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Table of Contents

1. INTRODUCTION	9
2. AERODYNAMICS	10
2.1. Drag and lift.....	10
2.1.1. Drag and Lift Coefficients.....	10
2.2. Acceleration and Downforce	11
2.3. Braking and Downforce.....	11
2.4. Cornering and Downforce.....	12
2.5. Centre of Pressure	12
3. AERODYNAMIC OPTIMISATION	12
3.1. Effects on Drag.....	12
3.2. Effects on Downforce.....	13
4. AERODYNAMIC FACTORS	14
4.1. Cd testing method.....	14
4.2. Cl testing method.....	15
5. DAMPERS	16
6. METHODOLOGY	17
6.1. Aims of the test.....	17
6.2. Testing Procedure	18
6.2.1 Session 1.....	18
6.2.2 Session 2 (Dampers).....	19
7. ANALYSIS OF TEST DATA	20
7.1. Coast Down Data (Cd).....	20
7.2. Cl	23
8. Aerodynamic configurations, front and rear wing over one lap	24
8.1 Downforce vs Speed	25
8.2 Downforce over one lap.....	25

8.3 Drag Force over a lap	28
8.4 Constant corner test for sim steering	29
8.5 Lateral Acceleration vs speed	30
8.6 Centre of pressure	31
8.7 "Default", "Front min Rear mid", "Front max Rear mid" configurations over one lap comparison	32
8.8 "Default", "Rear min Front mid", "Rear max Front mid" configurations over one lap comparison	37
9. Load transfer behaviour Springs and ARB Setups	41
9.1 Spring and ARB slow and high corners	44
9.1.1 Slow Corner (Turn 6) Spring changes	44
9.1.2 Slow Corner (Turn 6) ARB changes	47
9.1.3 High Speed Corner (Turn 4) Spring changes	50
9.1.4 High Speed Corner (Turn 4) ARB changes	53
10. Dampers	57
10.1 Histograms to assess damper settings overall	58
10.2 Damper Setup transient handling	60
10.3 Low Speed Bump Setups	62
10.4 Low speed Rebound Setups	63
11. Conclusion	65
12. References	65

Table of Figures

Figure 1: Base Performance Simulator	9
Figure 2: Coordinate system used to define the directions of aerodynamic loads on a vehicle. (Katz, 1995)	10
Figure 3: Effect of aerodynamic downforce on the braking distance versus vehicle speed (Katz, 1995)	11
Figure 4: Effect of downforce and drag values due to angle of attack (Formula 1 Dictionary, n.d.)....	12
Figure 5: Downforce from a front wing increases as ground clearance decreases (Mcbeath, 2006) ..	13
Figure 6: Variation of vehicle speed versus time during a coast down test. (Katz, 1995)	14
Figure 7: Aerodynamic drag is negligible under 40 Km/h (Katz, 1995)	15
Figure 8: Damper Force vs Velocity (Samuel Philip Gacka, 2006).....	16
Figure 9 – Tyre loads for calculating the static weight of the Aston	20
Figure 10 – High speed and low speed sections.	21
Figure 11 – Pembrey track	24
Figure 12 – Downforce vs Speed plot	25
Figure 13 – Calculated Downforce.....	25
Figure 14 – Turn 1 drop in downforce	26
Figure 15 – Cl and Downforce Correlation.....	27
Figure 16 – Turn 4 drop in downforce	27
Figure 17 – Drag Force over	28
Figure 18 – Aerodynamic Efficiency.....	28
Figure 19 – Simulated steering ratio.....	29
Figure 20 – Lateral G force over one lap.....	30
Figure 21 – G force increases with speed	31
Figure 22 – Centre of Pressure Histogram	31
Figure 23 – Understeer, Corrected Theoretical Steer and Speed for “Default” and front max and min downforce configurations.....	35
Figure 24 – Front Downforce, Rear Downforce and COP for “Default” and front max and min downforce configurations.....	35
Figure 25 – Rake angle and speed for “Default” and front max and min downforce configurations ..	36
Figure 26 – Braking and speed for “Default” and front max and min downforce configurations.....	36
Figure 27 – Lift Force, Drag Force and Speed for “Default” and front max and min downforce configurations	37

Figure 28 - Understeer, Corrected Theoretical Steer and Speed for “Default” and rear max and min downforce configurations.....	38
Figure 29 - Front Downforce, Rear Downforce and COP for “Default” and rear max and min downforce configurations	38
Figure 30 - Rake angle and speed for “Default” and rear max and min downforce configurations	39
Figure 31 - Braking and speed for “Default” and rear max and min downforce configurations.....	39
Figure 32 - Lift Force, Drag Force and Speed for “Default” and rear max and min downforce configurations	40
Figure 33 – Load Transfer Forces build up with time (Haney, 1999).....	41
Figure 34 – Slow Speed front elastic and geometric load transfer spring setups	45
Figure 35 – Slow speed Front total predicted and tyre load, load transfer springs setups.....	45
Figure 36 – Slow Speed Rear elastic and geometric load transfer spring setups	46
Figure 37 - Slow speed Rear total predicted and tyre load, load transfer springs setups.....	46
Figure 38 – Slow Speed understeer and speed, load transfer springs setups	46
Figure 39 – Slow Speed front elastic and geometric load transfer ARB setups.....	48
Figure 40 - Slow speed Front total predicted and tyre load, load transfer ARB setups	48
Figure 41 - Slow Speed Rear elastic and geometric load transfer ARB setups	49
Figure 42 - Slow speed Rear total predicted and tyre load, load transfer ARB setups.....	49
Figure 43 - Slow speed understeer, speed and roll angle, load transfer ARB setups	50
Figure 44 - High Speed front elastic and geometric load transfer spring setups.....	51
Figure 45 - High speed Front total predicted and tyre load, load transfer springs setups.....	51
Figure 46 - High Speed Rear elastic and geometric load transfer spring setups	52
Figure 47 - High speed Rear total predicted and tyre load, load transfer springs setups	52
Figure 48 - High Speed understeer, speed and roll angle, load transfer springs setups	53
Figure 49 - High Speed front elastic and geometric load transfer ARB setups.....	54
Figure 50 - High speed Front total predicted and tyre load, load transfer ARB setups.....	54
Figure 51 - High Speed Rear elastic and geometric load transfer ARB setups	55
Figure 52 - High speed Rear total predicted and tyre load, load transfer ARB setups.....	55
Figure 53 - High Speed understeer, speed and roll angle, load transfer ARB setups	56
Figure 54 – Low Speed Bump setups	57
Figure 55 – Low Speed Rebound setups	58
Figure 56 – Baseline histogram.....	59
Figure 57 – Low Speed Bump 0 Clicks Histogram	59

Figure 58 – Low Speed Bump 8 Clicks	60
Figure 59 – Corner sections (Tudor, 2019)	60
Figure 60 – Damper Velocity Bump and Rebound, low speed bump settings.	62
Figure 61 – Weight Transfers and Understeer, low speed bump setting.	63
Figure 62 – – Damper Velocity Bump and Rebound, low speed rebound settings.	63
Figure 63 – Weight Transfers and Understeer, low speed rebound setting.....	64

Table of Tables

Table 1 – Session 1 Test Plan, the table was done by Vijay Kuner and forwarded to other students within the group.	18
Table 2 – Session 2 Test Plan, the table was done by Vijay Kuner and forwarded to other students within the group.	19
Table 3 – Coast down Setups	20
Table 4 – Data acquired from testing	21
Table 5.....	21
Table 6 - CD	22
Table 7 - Cl.....	23
Table 8 – Cd and Cl values.....	24

Table of Equations

$CD = D12\rho v^2A$ Equation 1	11
$CL = L12\rho v^2A$ Equation 2	11
$F = m * a$ Equation 3	14
$Drag\ Force = m\Delta V\Delta t - rolling\ resistance$ Equation 4.....	15
$Drag\ Force = m_{High\ Speed}\Delta V_{High\ Speed}\Delta t - m_{Low\ Speed}\Delta V_{Low\ Speed}\Delta t$ Equation 5	15
$CD = Drag\ Force12\rho v^2A$ Equation 6.....	15
$Velocity\ v_m = v_2 + v_12$ Equation 7 (Tudor, 2019)	22
$Rolling\ Resistance\ RR = m * a_2$ Equation 8 (Tudor, 2019)	22
$High\ speed\ deceleration\ a_1 = (v_2 - v_1)(t_2 - t_1)$ Equation 9 (Tudor, 2019).....	22
$Low\ Speed\ deceleration\ a_2 = (v_4 - v_3)(t_4 - t_3)$ Equation 10 (Tudor, 2019).....	22
$Cd = 2(ma_1 - ma_2)\rho v_m^2A$ Equation 11.....	22
$Cl = Downforce0.5 * \rho * A * v^2$ Equation 12.....	23
$Flift = Cl \times A \times 0.5 \times \rho \times V^2$ Equation 13 (Tudor, 2019)	26
$Aerodynamic\ Efficiency = FliftFdrag$ Equation 14 (Tudor, 2019)	28

<i>Corrected Theoretical Steer = Theoretical Steer × Sim steering Ratio</i>	Equation	15
(Tudor, 2019)		29
<i>Theoretical Steer = Wheelbase Corner Radius</i>	Equation 16 (Tudor, 2019)	29
<i>Corner Radius = speed²lateral acceleration</i>	Equation 17 (Tudor, 2019)	29
<i>COP = Front DownforceDownforce × 100</i>	Equation 18	31
<i>Downforce = Front Downforce + Rear Downforce</i>	Equation 19 (Tudor, 2019)	32
<i>Front Downforce = FL + FR – (FLstatic + FRstatic) – WTL</i>	Equation 20 (Tudor, 2019)	32
<i>Rear Downforce = RL + RR – RLstatic + RRstatic + WTL</i>	Equation 21 (Tudor, 2019)	32
<i>WTL = m * a * hw</i>	Equation 22 (Tudor, 2019)	32
<i>COP = Front DownforceDownforce * 100</i>	Equation 23 (Tudor, 2019)	32
<i>Understeer = abs(Steering Wheel Pct) – abs(Corrected Theoretical Steer)</i>	Equation 24	
(Tudor, 2019)		33
<i>Rake Angle = tan – 1Rear Ride Height – Front Ride Height1000Wheelbase</i>	Equation 25	
(Tudor, 2019)		33
<i>Rear Ride Height = Ride Height RL + Ride Height RR2</i>	Equation 26 (Tudor, 2019)	33
<i>Front Ride Height = Ride Height FL + Ride Height FR2</i>	Equation 27 (Tudor, 2019)	33
<i>Mot = Ms * ay * H</i>	Equation 28 (Tudor, 2019)	42
<i>Roll Centre = hr + hf * COGfw + hf</i>	Equation 29	42
<i>θ = MotKθ</i>	Equation 30	42
<i>Kθt = Kθf + Kθr</i>	Equation 31	42
<i>Kθf = Tf2 * Kw f2</i>	Equation 32	42
<i>Kw f = spring rate * suspension motion ratio2 + ARBf</i>	Equation 33	42
<i>WTsf = Kw f * Tf * θ2</i>	Equation 34 (Tudor, 2019)	42
<i>WTsRCf = Msf * ay * hfTf</i>	Equation 35 (Tudor, 2019)	42
<i>WTsRCr = Msr * ay * hrTr</i>	Equation 36 (Tudor, 2019)	43
<i>WTusf = Musf * ay * rfTf</i>	Equation 37 (Tudor, 2019)	43
<i>WTusr = Musr * ay * rrTr</i>	Equation 38 (Tudor, 2019)	43
<i>WTTf = WTsf + WTsRCf + WTusf</i>	Equation 39 (Tudor, 2019)	43
<i>WTTTr = WTsr + WTsRCr + WTusr</i>	Equation 40 (Tudor, 2019)	43
<i>WTT = WTTf + WTTTr</i>	Equation 41 (Tudor, 2019)	43
<i>Predicted MN = WTTfWTT</i>	Equation 42	43

LIST OF ACRONYMS

- Cd – Coefficient of drag
- Cl – Coefficient of lift
- D – Drag
- L – Lift
- ρ – Density of air
- V – velocity
- A – Frontal Area

1. INTRODUCTION

Aerodynamic and suspension set-up affect the way a car handles and behaves around a circuit, the tinkering of these setups can give the car the edge against its opponents.

This report will look at different aerodynamic and suspension set-ups on an Aston Martin DB9 race car around a circuit, in this case Pembrey. The different configurations will be tested on the “Base Performance” racing simulator (Figure 1) located at the University of Wales Trinity Saint David. The data collected from the simulator is further analysed using a data logger software called Motec.

The report will first showcase how aerodynamics affect the car around a circuit, as well as how dampers affect the vehicle. Furthermore, analysis of the different set-ups will be showcased, with their respective graphs and comparison tables. Finally, a conclusion will be made on what aerodynamic and damper set-up is the most apt for circuit racing.



Figure 1: Base Performance Simulator

2. AERODYNAMICS

The objective is to increase traction by increasing the downforce on the contact patch, without adding mass to the vehicle. The three major elements which produce downforce are the front wing, the rear wing and the underbody. The downside to the increase in downforce is the increase in drag, to overcome this penalty, additional power has to be given to the engine. (Seward, 2014). In general, the centre of pressure moves forward with speed. This is due to the front wing being the most efficient component of an aerodynamic package, because it is working in undisturbed air. (Balkwill, 2018)

2.1. Drag and lift

Two basic categories of aerodynamic forces acting on the car:

- Pressure: acts normal to the surface and contributes to lift and part of the drag. (Katz, 1995)
- Shear Force: acts parallel to the surface and contributes only to drag. (Katz, 1995)

From these categories, three forces can be defined, drag, lift and side force, for the purpose of this report only drag and lift will be taken into account, as the side forces are negligible due to the high speeds the vehicle will be travelling at. (Katz, 1995)

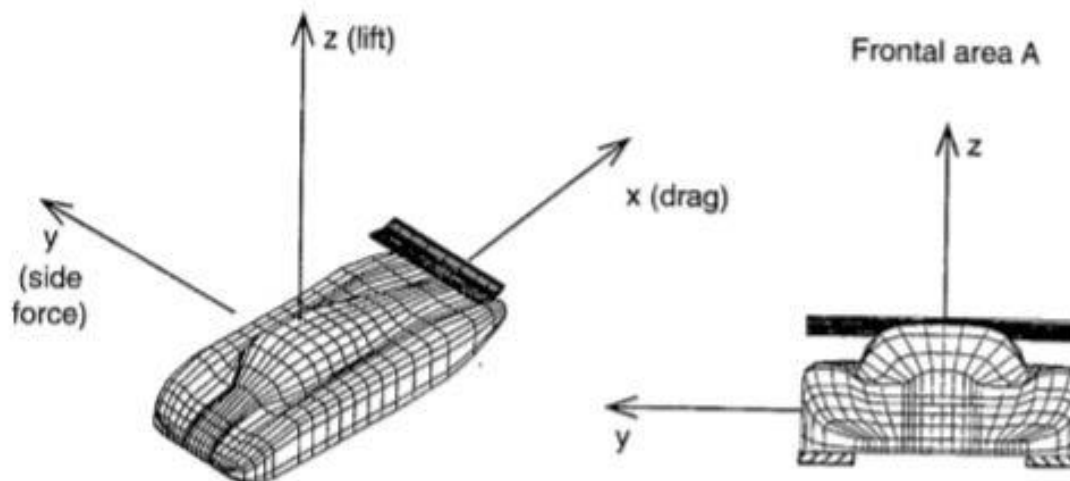


Figure 2: Coordinate system used to define the directions of aerodynamic loads on a vehicle. (Katz, 1995)

Downforce acts in the -Z direction (Figure 2)

2.1.1. Drag and Lift Coefficients

Aerodynamic Drag increases with the square of speed. To achieve non dimensional coefficients, it must be divided by the squared velocity. The reference area (frontal area), as seen on the right-hand side of Figure 2, automobile manufacturers measure accurately the frontal shadow of the car, while

others use a very broad definition of their reference area. There is usually a 5% deviation in the data of different studies for the same vehicle.

$$C_D = \frac{D}{\frac{1}{2}\rho v^2 A} \quad \text{Equation 1}$$

$$C_L = \frac{L}{\frac{1}{2}\rho v^2 A} \quad \text{Equation 2}$$

See List of Acronyms for further information.

