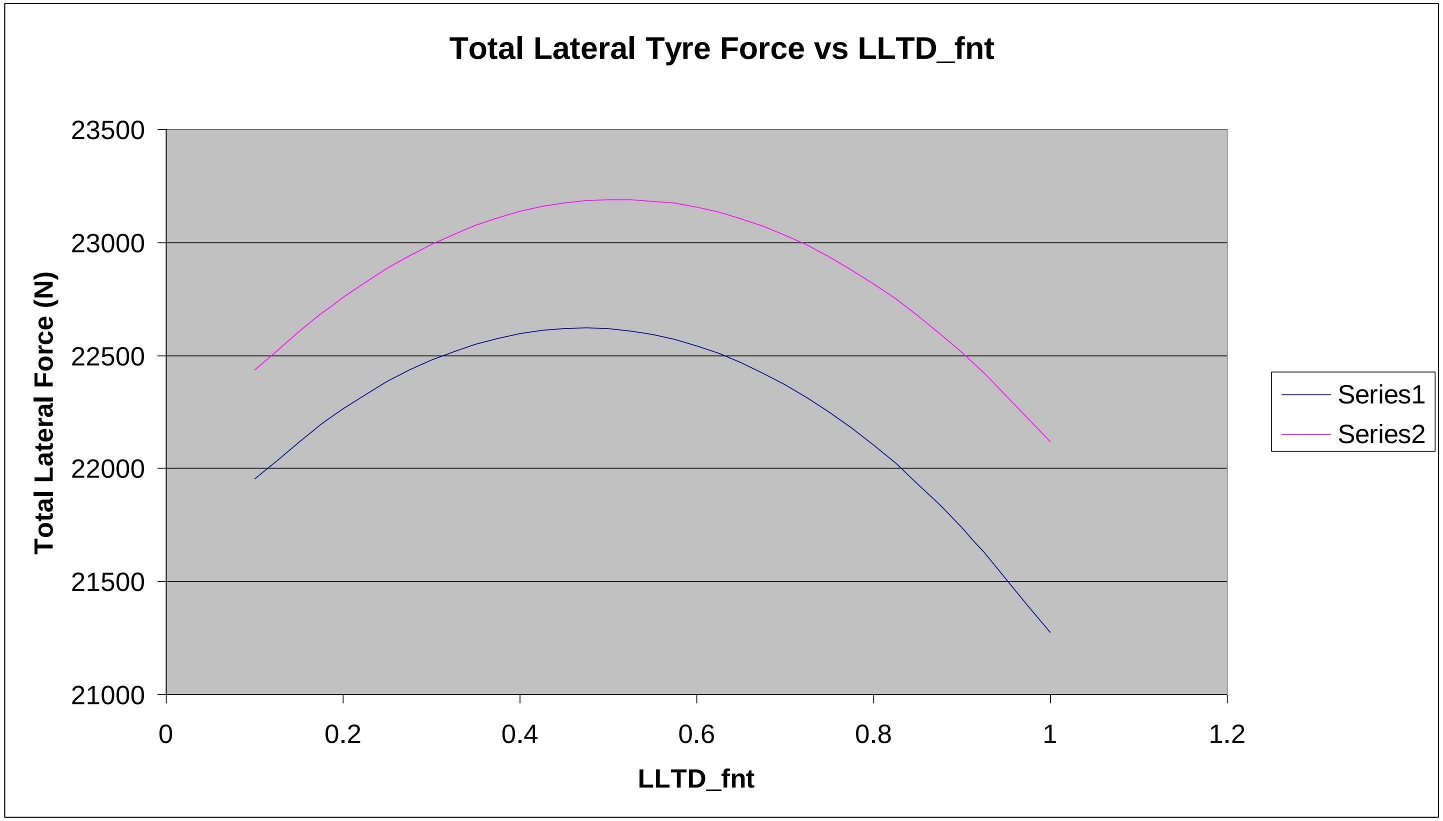
- Once you have deduced the tyre curve plug it in using the tyre force quick start.



- Use the tyre force modelling toolbox to fill in the blanks.