2.2. Acceleration and Downforce

For high power high downforce cars such as the Aston Martin, once it reaches speeds of about 150 km/h, downforce is developed. Transmission loads will increase, alongside the traction forces. If we assume, at those speeds there is an additional vertical force of 0.8G then there would be an 80% increase in transmission loads than those off the line. (Seward, 2014)

2.3. Braking and Downforce

Braking from friction at the tyre contact patch, will also be slowed by the aerodynamic drag. As soon as the driver lifts his foot off the throttle, the car slows down, without the need of using the brakes. This braking is applied at the Centre of Pressure on the front of the car. As its located close to the centre of mass, there will be little effect on longitudinal weight transfer. (Seward, 2014)

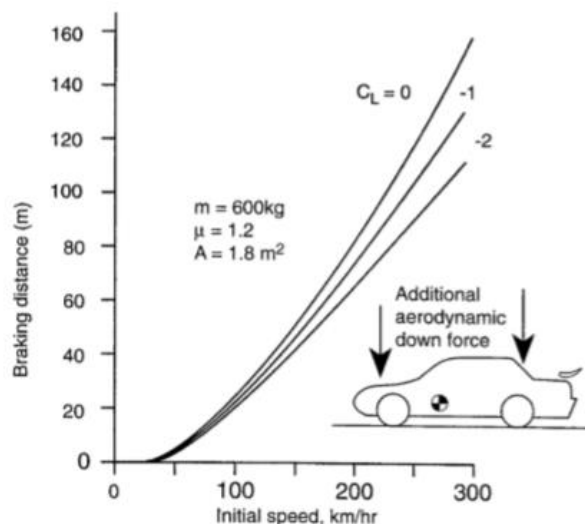


Figure 3: Effect of aerodynamic downforce on the braking distance versus vehicle speed (Katz, 1995)

Clearly, as shown in Figure 3, a shorter braking distance is needed at high speeds and high downforce (Katz, 1995) in straight line braking.

2.4. Cornering and Downforce

At high speed corners downforce is a major gain in performance. The large increase in effective weight and grip mean that the car can sustain large levels of lateral g force. (Seward, 2014)

2.5. Centre of Pressure

If the COP distance behind the front wheel centreline is less than the centre of mass distance it means you don't have enough rear downforce (or too much front downforce). If your COP distance is greater than the centre of mass distance it means you don't have enough front downforce (or too much rear downforce). (Machin)

3. AERODYNAMIC OPTIMISATION

This section talks about what can be optimised on the car to change its drag and downforce values.

3.1. Effects on Drag

C_d and C_l are directly linked with each other, by optimising the following components on a car, it is possible to increase or decrease the drag on a vehicle:

- Angle of attack rear and front wing, as seen in Figure 4
- Rake angle.

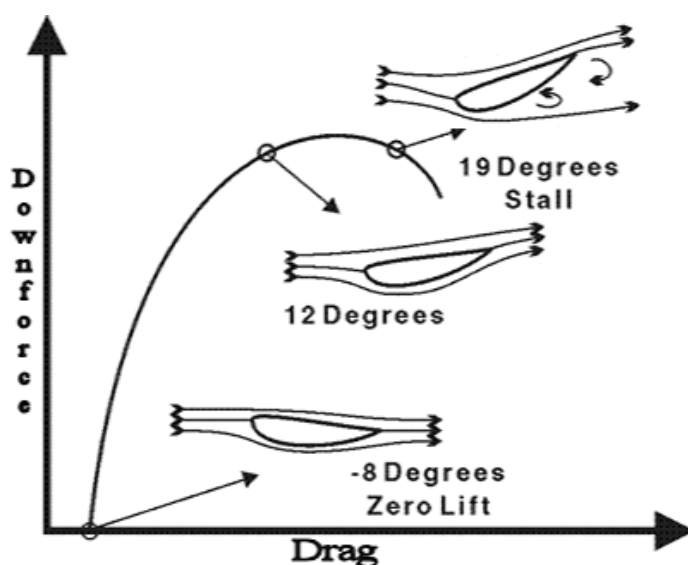


Figure 4: Effect of downforce and drag values due to angle of attack (Formula 1 Dictionary, n.d.)

3.2. Effects on Downforce

As downforce and drag are directly linked, the previous components would affect downforce, as well as other characteristics:

- Vehicle Pitching – when the car is moving around a track in a dynamic manner the downforce goes up and down affecting the pitch of the vehicle, which will in turn affect the proximity of the front wing to the ground and its angle of attack. (Mcbeath, 2006)
- Pitch sensitivity – Wings can stall at low dynamic ride height if they are run too close to the ground. Methods of lessening its effects are damping systems that enable the independent adjustment of high and low damper piston speeds (Mcbeath, 2006). In Figure 5, the max downforce gained was when the ground clearance from the wing was at 0.14, not at a lower ground clearance due to stall of the wing.

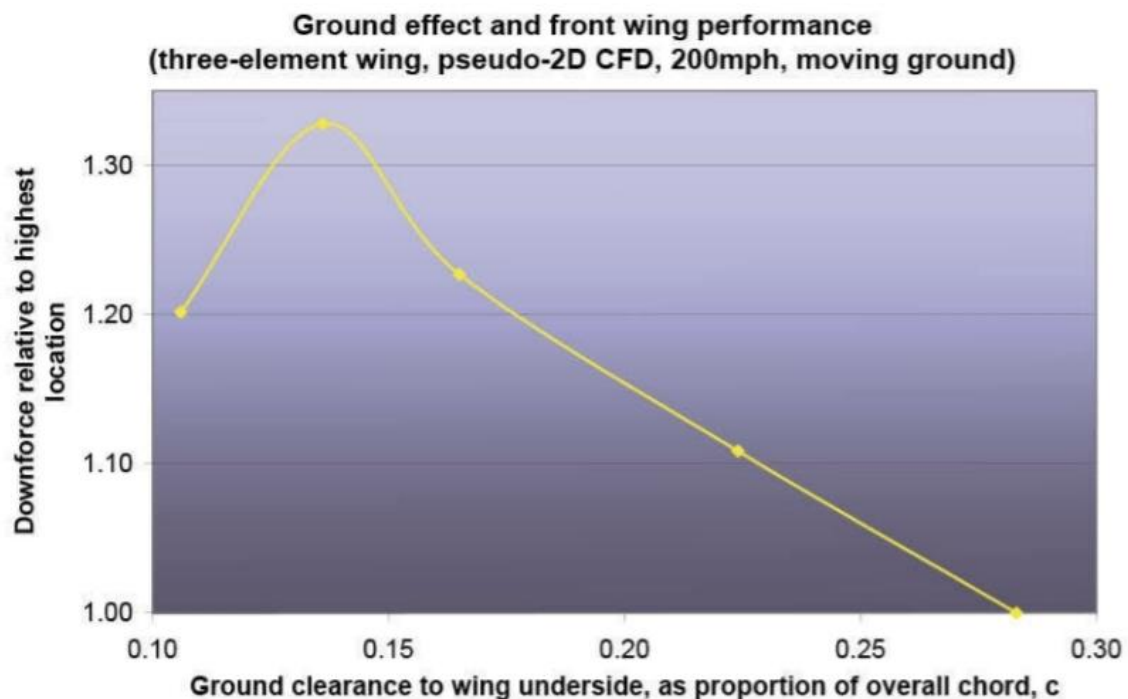


Figure 5: Downforce from a front wing increases as ground clearance decreases (Mcbeath, 2006)

- Rake angle – dropping the front or raising the rear increases total downforce, in essence the underfloor of the car is acting as a simple venturi (Mcbeath, 2006)

4. AERODYNAMIC FACTORS

These two factors are the C_d and the C_l .

4.1. Cd testing method

The vehicle is brought to a high speed, put into neutral, and allowed to slow down. It is known as a coast down (Mcbeath, 2006).

Aerodynamic drag is evaluated by using Newton's second law of motion (Katz, 1995):

$$F = m * a \quad \text{Equation 3}$$

Where the force (F) is the drag plus the rolling resistance, m is the mass of the vehicle and the acceleration (a) will be negative as the vehicle will be decelerating during the coast down phase (Katz, 1995). (Katz, 1995)

Using log data, selecting a small-time interval (Δt), during which the speed was reduced by ΔV , the vehicles deceleration can be estimated by $\frac{\Delta V}{\Delta t}$, Δt and ΔV are found by selecting an area of the curve such as in Figure 6. (Katz, 1995)

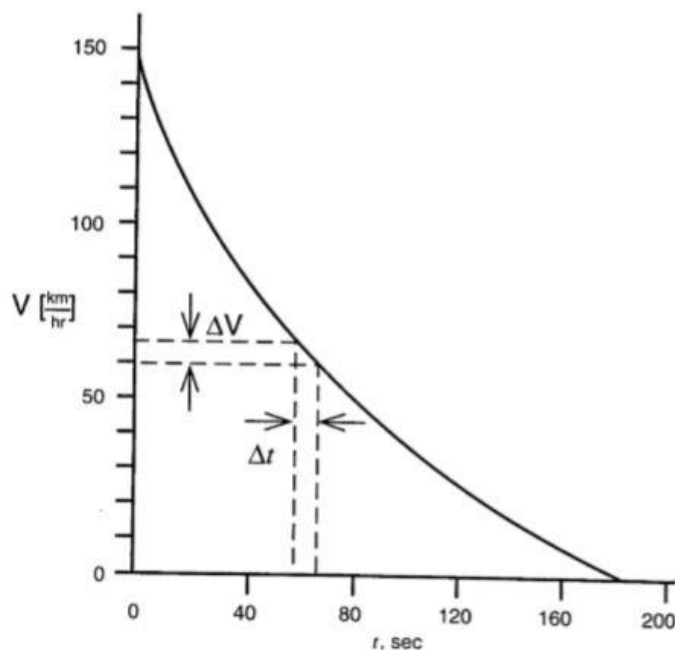


Figure 6: Variation of vehicle speed versus time during a coast down test. (Katz, 1995)

The drag can be calculated as:

$$\text{Drag Force} = m \frac{\Delta V}{\Delta t} - \text{rolling resistance} \quad \text{Equation 4}$$

The rolling resistance can be calculated by assuming that aerodynamic loads on a vehicle are negligible at very low speeds as seen in Figure 7.

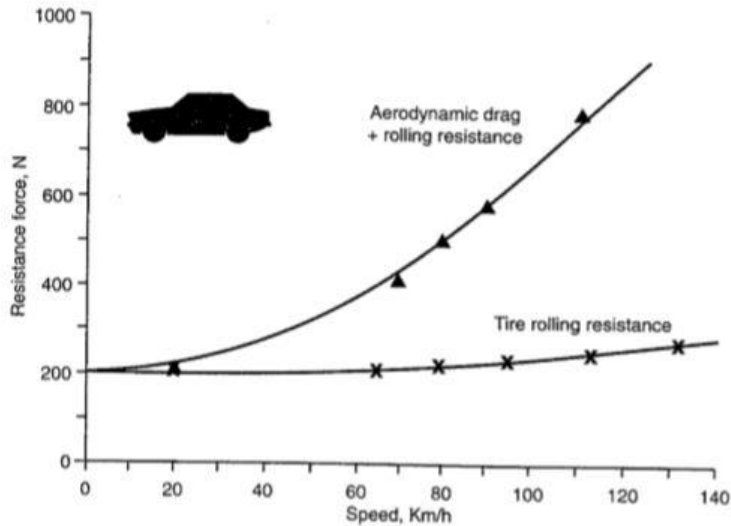


Figure 7: Aerodynamic drag is negligible under 40 Km/h (Katz, 1995)

From this data the following equation can be done:

$$\text{Drag Force} = m \frac{\text{High Speed } \Delta V}{\text{High Speed } \Delta t} - m \frac{\text{Low Speed } \Delta V}{\text{Low Speed } \Delta t} \quad \text{Equation 5}$$

Equation 1 can be modified with the new value in the following way:

$$C_D = \frac{\text{Drag Force}}{\frac{1}{2} \rho v^2 A} \quad \text{Equation 6}$$

4.2. Cl testing method

The coefficient of lift can be calculated by using the downforce data provided by data analysis in a constant speed test.

5. DAMPERS

Dampers are used within a suspension system, to control inertial movements done by the driver, and by imperfections on the track. It is designed to transform mechanical energy into heat. (Samuel Philip Gacka, 2006)

Dampers have two principal modes of operation: high speed and low speed. Heave, roll and pitch actuate the dampers in their low speed region, while single wheel inputs are usually high speed. The damper is used to control motions in four areas, high and low speed compression and rebound. (Samuel Philip Gacka, 2006)

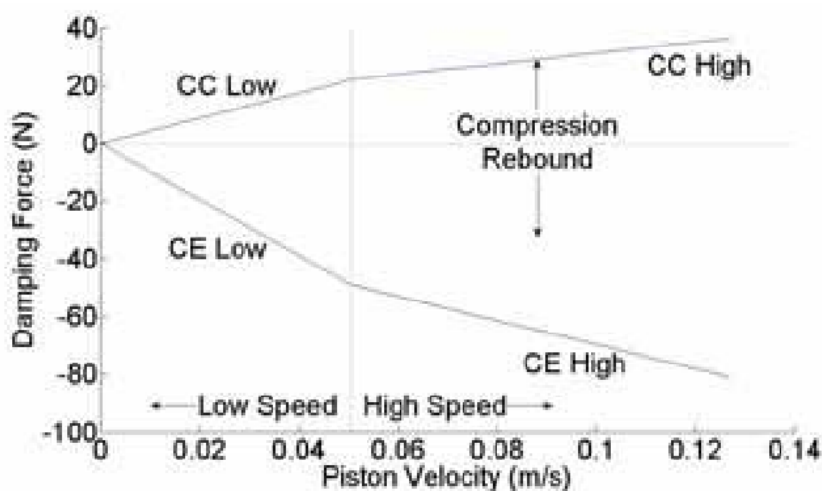


Figure 8: Damper Force vs Velocity (Samuel Philip Gacka, 2006)

A general car damper is designed to take half the force in the bump as in rebound. A large rebound coefficient helps a car's wheel to not drop in potholes. It is generally considered that the best total damping is, 60-70% is on the rebound stroke. This is expressed as, a 30/70 bump to rebound ratio, compression is always written first. (Dixon, 1991)

6. METHODOLOGY

In this section, it is shown what were the aims of the test and how it was conducted.

6.1. Aims of the test

Using the Aston Martin DB9 race car model the following testing was done to obtain the following targets:

- A Coast down test to be conducted with multiple set up changes to the front and rear wings, for calculating the CD and CL of the vehicle. The student writing this report (Vijay Kuner) wasn't in the same academic year as other students, due to a year in industry, so Student (Harry Farnhill) facilitated coast down log files for Vijay Kuner.
- Different Front and Rear Wing setups conducted over lapped times, to analyse vehicle balance over a lap.
- Rake and ride height changed to observe vehicle handling.
- Different damper setups conducted over lapped times, to analyse vehicle performance over one lap. Observe, low speed and high-speed changes.
- Full Steering lock constant speed circle to be done, to calculate Sim Steering.

6.2. Testing Procedure

6.2.1 Session 1

In the first simulator session aero, rake and ride height setups were tested.

Table 1 – Session 1 Test Plan, the table was done by Vijay Kuner and forwarded to other students within the group.

Run	File Name	Description	Aero		Springs		ARB		Ride h	
			Front	Rear	Front	Rear	Front	Rear	Front	Rear
1	Default Setup	Pembrey	Standard	Standard	Standard	Standard	Standard	Standard	Standard	Standard
	Set up change									
2	Splitter Min	Pembrey	Min	Mid	Standard	Standard	Standard	Standard	Standard	Standard
	Set up change									
3	Splitter Max	Pembrey	Max	Mid	Standard	Standard	Standard	Standard	Standard	Standard
	Set up change									
4	Wing Min	Pembrey	Mid	Min	Standard	Standard	Standard	Standard	Standard	Standard
	Set up change									
5	Wing Max	Pembrey	Mid	Max	Standard	Standard	Standard	Standard	Standard	Standard
	Set up change									
6	Springs Fmin Rmax	Pembrey	Standard	Standard	202	307	Standard	Standard	Standard	Standard
	Set up change									
7	Springs Fmid Rmid	Pembrey	Standard	Standard	254	254	Standard	Standard	Standard	Standard
	Set up change									
8	Springs Fmax Rmin	Pembrey	Standard	Standard	307	202	Standard	Standard	Standard	Standard
	Set up change									
9	ARB Fmin Rmax	Pembrey	Standard	Standard	Standard	Standard	160	72	Standard	Standard
	Set up change									
10	ARB Fmid Rmid	Pembrey	Standard	Standard	Standard	Standard	280	48	Standard	Standard
	Set up change									
11	ARB Fmax Rmin	Pembrey	Standard	Standard	Standard	Standard	400	12	Standard	Standard
	Set up change									
12	RH Fmid Rmin	Pembrey	Standard	Standard	Standard	Standard	Standard	Standard	Mid	Min
	Set up change									
13	RH Fmid Rmax	Pembrey	Standard	Standard	Standard	Standard	Standard	Standard	Mid	Max
	Set up change									
14	RH Fmin Rmid	Pembrey	Standard	Standard	Standard	Standard	Standard	Standard	Min	Mid
	Set up change									
15	RH Fmax Rmid	Pembrey	Standard	Standard	Standard	Standard	Standard	Standard	Max	Mid
	Set up change									
16	RH Fmax Rmin	Pembrey	Standard	Standard	Standard	Standard	Standard	Standard	Max	Min
	Set up change									
17	RH Fmin Rmax	Pembrey	Standard	Standard	Standard	Standard	Standard	Standard	Min	Max
	Set up change									
18	Circle	Skidpan	Standard	Standard	Standard	Standard	Standard	Standard	Min	Max

- Runs 1 to 17 were conducted on Pembrey circuit, as seen in Table 1. Lapped times were conducted during those runs, due to time constraints it was agreed that there would be 1 out lap and 2 flying laps to be done.
- Run 18 was conducted on the skidpan, as seen on Table 1, to obtain data for calculating the simulated steering. This was done by driving at the lowest possible speed with full steering lock.

- The standard setup of the car was set as the default and all setups will be compared from that.
- Columns in Table 1 showcase the different setup changes which will be made to the car, Aerodynamics (Front and Rear), Springs, Anti Roll Bars and Ride Height.

6.2.2 Session 2 (Dampers)

Table 2 – Session 2 Test Plan, the table was done by Vijay Kuner and forwarded to other students within the group.

Run	File Name	Description	Dampers		
			Front	Rear	Clicks
Baseline 01	Default Setup	Pembrey	Standard	Standard	Standard
	Set up change				
01	Low speed bump	Pembrey	6000	6600	0
	Set up change				
02	Low speed bump	Pembrey	6600	6600	2
	Set up change				
03	Low speed bump	Pembrey	7200	7200	4
	Set up change				
04	Low speed bump	Pembrey	7800	7800	6
	Set up change				
05	Low speed bump	Pembrey	8400	8400	8
	Set up change				
Baseline 02	Default Setup	Pembrey	Standard	Standard	Standard
	Set up change				
06	Low speed rebound	Pembrey	10000	10000	0
	Set up change				
07	Low speed rebound	Pembrey	11200	11200	2
	Set up change				
08	Low speed rebound	Pembrey	12400	12400	4
	Set up change				
09	Low speed rebound	Pembrey	13600	13600	6
	Set up change				
10	Low speed rebound	Pembrey	14800	14800	8
	Set up change				
Baseline 03	Default Setup	Pembrey	Standard	Standard	Standard
	Set up change				
11	High speed bump	Pembrey	2800	2800	0
	Set up change				
12	High speed bump	Pembrey	3100	3100	2
	Set up change				
13	High speed bump	Pembrey	3400	3400	4
	Set up change				
14	High speed bump	Pembrey	3700	3700	6
	Set up change				
15	High speed bump	Pembrey	4000	4000	8
	Set up change				
Baseline 04	Default Setup	Pembrey	Standard	Standard	Standard
	Set up change				
16	High speed rebound	Pembrey	4600	4600	0
	Set up change				
17	High speed rebound	Pembrey	5200	5200	2
	Set up change				
18	High speed rebound	Pembrey	5800	5800	4
	Set up change				
19	High speed rebound	Pembrey	6400	6400	6
	Set up change				
20	High speed rebound	Pembrey	7000	7000	8
	Set up change				
Baseline 05	Default Setup	Pembrey	Standard	Standard	Standard

- A baseline lap was conducted every 5 runs, these were done to compare the levels of performance of the driver throughout the test. These were not conducted in session one, because it was not thought of at the time.
- Only dampers were changed during this session. All other configurations were as standard.

7. ANALYSIS OF TEST DATA

7.1. Coast Down Data (Cd)

From the log files acquired from student Harry Farnhill, a comparison of the three aero setups and 3 rake setups can be made from table 4.

Table 3 – Coast down Setups

	Aero		Rake
	Front	Rear	
1	min	min	standard
2	max	min	standard
3	max	max	standard
4	standard	standard	none
5	standard	standard	medium
6	standard	standard	max

The static weight of the Aston is obtained via the tyre loads, as seen in Figure 9. This would be used in Equation 11 for calculating Cd. The total static weight of the car is of 1283Kg.

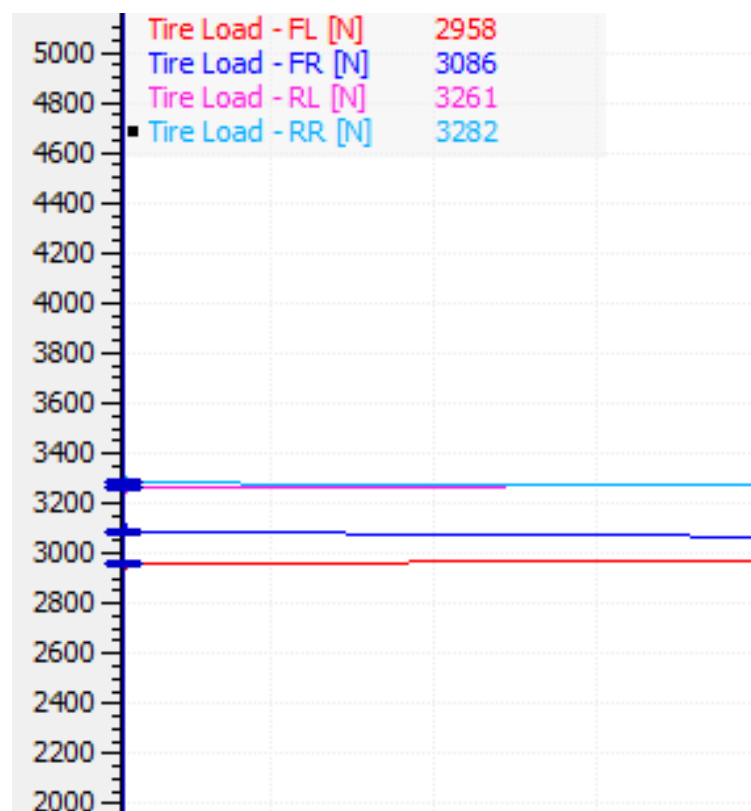


Figure 9 – Tyre loads for calculating the static weight of the Aston

Table 4 – Data acquired from testing

	v1	v2	v3	v4	t1	t2	t3	t4
	m/s	m/s	m/s	m/s	s	s	s	s
1	53.469	49.75	1.567	0.628	47.214	50.252	114.452	116.503
2	54.253	51.466	1.081	0.459	20.556	21.896	85.71	87.05
3	54.276	51.386	1.013	0.438	4.04	5.264	65.861	67.085
4	54.113	51.297	0.965	0.4	3.511	4.721	65.852	67.063
5	54.097	51.174	0.994	0.413	3.994	5.242	65.896	67.144
6	54.166	51.243	1.017	0.441	3.94	5.171	65.503	66.734

The high-speed points v1, v2, t1 and t2 and the low speed points v3, v4, t3 and t4, are collected from data in Figure 10.

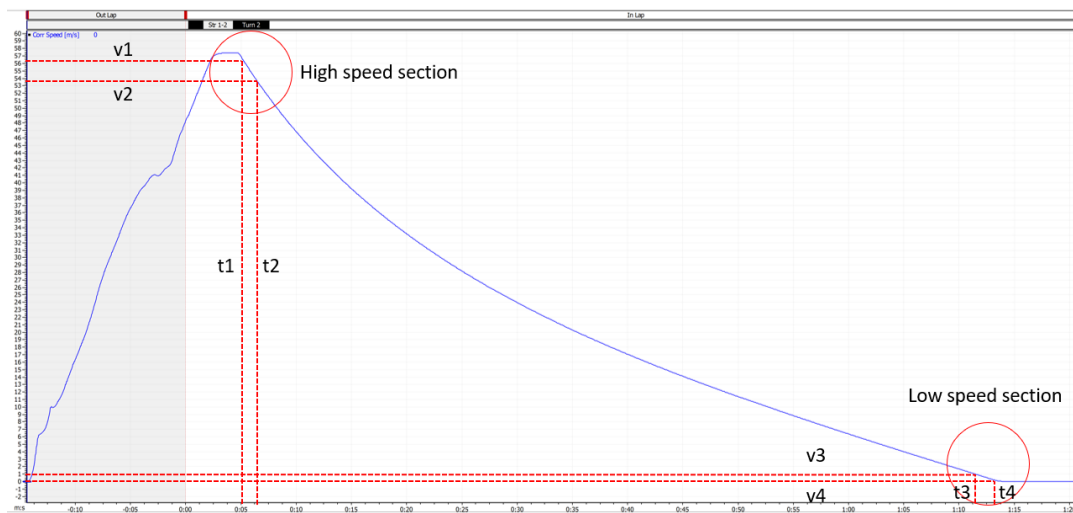


Figure 10 – High speed and low speed sections.

The testing only had to be done in one direction as there is no gradient on the track used (Skidpad)

Using the data from Table 5, the values in table 6 can be calculated:

Table 5

	vm	RR	a1	a2
	m/s		m/s ²	m/s ²
1	51.6095	587.3901	-1.22416	-0.45783
2	52.8595	595.5418	-2.07985	-0.46418
3	52.831	602.7165	-2.36111	-0.46977
4	52.705	598.5921	-2.32727	-0.46656
5	52.6355	597.2941	-2.34215	-0.46554
6	52.7045	600.3314	-2.37449	-0.46791

The equations used in table 6 are:

$$\text{Velocity (vm)} = \frac{v_2 + v_1}{2} \quad \text{Equation 7 (Tudor, 2019)}$$

$$\text{Rolling Resistance (RR)} = m * a_2 \quad \text{Equation 8 (Tudor, 2019)}$$

$$\text{High speed deceleration (a1)} = \frac{(v_2 - v_1)}{(t_2 - t_1)} \quad \text{Equation 9 (Tudor, 2019)}$$

$$\text{Low Speed deceleration (a2)} = \frac{(v_4 - v_3)}{(t_4 - t_3)} \quad \text{Equation 10 (Tudor, 2019)}$$

From table 6 the coefficient of drag can be calculated, shown in table 7:

Table 6 - CD

	Aero		Rake	Cd
	Front	Rear		
1	min	min	standard	0.503
2	max	min	standard	1.011
3	max	max	standard	1.184
4	standard	standard	none	1.171
5	standard	standard	medium	1.180
6	standard	standard	max	1.200

The equation used for calculating the Cd is:

$$Cd = \frac{2(ma_1 - ma_2)}{\rho v_m^2 A} \quad \text{Equation 11}$$

Comparison of the 3 aero setups in table 7. As expected, the highest drag coefficient is coming from the max aero setup. This is because the wings are set to their maximum angle of attack, while in contrast, the setup with the least coefficient of drag is the one with the wings set at their minimum angle of attack. Furthermore, the max min setup is somewhere in the middle.

Comparison of the 3 rake setups in table 7. The highest drag coefficient happens on the max rake setup, this larger rake angle will increase the venturi effects under the car and therefore produce more downforce and in turn increase drag. The lowest drag coefficient comes from the neutral rake setup, this makes sense, as the negligible rake wouldn't take full advantage of the possible downforce that could be generated, it produces less drag. While the medium rake setup is somewhere in the middle.

7.2. CI

The CI is calculated using the following equation:

$$CI = \frac{\text{Downforce}}{0.5 \cdot \rho \cdot A \cdot v^2} \quad \text{Equation 12}$$

From Equation 12, the values for table 8 can be deduced.

Table 7 - CI

	Aero		Rake	CI
	Front	Rear		
1	min	min	standard	1.350
2	max	min	standard	1.620
3	max	max	standard	2.000
4	standard	standard	none	1.990
5	standard	standard	medium	1.990
6	standard	standard	max	1.920

As expected, the setup with the minimum aero configuration has the smallest coefficient of lift due to the low angle of attack of the front and rear wing. While, the max aero configuration has the highest coefficient of lift, due to its highest downforce, and the max front rear min configuration is somewhere in the middle. On the other hand, the max rake configuration is giving a lower coefficient of lift to the other two, because the neutral and the medium rake configurations mean the front ride height is lower than on the max rake configuration, so producing more downforce.

8. Aerodynamic configurations, front and rear wing over one lap

The track used for testing was Pembrey. Due to its flat course, straights, high and slow speed corners, all aspects of the vehicle can be analysed, as seen in Figure 11.

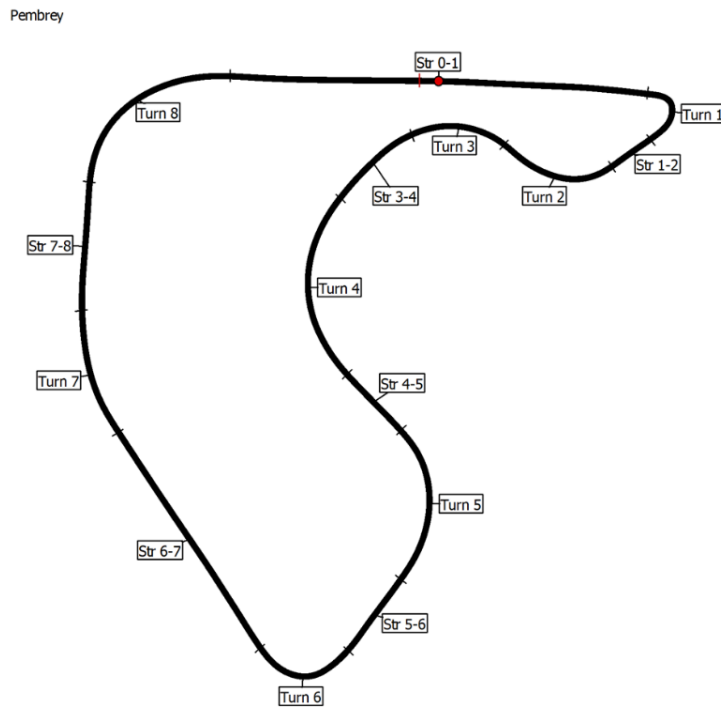


Figure 11 – Pembrey track

As shown in testing plan from Table 1, four different aerodynamic setups and one default setup will be analysed. Each section of the track will be analysed, with each configuration.

The following C_D and C_L , provided by student Ryan James, will be used for the downforce configurations:

Table 8 – C_D and C_L values

	Configuration	C_L	C_D
1	Default	2.0972	1.2652
2	Front min Rear mid	1.836	1.149
3	Front max Rear mid	2.1593	1.3047
4	Rear min Front mid	1.81	1.1343
5	Rear max Front mid	2.0894	1.2872

8.1 Downforce vs Speed

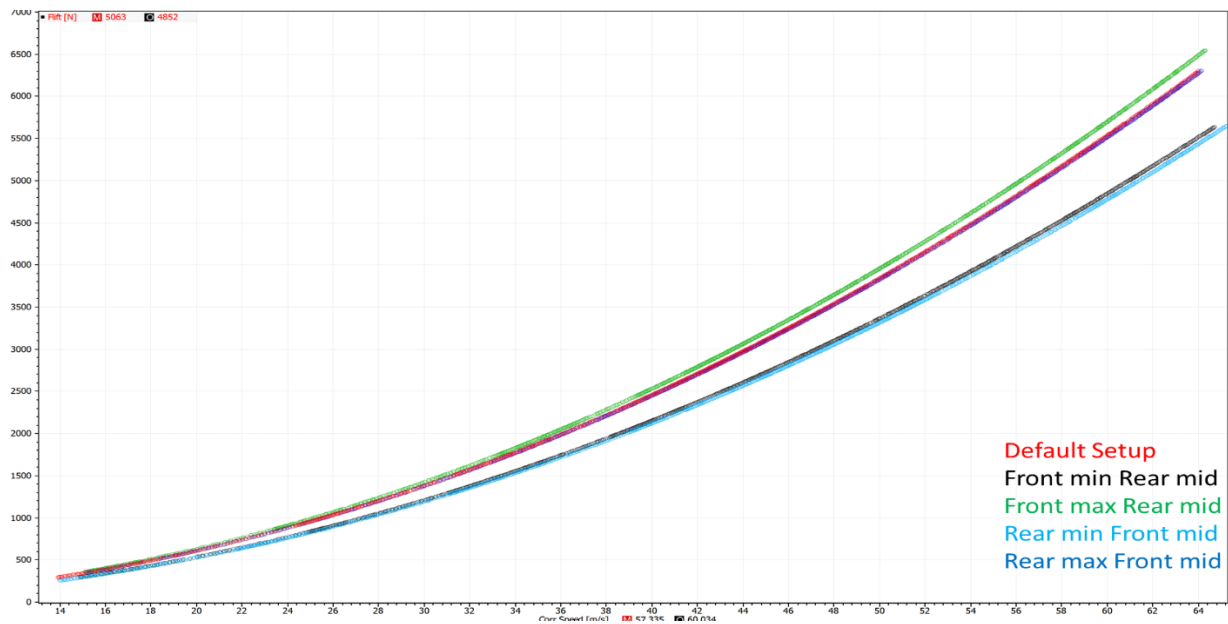


Figure 12 – Downforce vs Speed plot

The Speed vs Downforce trendline in Figure 12, shows how downforce increases with speed.