Why a tyre model? What Lateral Load transfer at the front tells you

- Lateral Load transfer gives you a 1st cut of grip and stability



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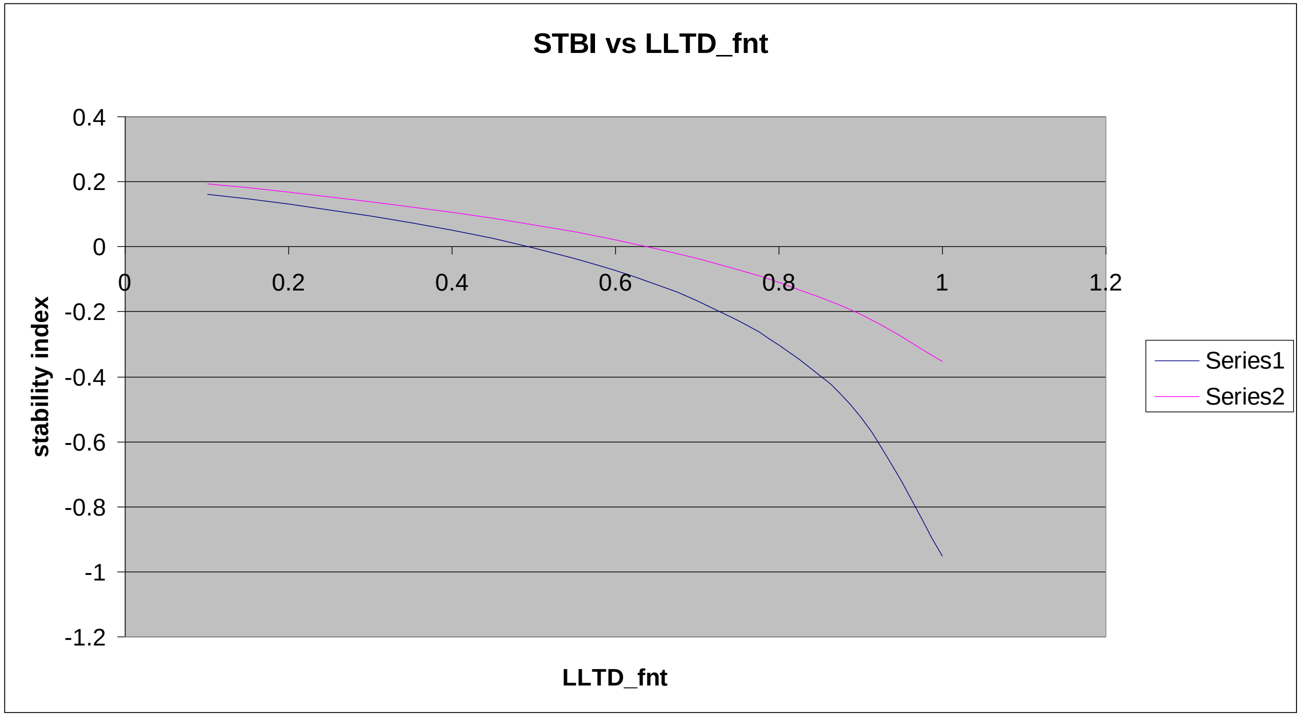
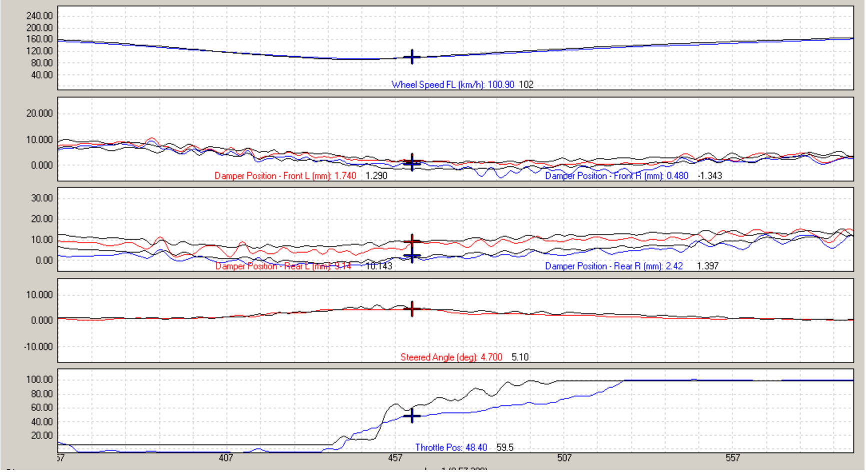


- This is the mechanical grip/balance equation and dictates the setup.

How to interpret Simulated Data and what to focus on.

Quantifying setup changes

- Current tyre models (2D models in particular) represent a setup well, in particular.