8.2 Downforce over one lap

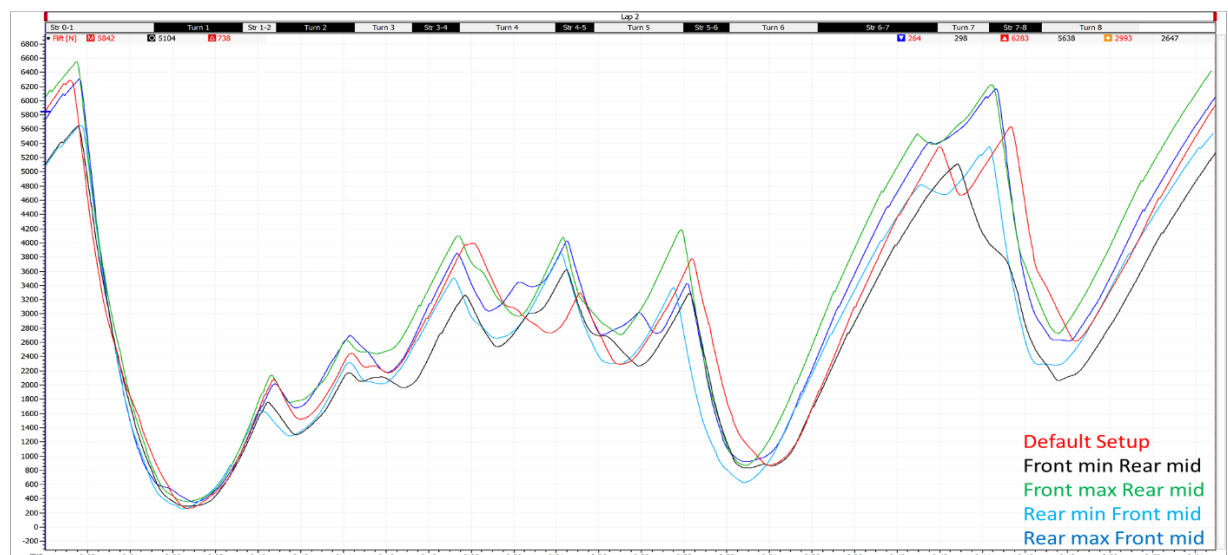


Figure 13 – Calculated Downforce

Figure 13 showcases the downforce generated by the vehicle over one lap, the configuration with the highest force on average along the lap is the “Front max Rear mid”, then it would be the “Rear max

Front mid”, then the “Default setup”. Furthermore, the “Front min Rear mid”, “Rear min Front mid” configurations create the least amount of downforce.

In low speed corners, see Figure 14, the most obvious would be at Turn 1 (Figure 11). There is a drop in downforce from all configurations. As shown in Figure 12 speed and downforce are directly linked.

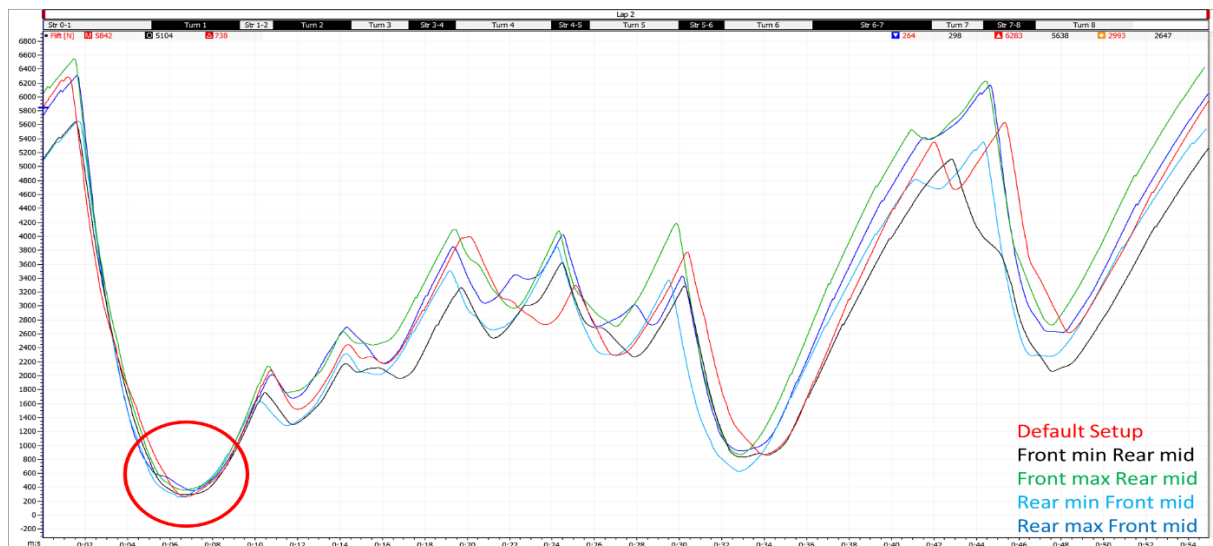


Figure 14 – Turn 1 drop in downforce

The force shown in Figure 12, Figure 13 and Figure 14, is the calculated Downforce using the Coefficient of lift from Table 9. The equation used to calculate this force is the following:

$$F_{\text{lift}} = C_l \times A \times 0.5 \times \rho \times V^2 \quad \text{Equation 13 (Tudor, 2019)}$$

This equation gives us the calculated downforce using the C_l obtained using a constant speed test, explained in Section 4.2 of this report.

A comparison of the calculated data and the tyre load data is made in Figure 15 to check correlation.

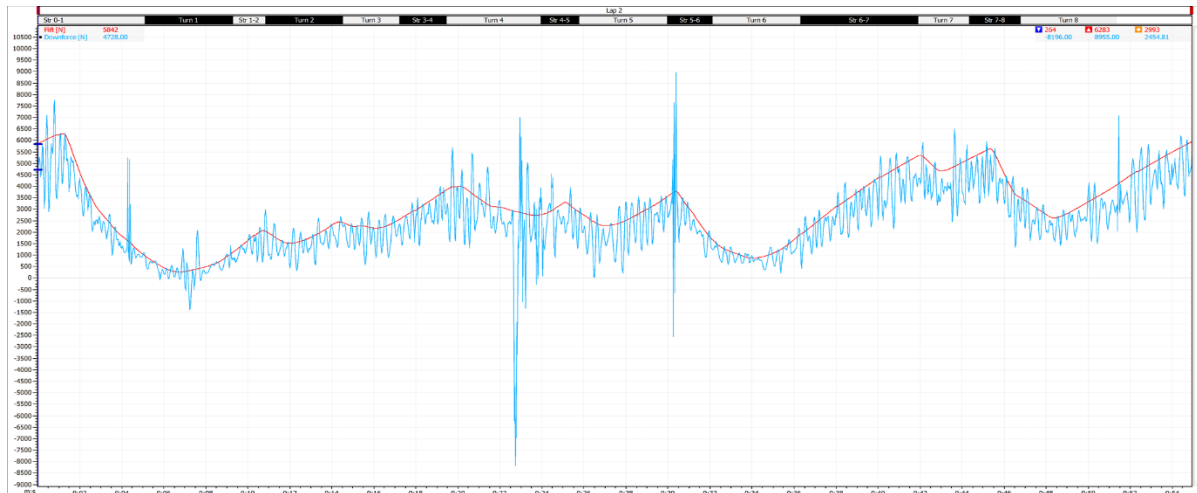


Figure 15 – Cl and Downforce Correlation

As seen in Figure 15, both paths follow each other which means there is a good correlation between the calculated force and the simulated data.

In Figure 15 there is a sudden fall in the tyre load downforce at the exit of Turn 4, a close up in Figure 16 shows there is a sudden drop on the Front Right and Rear Right Tyres. At a high speed corner, such as turn 4, hitting curves aggressively will upset the airflow over and under the car, leading in a loss of aero performance.

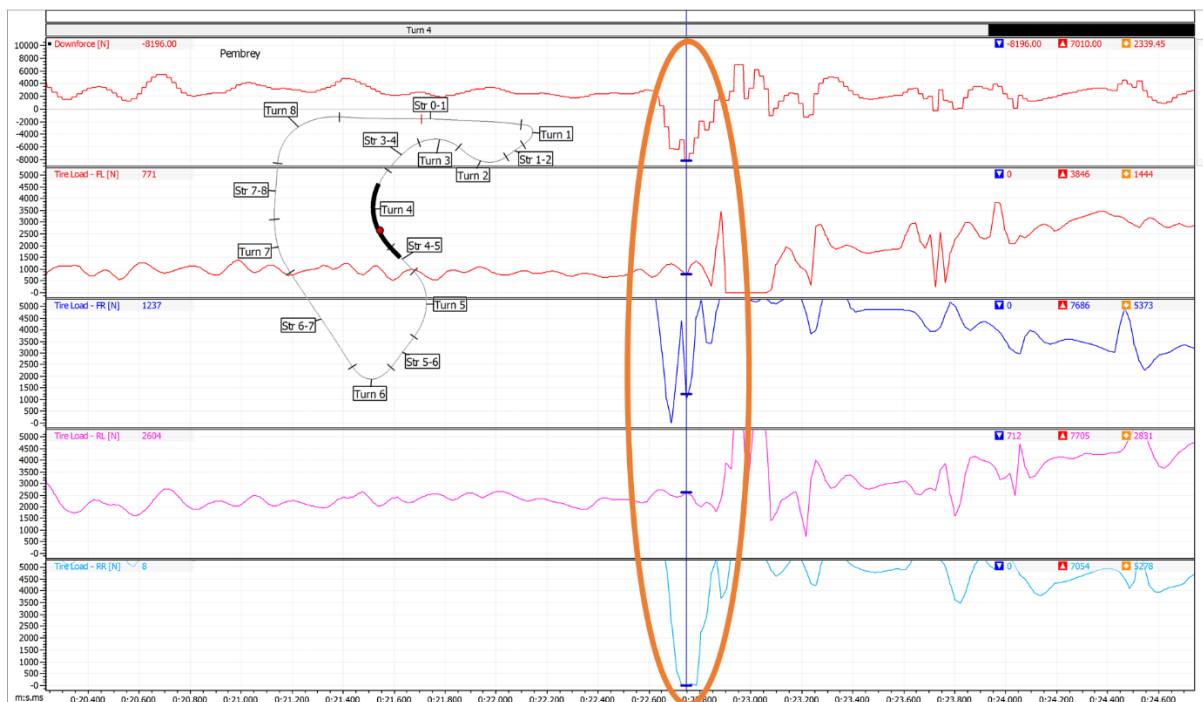


Figure 16 – Turn 4 drop in downforce

8.3 Drag Force over a lap

The drag force follows the same path as the downforce, in order of most to least drag, “Front max Rear mid”, “Rear max Front mid”, “Default”, “Rear min Front mid” and “Front min Rear mid”. The results make sense as it follows the same path as the downforce.

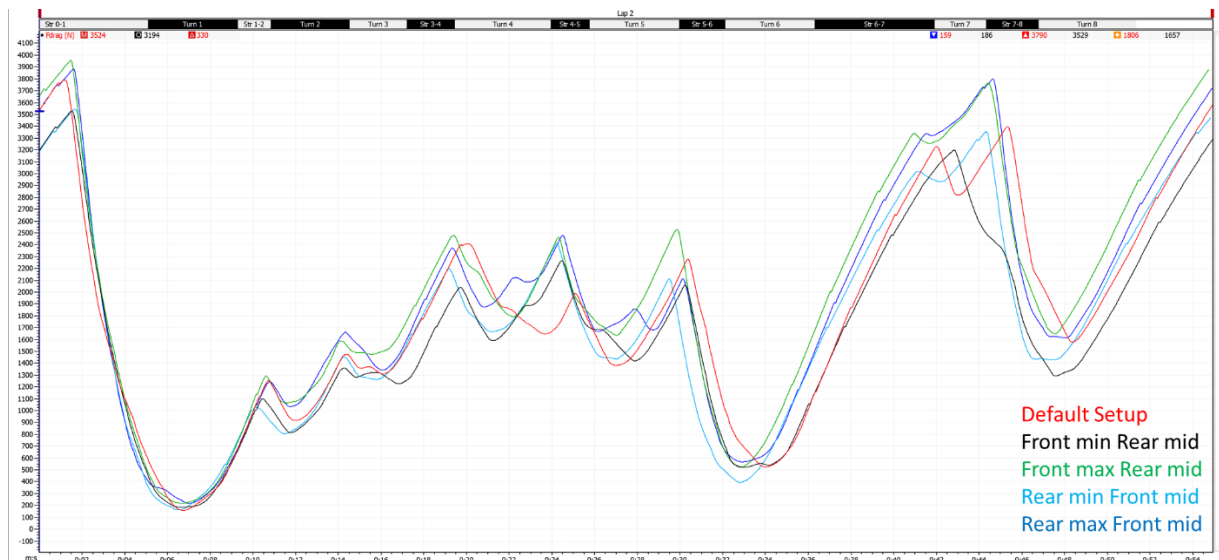


Figure 17 – Drag Force over

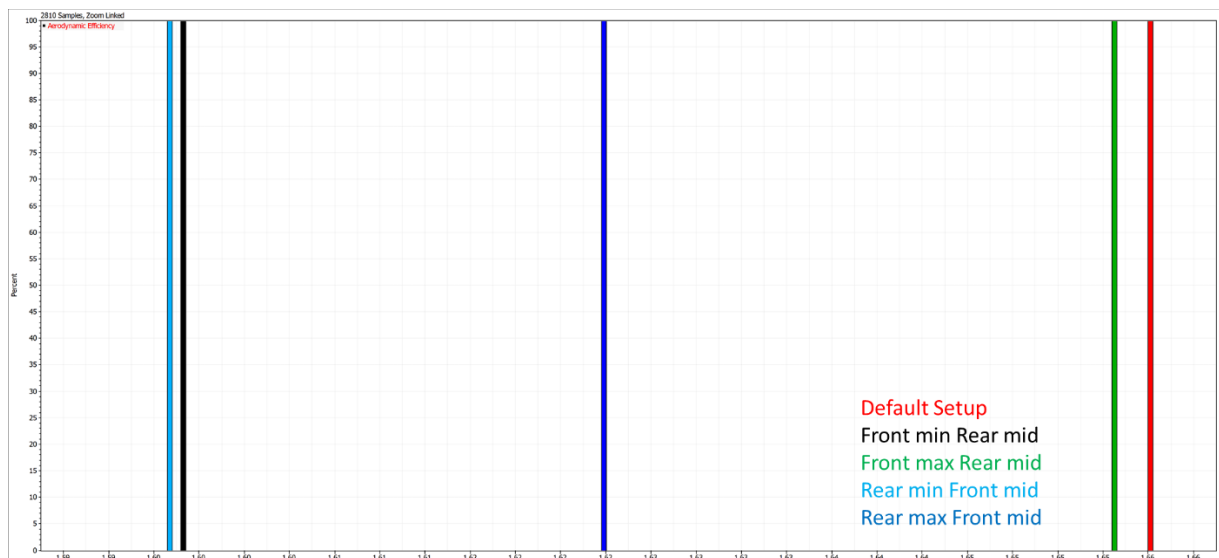


Figure 18 – Aerodynamic Efficiency

$$\text{Aerodynamic Efficiency} = \frac{\text{Flift}}{\text{Fdrag}} \quad \text{Equation 14 (Tudor, 2019)}$$

Using equation 14 the aerodynamic efficiency can be calculated to compare each configuration.

The most efficient setup as seen in green in figure 18 is the “Default” configuration, while the least efficient is the light blue “Rear min Front mid” setup. A comparison between the “Front max Rear mid” and “Rear max Front mid”, shows that the higher downforce on the front is the more efficient option. On the other hand, the “Rear min Front mid” and “Front min Rear mid” configurations are of equal efficiency of 1.60

8.4 Constant corner test for sim steering

To calculate the corrected theoretical steer, the sim steering ratio is obtained from steering wheel percentage and theoretical steer data. A slow speed corner is done in the skidpan at a steady speed, the low speeds mean that slip from the wheels is minimized. (Tudor, 2019) From the data it can be gathered that the ratio is of -38.09 to 8.