- Numerically the force differences from setup to setup are small

- This is due to the nature of the tyre model.

Quantifying setup changes - Example

- Consider this simple 2D tyre model of a V8 Supercar

Parameter	Value
Initial co-efficient of friction	2.2
Peak Load	850 kg

- Let's consider the effect of a 10mm rear roll centre change.

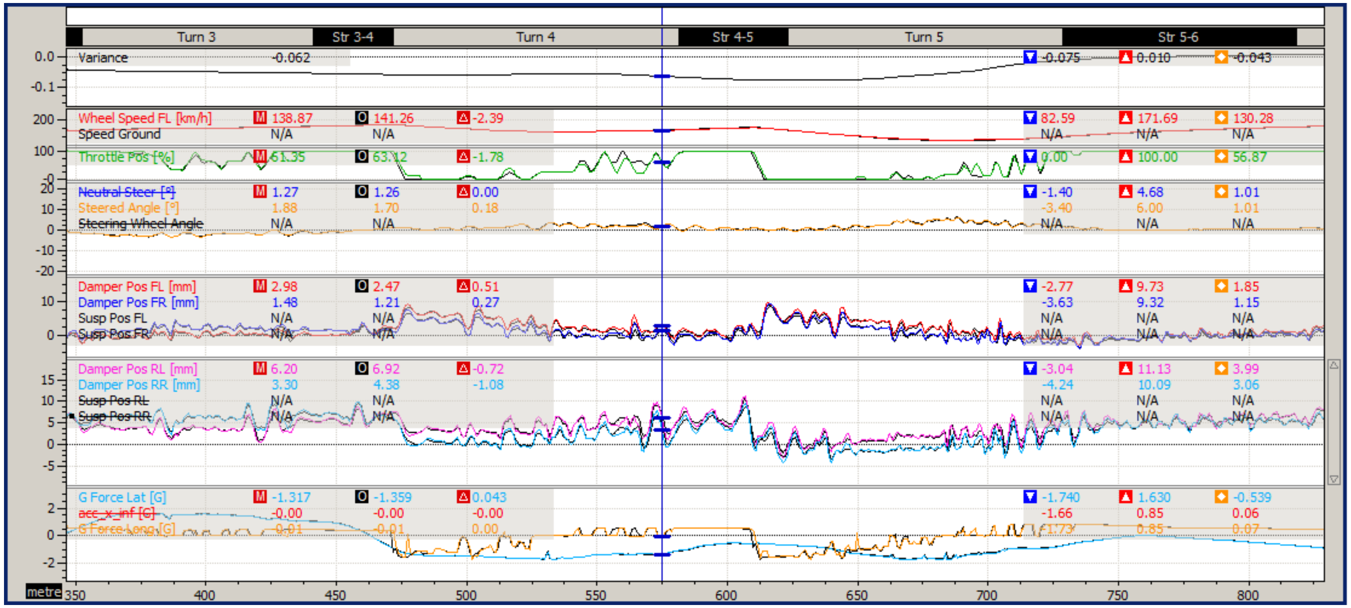
Setup	Load FL	Load FR	Load RL	Load RR	FyR	V_pred
RRC 240	674.96	133.82	694.58	54.47	9993.5	81.47
RRC 250	671.61	137.16	697.93	51.1	9938	81.27

- Yet this is something a driver will report a difference in feedback.

- The true difference is something in the middle but the true value would err to the conservative side.

Simulated changes will always be smaller than actual data

- Reason 1 – For the reason we just discussed.
- Reason 2 – A simulator has no concept of it’s own mortality
- Simulated changes show up as cornering speeds



- This is the key difference between simulated and actual data

Evaluating what the simulator means

- Here are some rough rules of thumb

Change delta	Severity
0.1 – 0.2 km/h	Mild
0.2 – 0.6 km/h	Moderate
0.6 km/h +	Extreme