Corrected Theoretical Steer = Theoretical Steer × Sim steering Ratio

Equation 15 (Tudor, 2019)

$$\text{Theoretical Steer} = \frac{\text{Wheelbase}}{\text{Corner Radius}}$$

Equation 16 (Tudor, 2019)

$$\text{Corner Radius} = \frac{\text{speed}^2}{\text{lateral acceleration}}$$

Equation 17 (Tudor, 2019)

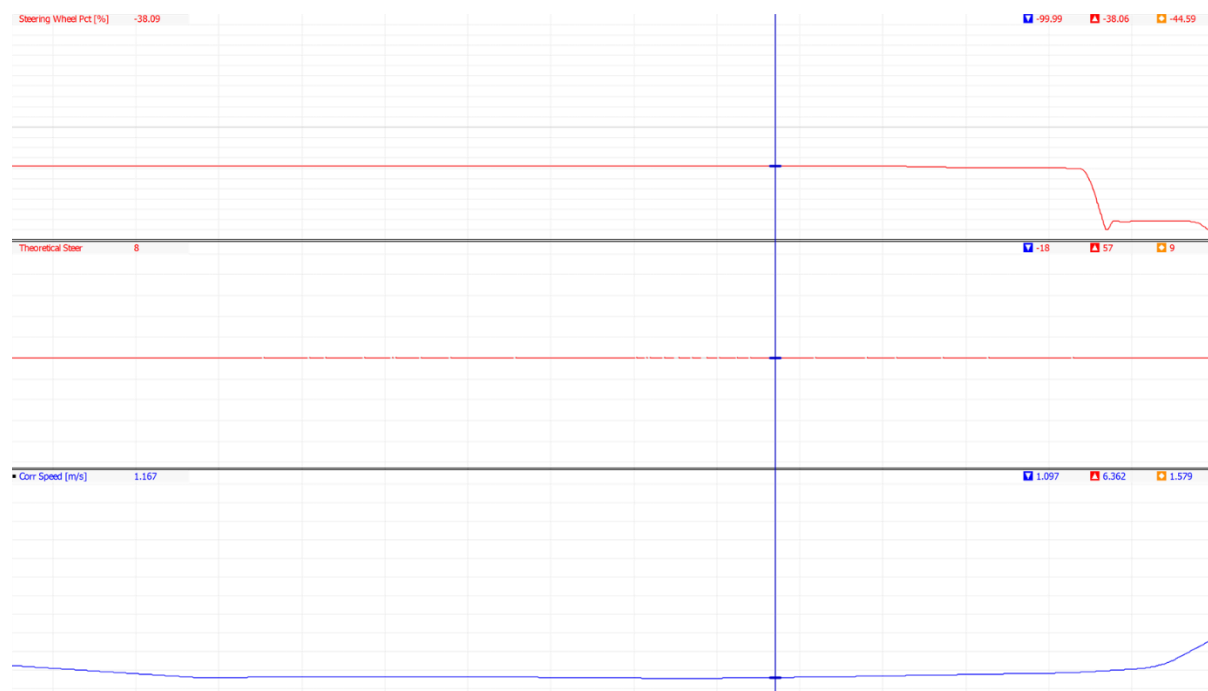


Figure 19 – Simulated steering ratio

8.5 Lateral Acceleration vs speed

Figure 20 showcases the lateral acceleration of the vehicle around the track. At a first glance the green dotted path, “Front max Rear mid” configuration, is pulling the most G in Turn 2, 3, 4, 5 and 8, these turns are medium and high speed corners. Speed and G are directly linked, as seen in Figure 21, the higher the speed the bigger G forces the car will experience around corners. The reason the green configuration is the setup pulling the most G is because it is creating the most downforce, the more downforce a car has the more grip it will have around turns and it can take more speed.

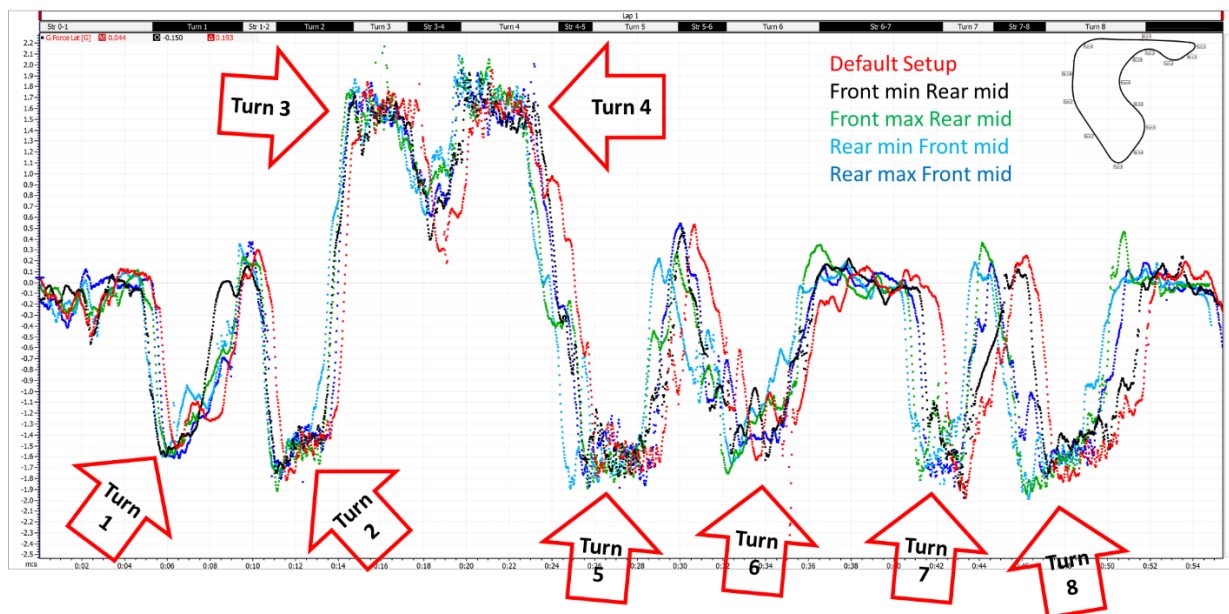


Figure 20 – Lateral G force over one lap

In slow corners, such as turn 1 and 6, the g force levels are low in comparison to the high-speed corners, again this is due to the lower speeds the car is going at.

In the red boxes in Figure 21, it is apparent that higher front downforce configuration (green) is aiding the driver achieve larger g forces, as it can grip better. On the other spectrum, the high rear downforce configuration (dark blue) is giving the driver less grip around corners as it is not entering the red boxes as much as the high front downforce configuration. While the “Front min Rear mid” configuration, again due to its lack of front downforce, is not achieving g forces high enough to enter in the boxed area. Furthermore, the “Rear min Front mid” configuration, although it has a low downforce setting on the rear, its middle range front downforce allows it to enter the high g forces boxed area.

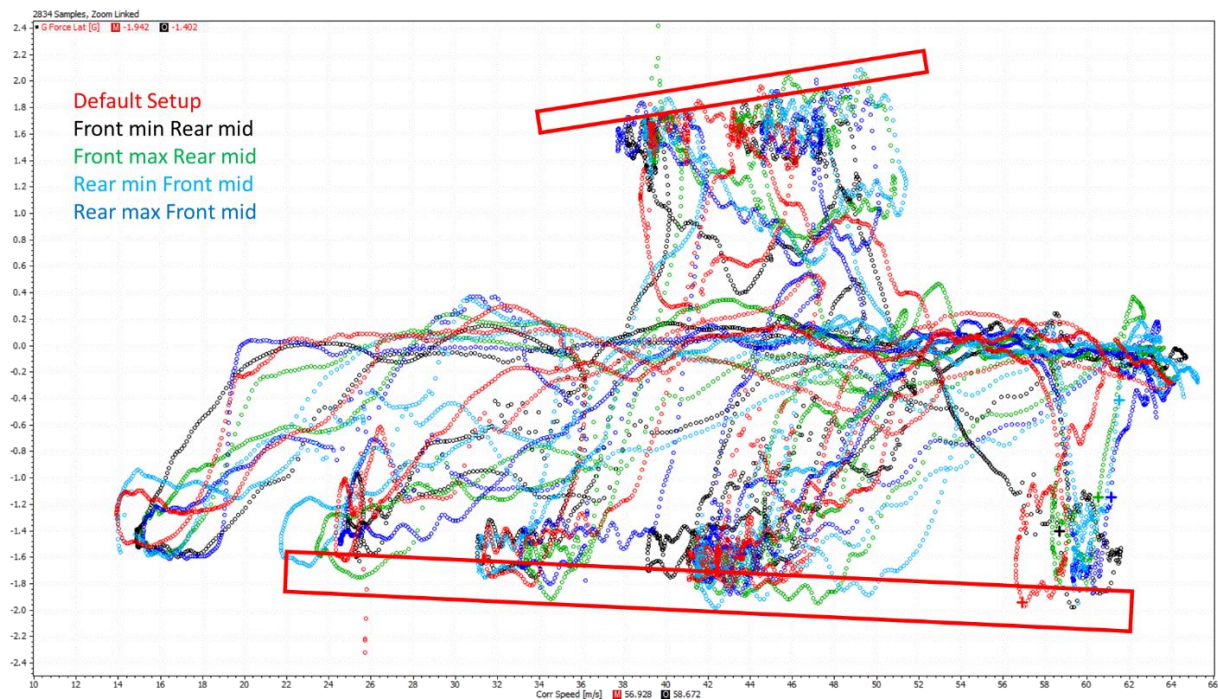


Figure 21 – G force increases with speed

8.6 Centre of pressure

The centre of pressure of a vehicle only becomes important relative to its centre of gravity at higher speeds where downforce is noticeable (Katz, 1995)

The following equation is used to calculate the Centre of Pressure:

$$\text{COP} = \frac{\text{Front Downforce}}{\text{Downforce}} \times 100 \quad \text{Equation 18}$$

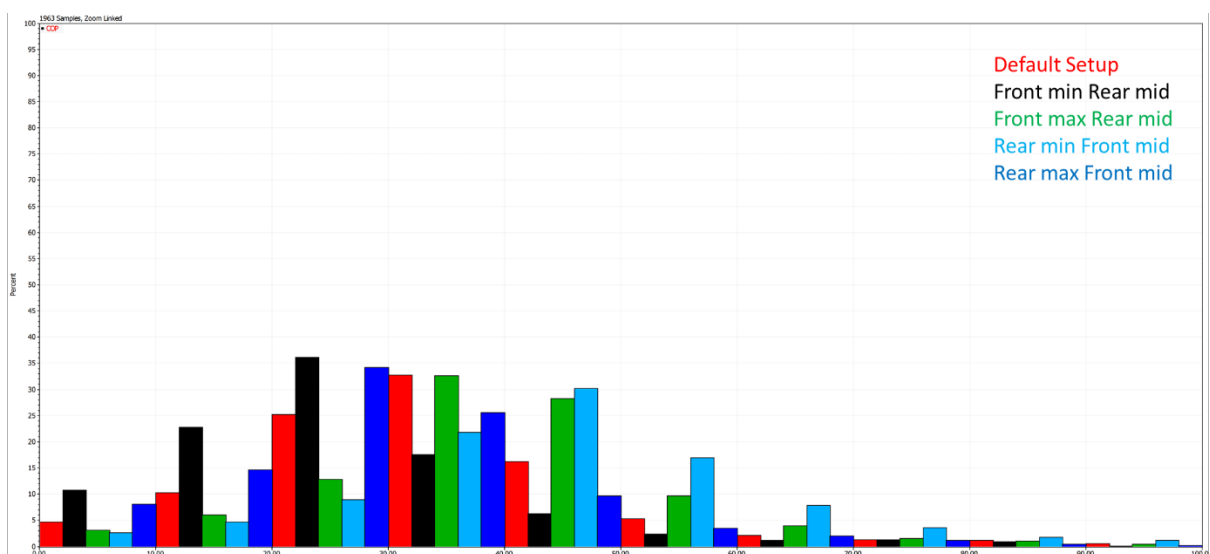


Figure 22 – Centre of Pressure Histogram

The centre of pressure histogram in Figure 22, shows the percentage it moves from the rear axle to the front. The setup with the most movement is the “Rear min Front Mid” setup, this is due to the removal of downforce from the rear axle while the front is still experiencing a standard amount. This induces pitching, which in turn moves the COP forwards. This configuration COP moves in the area of 35% to 60%.

The next configuration is “Front max Rear mid”, the max downforce on the front of the car pitches the vehicle forward moving the centre of pressure 30% to 50% area, the reason it doesn’t move more than the previous configuration, is due to its rear downforce being at a standard level and not at its minimum.

Furthermore the “Front min Rear mid” configuration, due to its low front downforce, has a COP movement in the area of 15% to 35%. On the other hand, “Rear Max Front mid” the COP moves in the region of 20% to 40%. Finally, the “Default” setup moves in the region of 20% to 45%

The vehicle is overall rear biased, this means it is more likely to understeer than to oversteer.

8.7 “Default”, “Front min Rear mid”, “Front max Rear mid” configurations over one lap comparison

The following section will look at how the vehicle acts around the track at each turn and how the vehicle reacts in high and low speed corners. Before any analysis can be done the following equations have been used to calculate the data for this section:

$$\text{Downforce} = \text{Front Downforce} + \text{Rear Downforce} \quad \text{Equation 19 (Tudor, 2019)}$$

$$\text{Front Downforce} = (\text{FL} + \text{FR}) - (\text{FLstatic} + \text{FRstatic}) - \text{WTL} \quad \text{Equation 20 (Tudor, 2019)}$$

Equation 20, FL = Front left tyre load; FR = Front right tyre load

$$\text{Rear Downforce} = (\text{RL} + \text{RR}) - (\text{RLstatic} + \text{RRstatic}) + \text{WTL} \quad \text{Equation 21 (Tudor, 2019)}$$

Equation 21, RL = Rear left tyre load; RR = Rear right tyre load

$$\text{WTL} = \frac{m \cdot a \cdot h}{w} \quad \text{Equation 22 (Tudor, 2019)}$$

Equation 22, WTL = Longitudinal weight transfer; m = total static weight; a = longitudinal acceleration; h = Centre of gravity height; w = wheelbase

$$\text{COP} = \frac{\text{Front Downforce}}{\text{Downforce}} * 100 \quad \text{Equation 23 (Tudor, 2019)}$$

Equation 23, COP = Centre of pressure

$$\text{Understeer} = \text{abs}(\text{Steering Wheel Pct}) - \text{abs}(\text{Corrected Theoretical Steer}) \quad \text{Equation 24 (Tudor, 2019)}$$

$$\text{Rake Angle} = \tan^{-1} \frac{\frac{\text{Rear Ride Height} - \text{Front Ride Height}}{1000}}{\text{Wheelbase}} \quad \text{Equation 25 (Tudor, 2019)}$$

$$\text{Rear Ride Height} = \frac{\text{Ride Height RL} + \text{Ride Height RR}}{2} \quad \text{Equation 26 (Tudor, 2019)}$$

$$\text{Front Ride Height} = \frac{\text{Ride Height FL} + \text{Ride Height FR}}{2} \quad \text{Equation 27 (Tudor, 2019)}$$

Using these equations Figures 23, 24 and 25 can be plotted, with these graphs a full lap turn by turn is going to be analysed.

The green colour is configuration “Front max Rear mid”, the black colour is configuration “Front min Rear mid” and the red is configuration “Default”

- Turn 1 (T1): Right hand corner with hard braking from high speed.
 - Looking at downforce levels in Figure 24, downforce levels are pretty much the same for all 3 configurations due to the low speed nature of the turn.
 - The rake angle in Figure 25 it is obvious how the loads move from the front of the car at high speeds to the rear of the car under braking.
 - The COP in Figure is moving from the front of the car to the back due to pitching of the vehicle under braking.
 - There is high spike of understeer for configuration “Front min Rear mid”, this is due to the lack of downforce on the front axle of the car.
 - The higher Brake percentage in Figure 26 for configuration “Front max Rear mid” shows how the higher downforce at the front aids the driver to brake later and harder.
- Straight 1-2 (S1-2): Short straight between turns 1 and 2.
 - Due to the low drag of “Front min Rear mid” the vehicle accelerates out of turn 1 at a higher speed, as seen in Figure 27.
 - The rake angle increases as the speed increases, due to the increase in front downforce on the car. Closing the gap between the front splitter and the road. The setup with the Front max downforce will produce the largest rake angle.
- Turn 2 (T2): Medium speed right hand corner with some slight braking.
 - Usual understeer in Figure 23, as the COP of the car is mainly rear biased, the max front configuration thanks to its larger front downforce doesn’t understeer as much.

- In this case the Front max downforce setup exits the corner with a higher speed thanks due to it being a medium speed corner, helping the car achieve a high enough speed for aerodynamics to take place.
- Turn 3 (T3), Straight 3-4 (S3-4) and Turn 4: a series of left hand medium to high speed corners.
 - The higher front downforce setup can take each corner at a higher speed thanks to its higher rake angle producing more downforce, therefore helping it grip to the ground.
 - At turn 3 the driver had to brake ever so slightly on the Front max setup due to the higher understeer.
- Turn 5 (T5), fast right corner
 - Same effects as before, but there is a sudden change in the front and rear downforce at the exit of the corner for configuration “default” this is telling me that the driver ran out wide and upset the airflow over the vehicle.
- Straight 5-6 (S5-6) and Turn 6 (T6)
 - Same trend as Straight 0-1 into turn 1, as it is a low speed turn.
- Straight 6-7 (S6-7), Turn 7 (T7), Straight 7-8 (S7-8) and Turn 8.
 - Same trend as Turn 3 (T3), Straight 3-4 (S3-4) and Turn 4.
 - High speed corners in which the Front Max Downforce takes an advantage.
- Straight 0-1 (S0-1)
 - Towards the end of the lap the Front low setup starts gaining time on the other setups thanks to the lower drag it has, but the straight isn’t long enough for it to capitalize on the low downforce package.

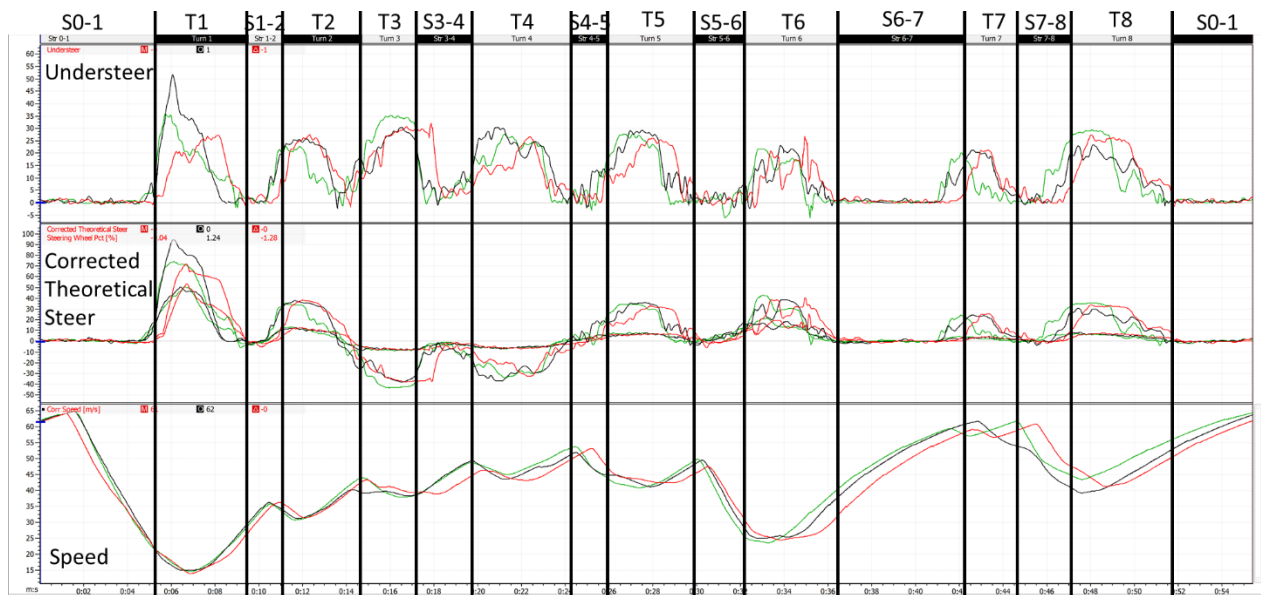


Figure 23 – Understeer, Corrected Theoretical Steer and Speed for “Default” and front max and min downforce configurations

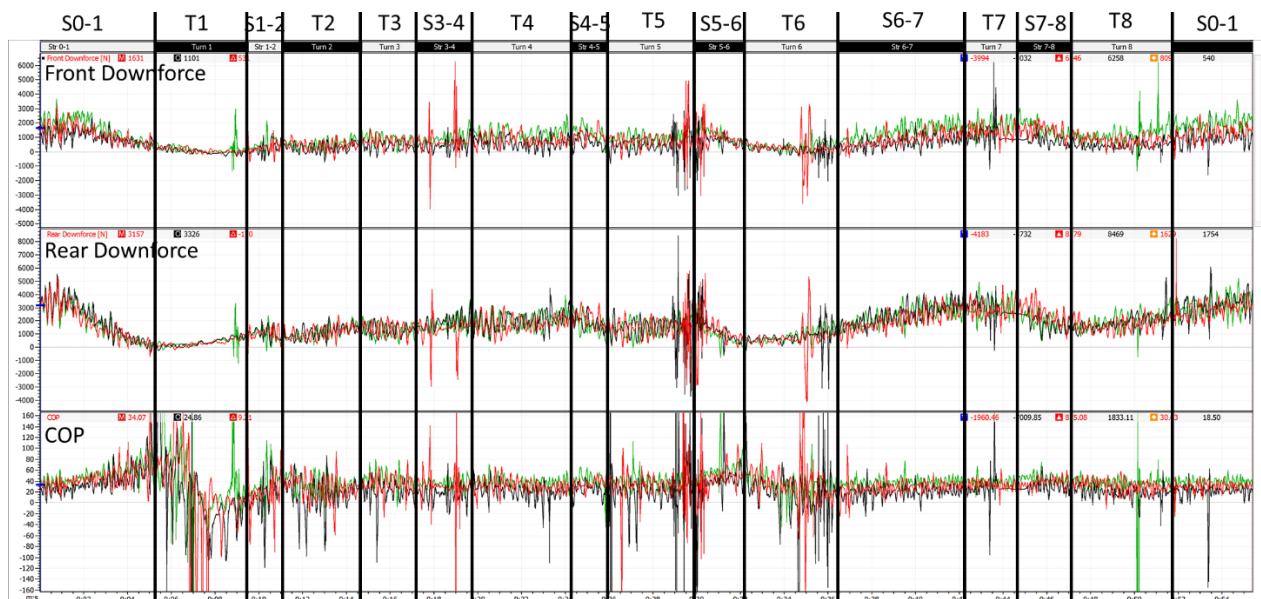


Figure 24 – Front Downforce, Rear Downforce and COP for “Default” and front max and min downforce configurations

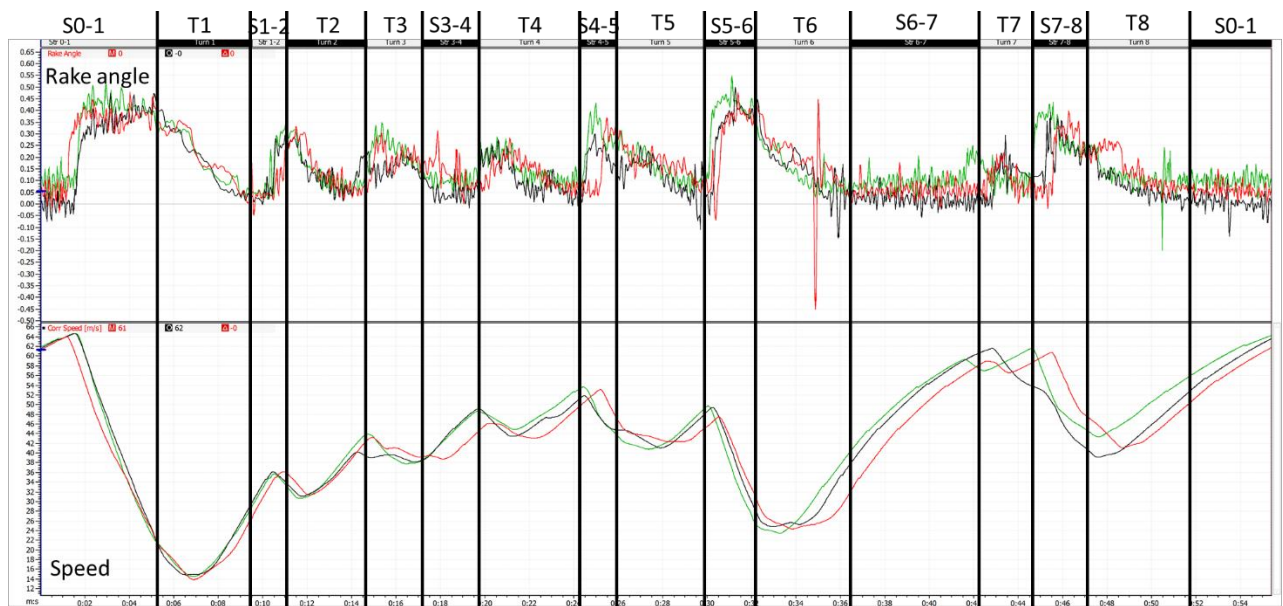


Figure 25 – Rake angle and speed for “Default” and front max and min downforce configurations

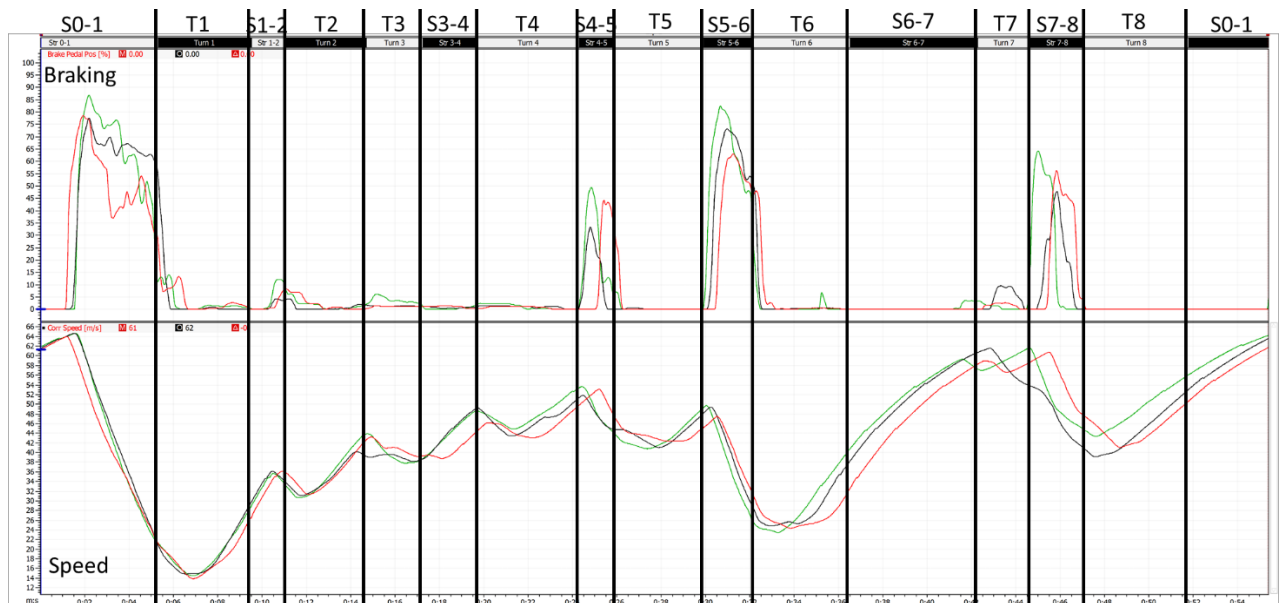


Figure 26 – Braking and speed for “Default” and front max and min downforce configurations

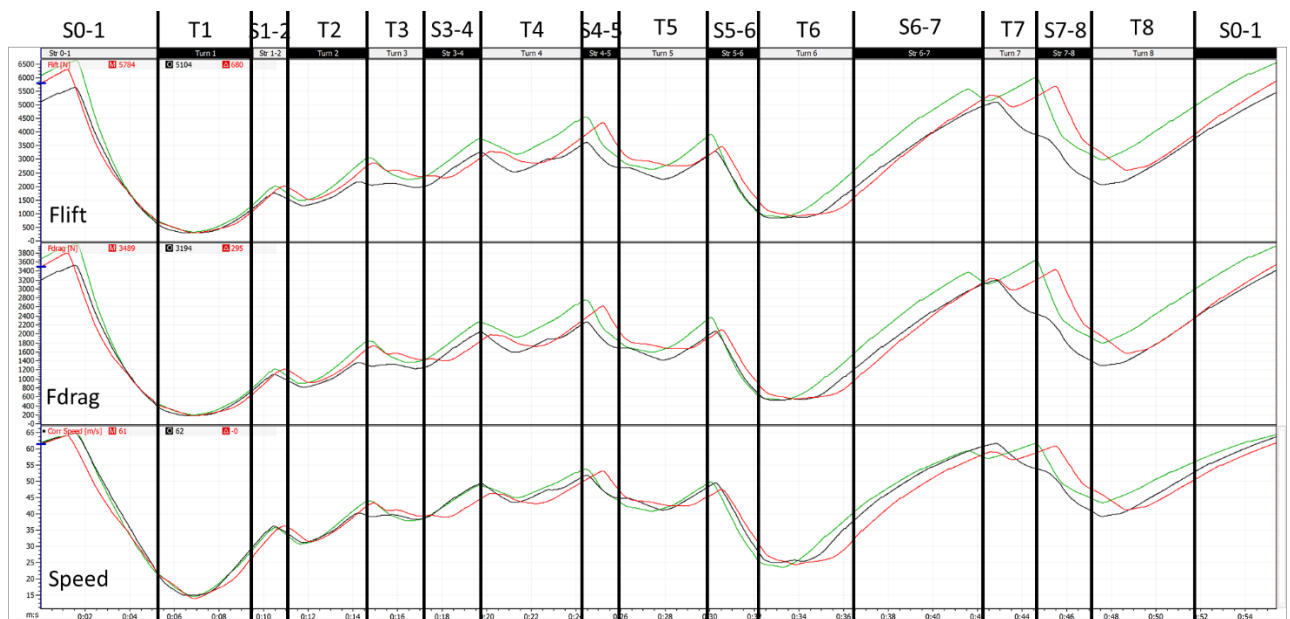


Figure 27 – Lift Force, Drag Force and Speed for “Default” and front max and min downforce configurations

8.8 “Default”, “Rear min Front mid”, “Rear max Front mid” configurations over one lap comparison

These setups very much follow the same paths as the ones in section 8.3.7

In this case configuration “Rear min Front mid” is in light blue, configuration “Rear max Front mid” is in a dark blue and “default” is in red.

In general, over the lap the “Rear min Front mid” configuration has the centre of pressure further forward than the other two giving the car a larger rake angle (Figure 29), as well as helping the car to understeer less than the other two configurations. Due to its low downforce setup, it can pick up speed faster out of low speed corners. Interestingly, the higher front downforce of this setup in comparison to the other two, help the driver brake harder into low speed corners (Figure 31)

While the rear high downforce setup creates the most downforce, consequently it creates the most drag (Figure 32). The rake angle is lower than the “Rear min” setup, because the rear loads are so much stronger than the front loads, it pushes the car down on its rear axle.

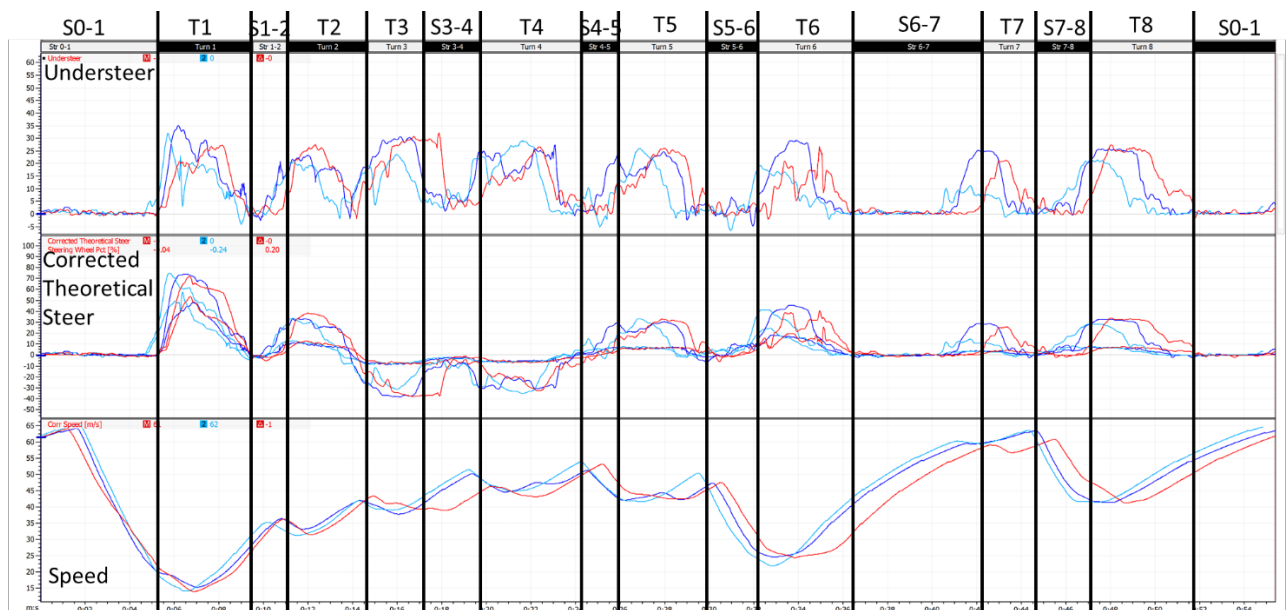


Figure 28 - Understeer, Corrected Theoretical Steer and Speed for "Default" and rear max and min downforce configurations