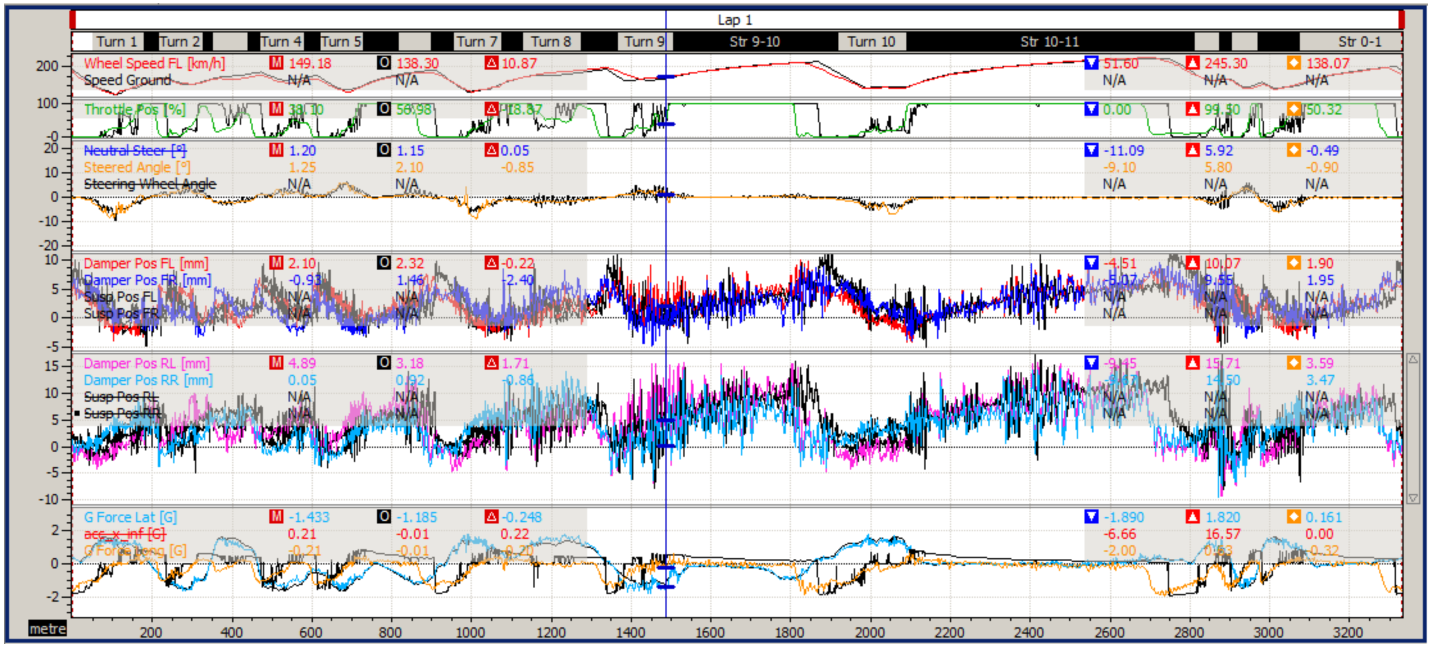
- You are also looking for small consistent changes.

Correlation – what to focus on

- Here are some rough rules of thumb

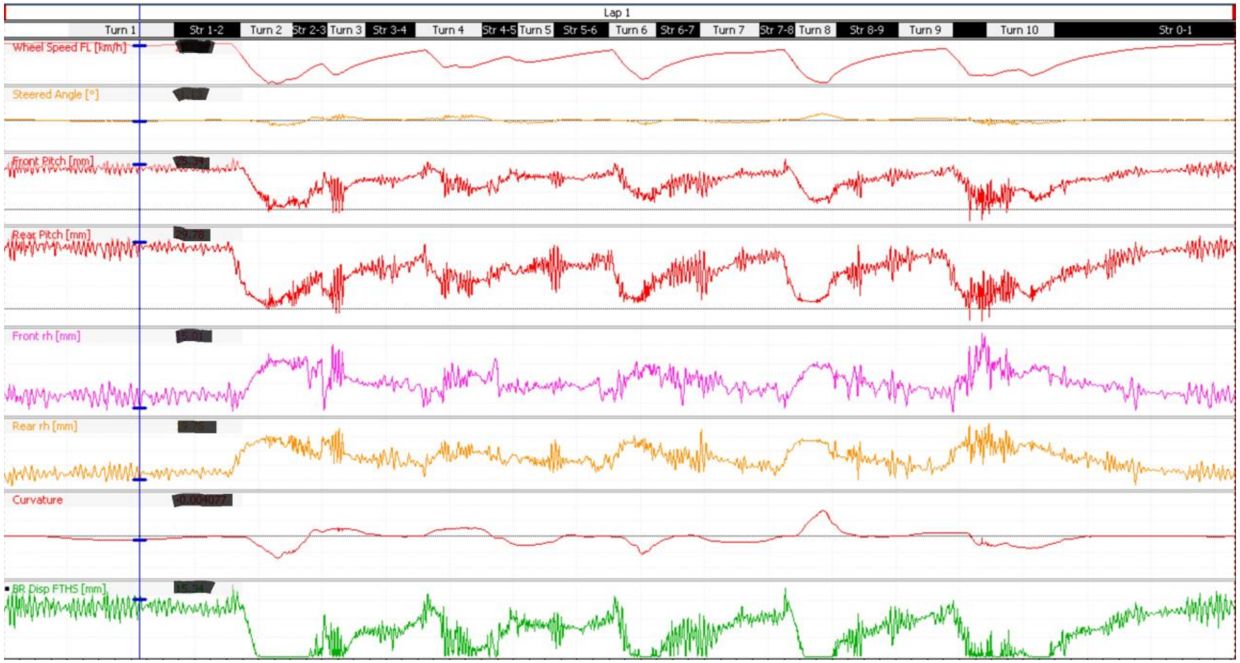
Corner speed	Delta
80 - 120 km/h	1-2 km/h
120 - 160 km/h	2-3 km/h
160 km/h	3-4 km/h

- This is good enough.



Some rules of thumb on how to use simulation

- This is using simulation for ride height calculations



- In this case I wasn't concerned with lap time.

- All I was concerned about was using the simulation to see the Bump rubber displacement and ride heights.

What setup parameters should you be working with?

- Spring Rates +/- 20 % of the base setup.
- Keep damping ratios to known values of the base setup.
- Suspension Geometry +/- 20% of roll centre migration.
- However you can lean on camber gain changes.
- Bars within +/- 30% of the base setup.
- Also start from a well known model and modify to suit.

Simulation in Action – The 24 Hours of LeMans.

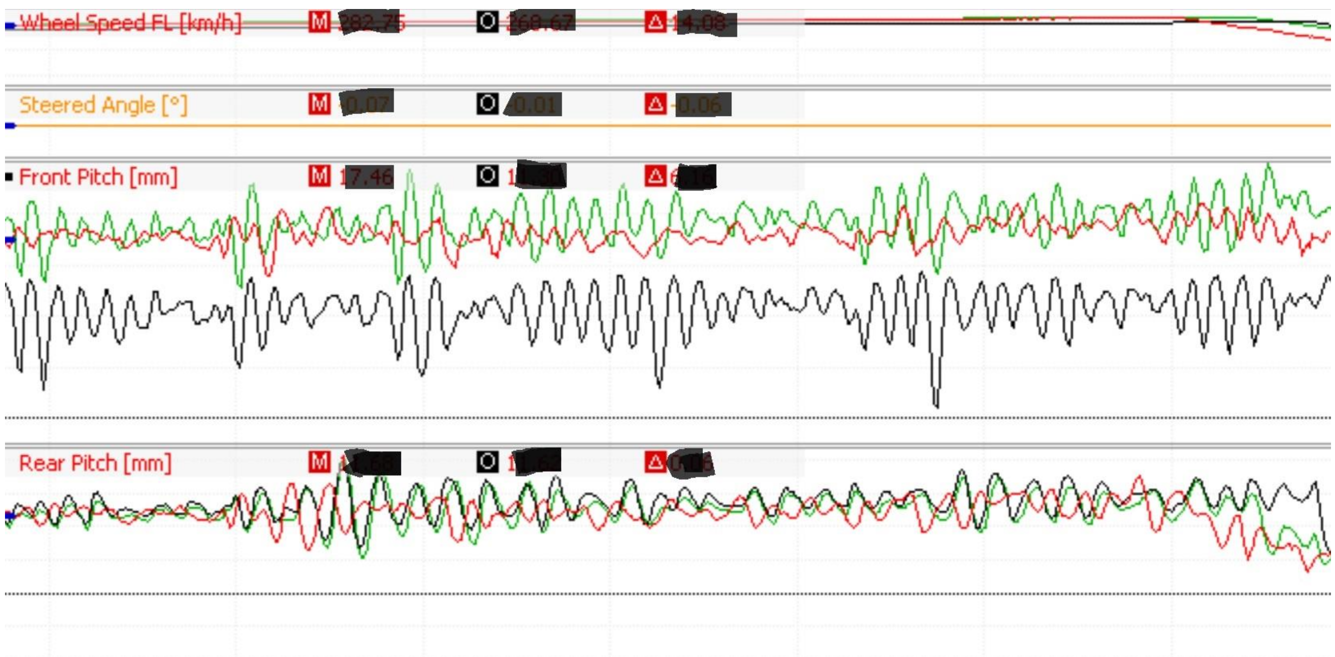
Introduction

- When you are under the pump it is really tempting to push simulation to the back burner.
- This was a new team and they where a stuck.
- What will be shown here came from 2 x 4 hours session of simulation work.