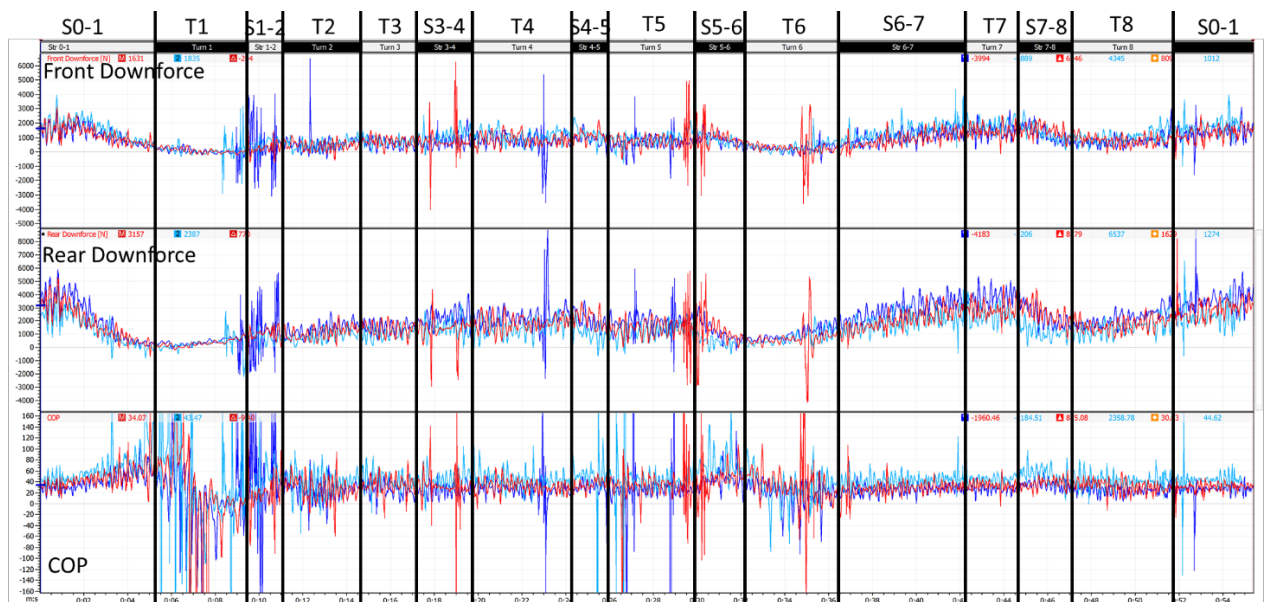


Figure 29 - Front Downforce, Rear Downforce and COP for "Default" and rear max and min downforce configurations

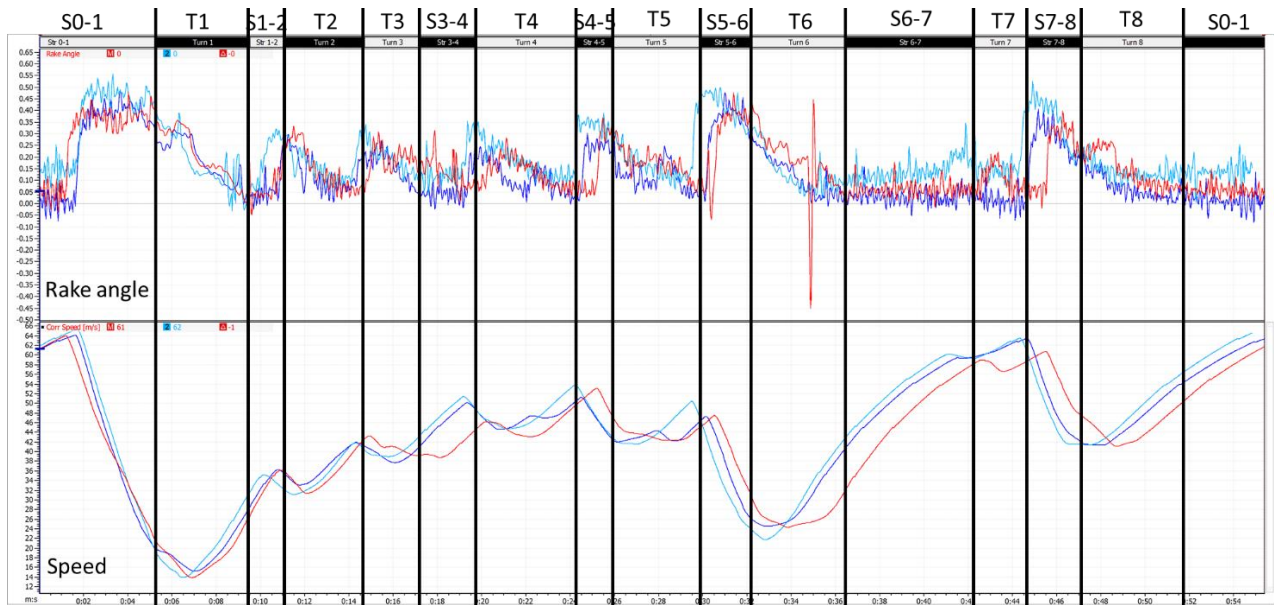


Figure 30 - Rake angle and speed for "Default" and rear max and min downforce configurations

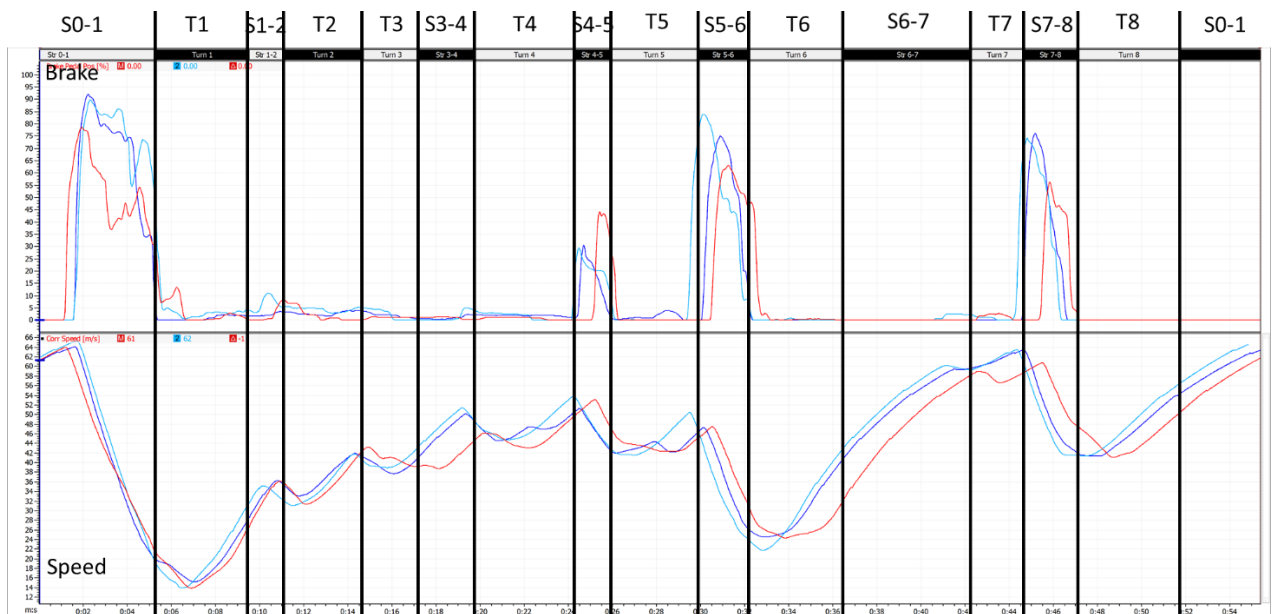


Figure 31 - Braking and speed for "Default" and rear max and min downforce configurations

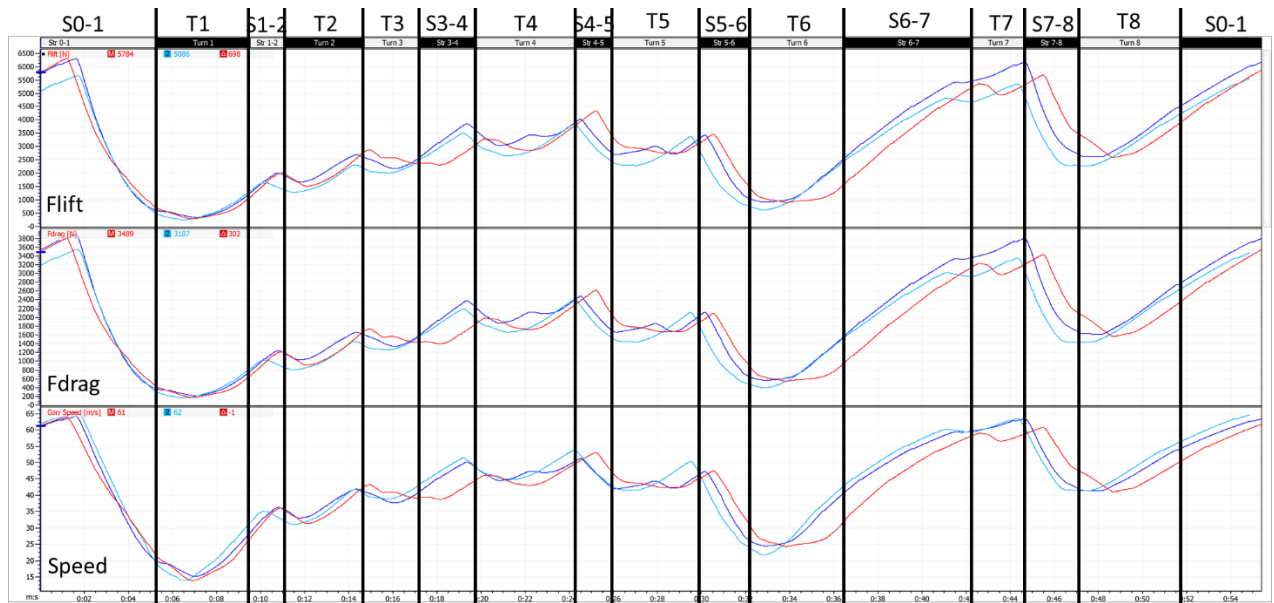


Figure 32 - Lift Force, Drag Force and Speed for "Default" and rear max and min downforce configurations

9. Load transfer behaviour Springs and ARB Setups

There are two types of load transfer which this section is going to base itself on, the elastic load transfer and the geometric load transfer. When a car steers into a corner it develops lateral forces, which translate to the car through the suspension linkages, these forces create a roll moment that wants to rotate the chassis around the centre of rotation. The springs and dampers control the elastic forces, but they build up after the start of the geometric forces. (Haney, 1999)

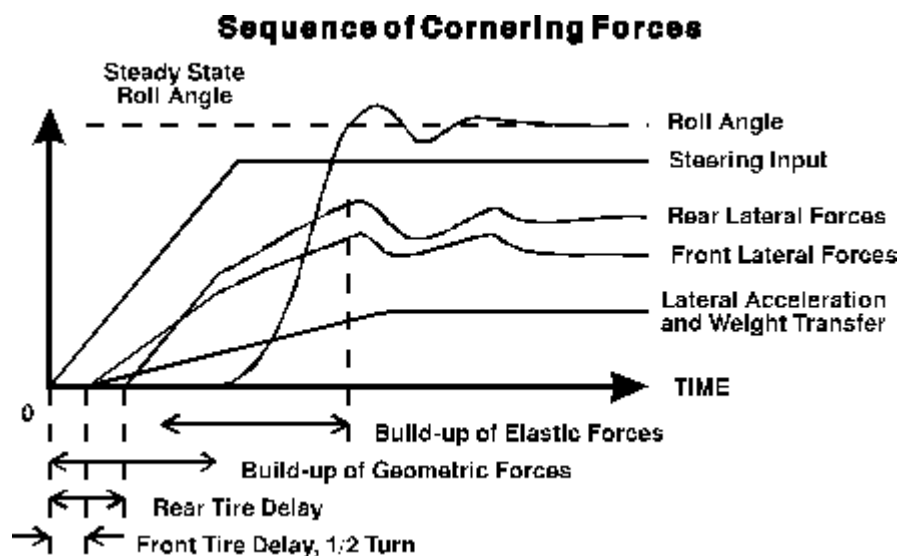


Figure 33 – Load Transfer Forces build up with time (Haney, 1999)

If the rear tyres of a car were not fixed they would rotate, and the car would spin out on a corner. At the entry of a corner the tyres feed lateral forces through the suspension links into the chassis, these forces are geometric. (Haney, 1999)

There is also a roll force trying to roll the chassis towards the outside of the turn. This roll force is counteracted by the resisting force of springs, ARB and dampers. These load transfers are elastic as they are delayed, while the geometric are instantaneous. (Haney, 1999) (Rouelle)

Magic numbers are very much driver style dependant and circuit dependant (Rouelle)

The Aston Martin chassis will have a tendency to raise during cornering, this is a phenomenon called jacking and it happens when the roll centre is located above the ground (Tudor, 2019)

The following equations will be used to calculate the predicted load transfers:

- Overturning moment:

$$M_{ot} = M_s * a_y * H \quad \text{Equation 28 (Tudor, 2019)}$$

Where M_s is the Total Static mass of the vehicle; a_y is the lateral G force in newtons and H is the distance between the Roll centre and the Centre of Gravity.

$$\text{Roll Centre} = \frac{(h_r + h_f) * COG_f}{w} + h_f \quad \text{Equation 29}$$

Where h_r is the rear roll centre height; h_f is the front roll centre height; w is the wheelbase; COG_f is the Centre of gravity distance from the front axle.

- Roll angle:

$$\theta = \frac{M_{ot}}{K_{\theta}} \quad \text{Equation 30}$$

Where K_{θ} is the roll stiffness.

$$K_{\theta t} = K_{\theta f} + K_{\theta r} \quad \text{Equation 31}$$

Where $K_{\theta t}$ is the total roll stiffness; $K_{\theta f}$ is the front roll stiffness; $K_{\theta r}$ is the rear roll stiffness.

$$K_{\theta f} = \frac{T_f^2 * K_{wf}}{2} \quad \text{Equation 32}$$

Where K_{wf} is the wheel rate; T_f is the front track, the same equation is used with rear values.

$$K_{wf} = (\text{spring rate} * \text{suspension motion ratio}^2) + ARB_f \quad \text{Equation 33}$$

Where ARB_f is the front anti roll bar rate, the same equation is used with rear values.

- Elastic Weight Transfer

$$WT_{sf} = \frac{K_{wf} * T_f * \theta}{2} \quad \text{Equation 34 (Tudor, 2019)}$$

The same equation is used for the rear with rear values.

- Sprung Mass Geometric Weight Transfer

$$WT_{sRCf} = \frac{M_{sf} * a_y * h_f}{T_f} \quad \text{Equation 35 (Tudor, 2019)}$$

Where WT_{sRCf} is Front Geometric Weight Transfer.

$$WT_{sRCr} = \frac{M_{sr} * a_y * h_r}{T_r} \quad \text{Equation 36 (Tudor, 2019)}$$

Where WT_{sRCr} is Rear Geometric Weight Transfer

- Unsprung Mass Geometric Weight Transfer.

$$WT_{usf} = \frac{M_{usf} * a_y * r_f}{T_f} \quad \text{Equation 37 (Tudor, 2019)}$$

Where WT_{usf} is the Front Unsprung Mass Geometric Weight Transfer

$$WT_{usr} = \frac{M_{usr} * a_y * r_r}{T_r} \quad \text{Equation 38 (Tudor, 2019)}$$

Where WT_{usr} is the Rear Unsprung Mass Geometric Weight Transfer

- Total Predicted Weight Transfer

$$WT_{Tf} = WT_{sf} + WT_{sRCf} + WT_{usf} \quad \text{Equation 39 (Tudor, 2019)}$$

Where WT_{Tf} is the total weight transfer at the front

$$WT_{Tr} = WT_{sr} + WT_{sRCr} + WT_{usr} \quad \text{Equation 40 (Tudor, 2019)}$$

Where WT_{Tr} is the total weight transfer at the rear

$$WTT = WT_{Tf} + WT_{Tr} \quad \text{Equation 41 (Tudor, 2019)}$$

- Predicted Magic Number

$$\text{Predicted MN} = \frac{WT_{Tf}}{WTT} \quad \text{Equation 42}$$

9.1 Spring and ARB slow and high corners

Data gathered in this section is from a fast and a slow corner, it will be separated in 3 sections: Entry, Apex and Exit.

9.1.1 Slow Corner (Turn 6) Spring changes

- **Corner entry:**

The “Front min Rear max” configuration experiences the least amount of load transfer on the front axle (Figure 34, 35), while on the back axle initially it experiences less load transfer but further into the entry of the corner it experiences a sudden increase in geometric transfer in comparison with the other two setups (Figure 36). This is due to the higher rear spring rate of this setup. This setup enters the corner with the most amount of speed, thanks to its lower front spring rate the car has a larger rake angle allowing the driver to brake later, due to its increased downforce.

The “Front max Rear min” configuration experiences the most load transfer initially on the front due to its higher spring rate, but later into the corner entry the “Front mid Rear mid” configuration takes more load (Figure 34, 35). Furthermore, on the rear of the car the “Front max Rear min” configuration experiences less load transfer than the “Front mid Rear mid” (configuration due to its lower rear spring rate. While the “Front mid Rear mid” enters the corner with the least speed.

- **Corner Apex:**

The three setups at the corner all level out into a steady state, as all three setups have a similar steering input and corner speed.

- **Corner Exit:**

The “Front mid Rear mid” setup exits the corner with the most speed, this is thanks to its balanced setup, helping the car to understeer less on exit in comparison with the other two setups.

On the rear axle the setup which experienced the highest level of load transfer was the “Front min Rear max” due to its higher spring rate. It also experienced at the beginning of the exit more understeer than the other two setups, thus experiencing more load transfer at the front. Once this understeer subsided, the “Front max Rear min” setup experienced larger levels of load at the front axle, due to its higher front spring rate.