Step 1 – Aero Correlation

- Fortunately there was a stock model to go from.

- This was the initial aero correlation



- Given this was done on CFD this was to be expected.

Step 1 – Aero Correlation

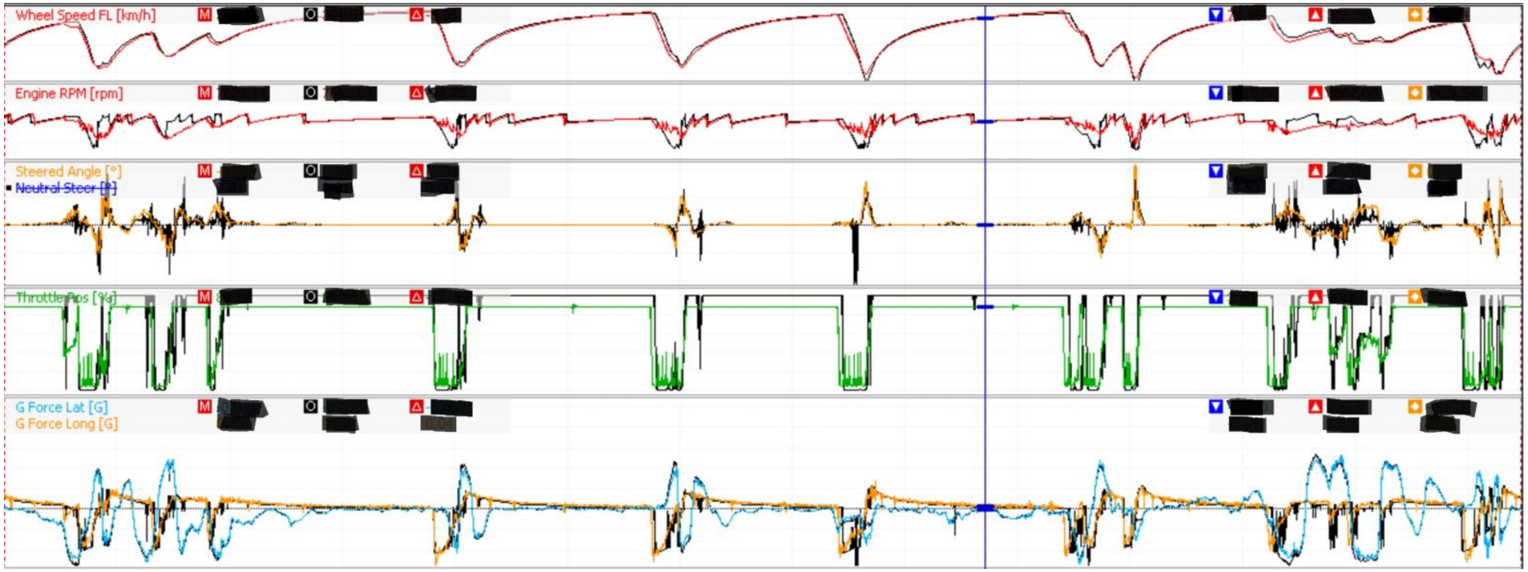
- In this situation focus on end of straight correlation
- This was what had to be done for the Aero coefficients

Item	Baseline	Final
C_LA Max	Bline	-9%
C_DA Max	Bline	0%
Aero balance offset	Bline	+4%

- This is about typical of what you would expect from CFD results.

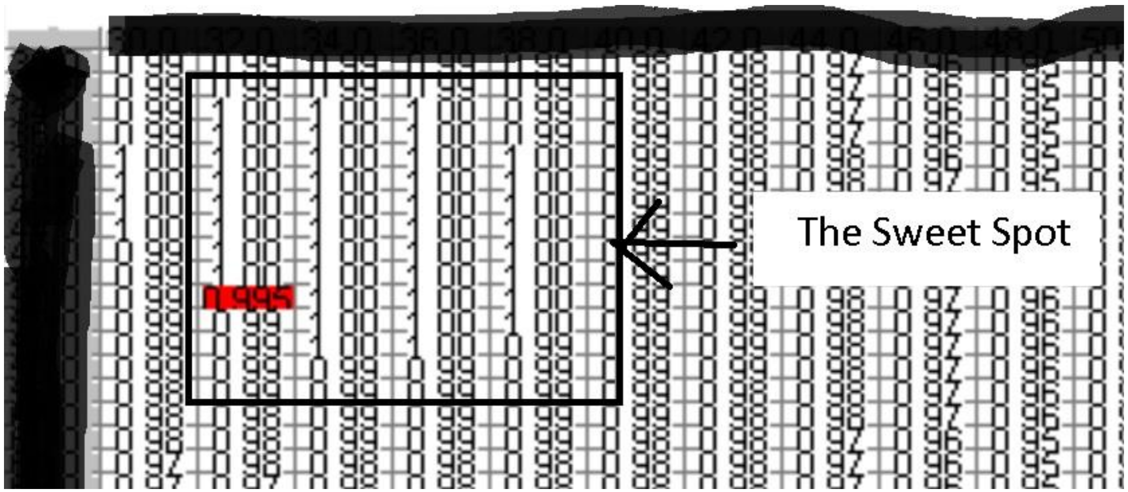
Step 2 – Corner correlation.

- Since ChassisSim is transient to dial in the corners we did the following,
- Altitude and road camber effects, bump scale factor and local grip scale factors
- This was the end result,



Racecar Tuning – the aero sweetspot

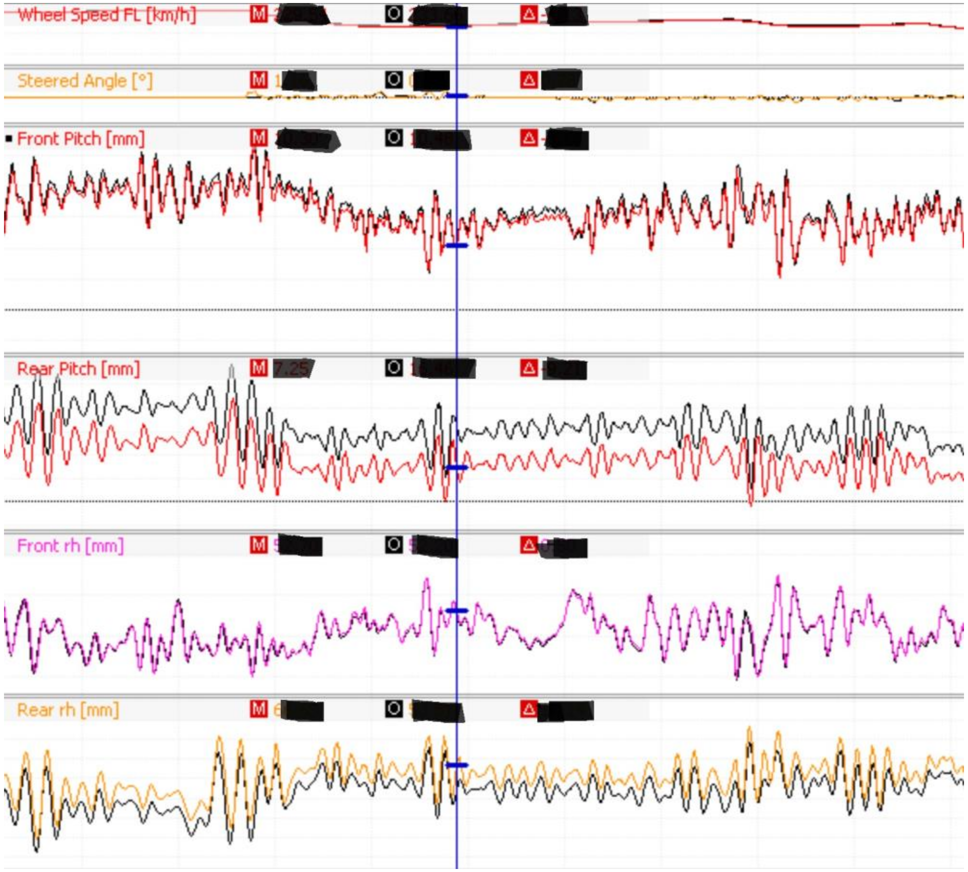
- Since these are aero cars nailing the ride height envelope was key.
- You want the transient ride height here,



- To do this ChassisSim third spring features where used heavily

Racecar Tuning – Third spring tuning

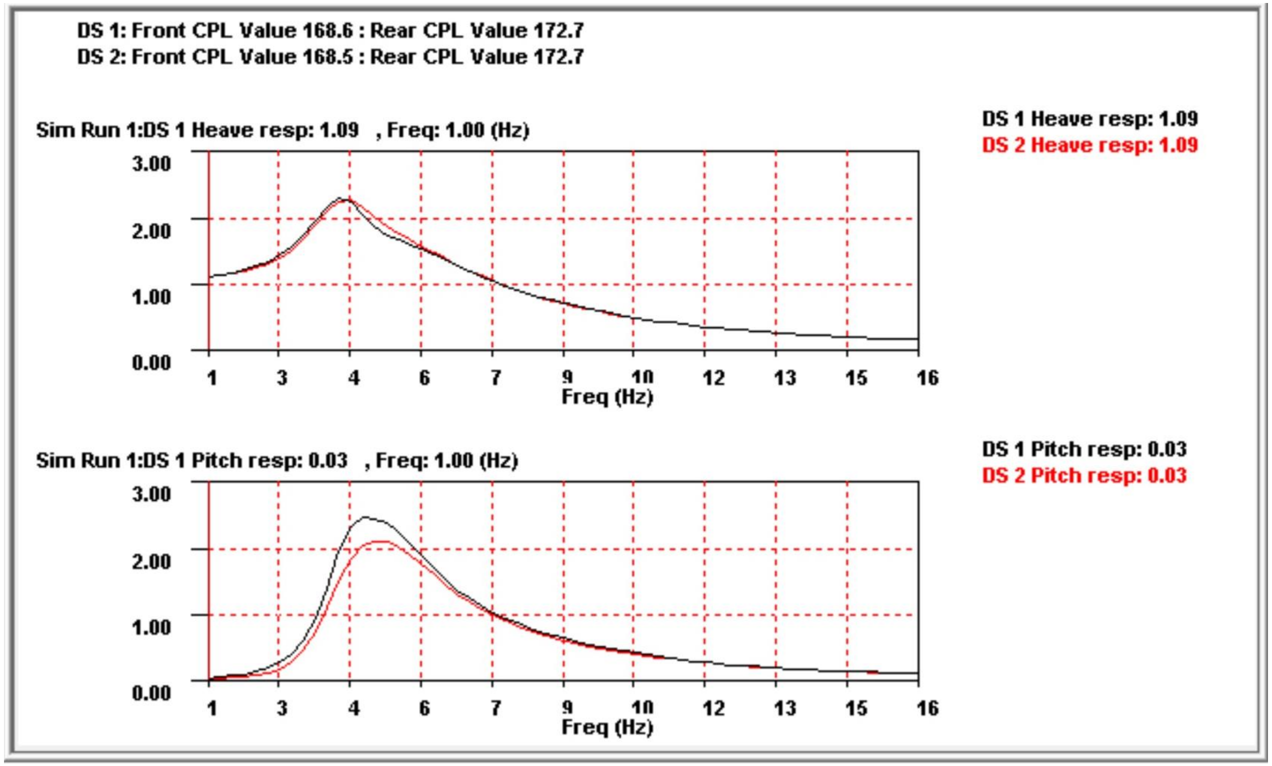
- The net result of this tuning was shown below,



- Net result in the high speed corners the car was 2 – 3 km/h quicker.

Racecar Tuning – Dampers

- To give the race engineer some options some damper tuning was done.
- The end result is shown below



- Not applied to the car but shown for completeness.

Results

- The initial goal was to make sure they didn't run last!
- This was completed.
- However as other things came together the car got quicker.
- They where 4th in the morning warmup

Conclusion

- What racecar simulation does is it forces you to quantify your car.
- We saw that dampers can be viewed as load cells
- A basic tyre model can yield much about how to tune the car.
- However the real nail with racecar simulation is it forces you to race engineer numerically.

Parting thoughts – 2019 24 hours of LeMans

- "*ChassisSim was just the final push we needed at Le Mans. We start to go from baby steps to real step in our performance. Many thanks for your help and for your tools!*" - Roberto Hernandez Garcia the race engineer for Car 34.