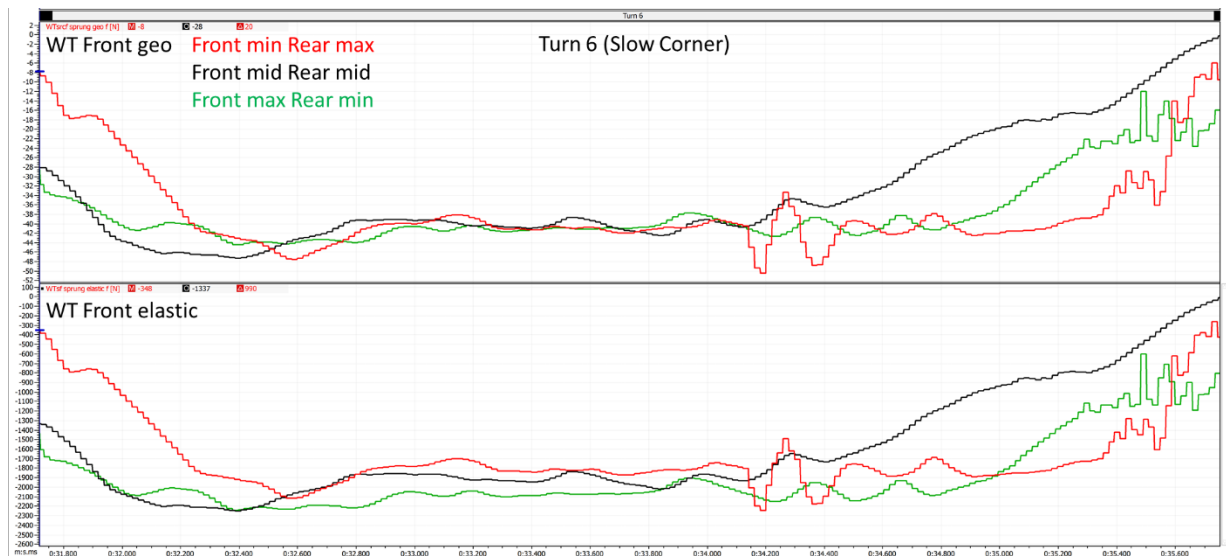


Figure 34 – Slow Speed front elastic and geometric load transfer springs setups

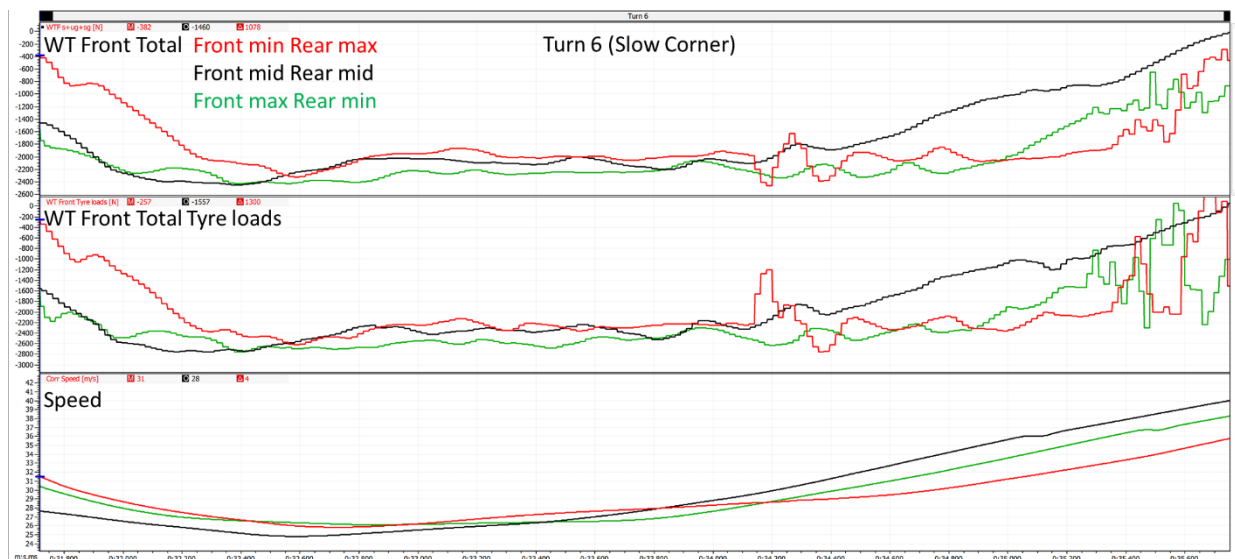


Figure 35 – Slow speed Front total predicted and tyre load, load transfer springs setups

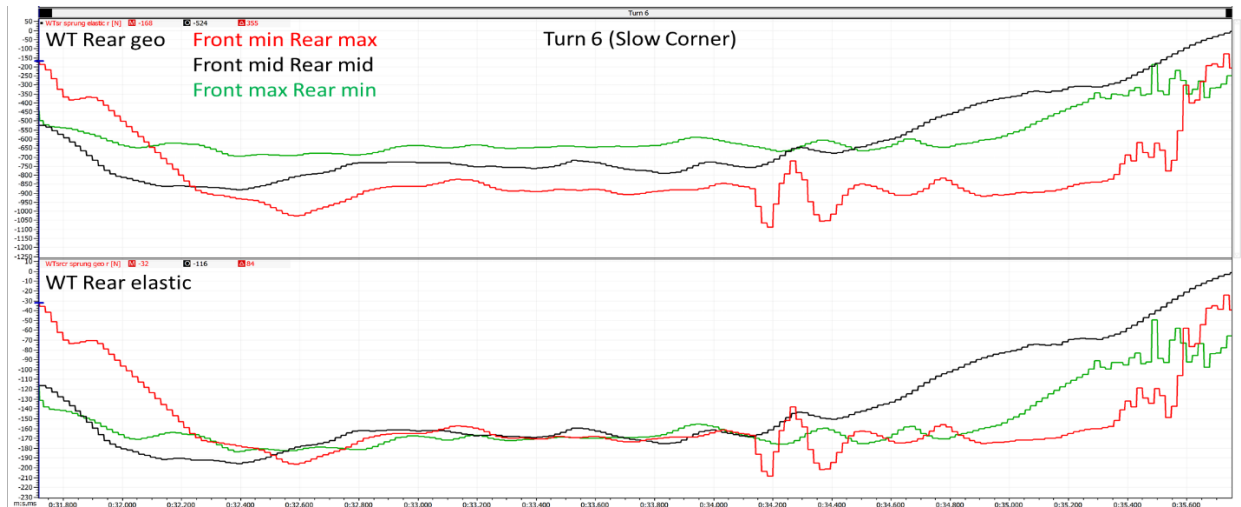


Figure 36 – Slow Speed Rear elastic and geometric load transfer spring setups

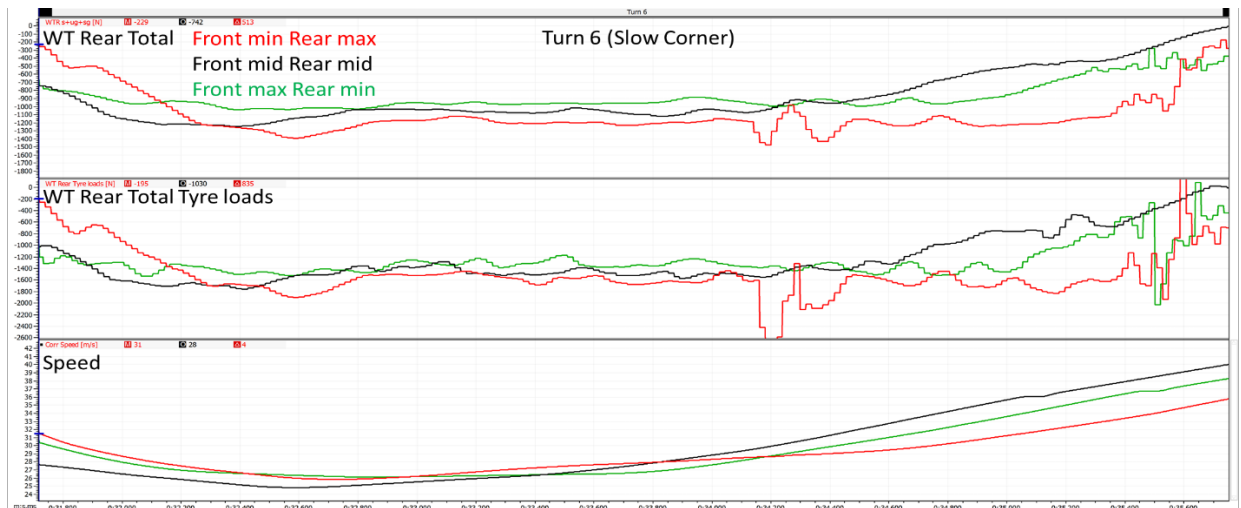


Figure 37 - Slow speed Rear total predicted and tyre load, load transfer springs setups

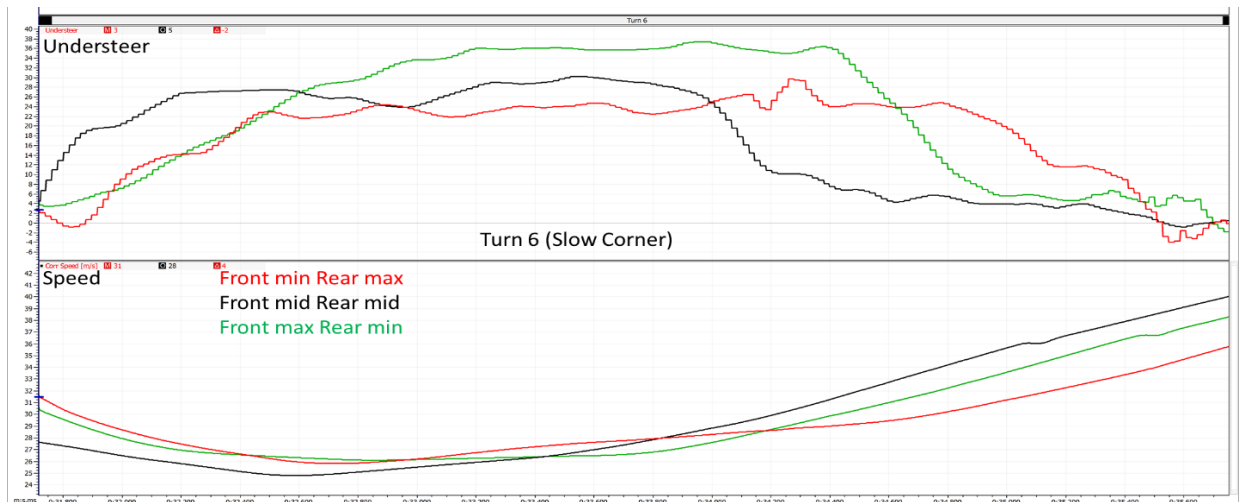


Figure 38 – Slow Speed understeer and speed, load transfer springs setups

9.1.2 Slow Corner (Turn 6) ARB changes

- **Corner entry:**

Configuration “Front min Rear Max” experiences the largest load transfer on the front and rear axle (Figure 39,41), as well as the most amount of roll (Figure 43). The min ARB setting at the front of the vehicle makes the car understeer the most out of the three setups (Figure 43). The “Front mid Rear mid” configuration experiences the least amount of roll angle and the least amount of load transfer on the front and rear axle, except at the very start of the corner where it experiences higher load transfer front and rear in comparison to the (Front max Rear min) configuration.

- **Corner apex:**

The geometric loads on the setups level out as there are no more instant forces acting on the vehicle, while the “Front max Rear min” setup takes the most front load transfer of the three setups and the least rear load transfer, due again to its max front ARB setup. Furthermore, “Front Mid Rear mid” setup is the most balanced of the two.

- **Corner exit:**

On corner exit the setup which had no spikes of understeer or oversteer was the middle range setup as expected.

“Front min Rear max” experienced some oversteer when exiting the corner (Figure 43). Due to the high rear ARB rate, the rear of the car is a lot stiffer which makes it prone to oversteering. On the other hand, “Front max Rear min” experienced a large amount of understeer on corner exit, due to the stiffer front, prone to sliding.

Even with the slight oversteer the “Front min Rear max” setup exited the corner with the highest speed, while the high levels of understeer for configuration “Front max Rear min”, meant it exited the corner with the least amount of speed.

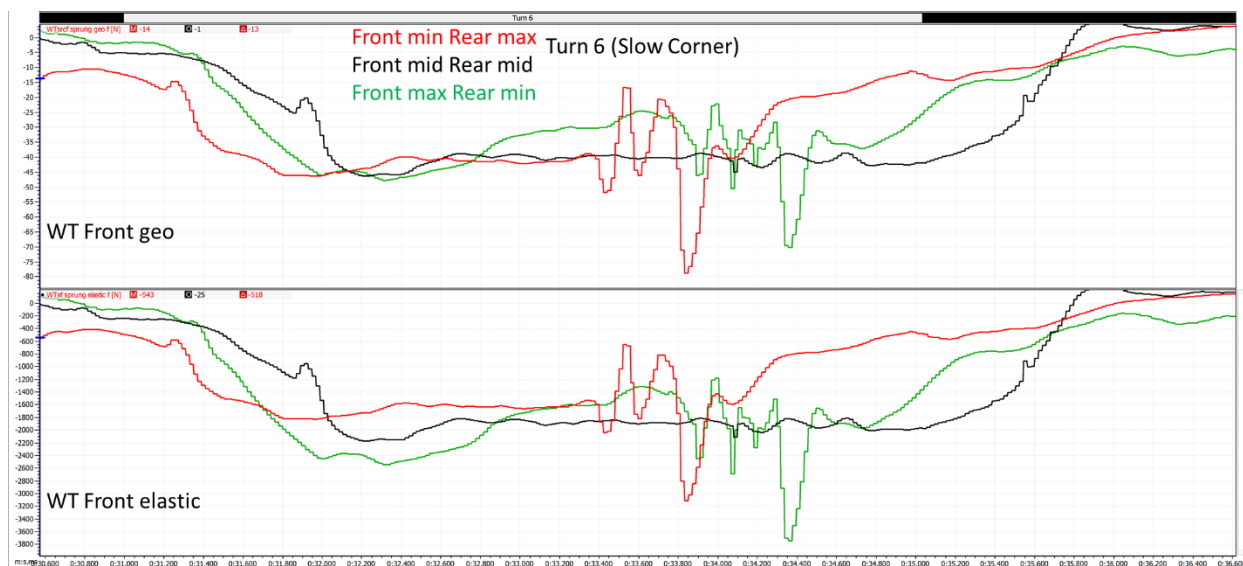


Figure 39 – Slow Speed front elastic and geometric load transfer ARB setups

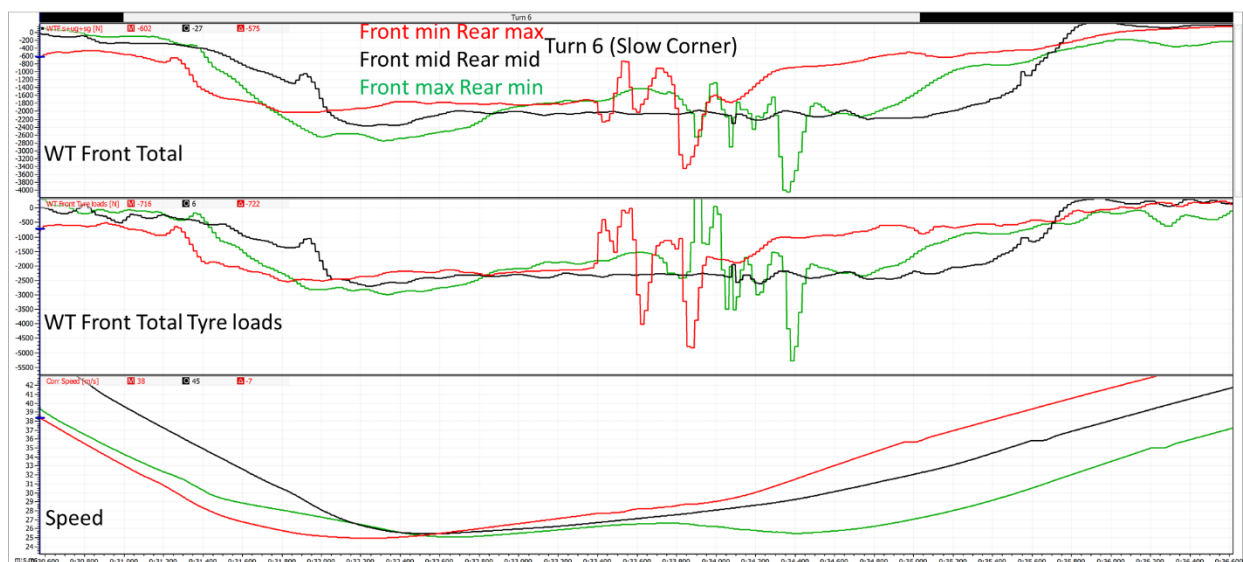


Figure 40 - Slow speed Front total predicted and tyre load, load transfer ARB setups

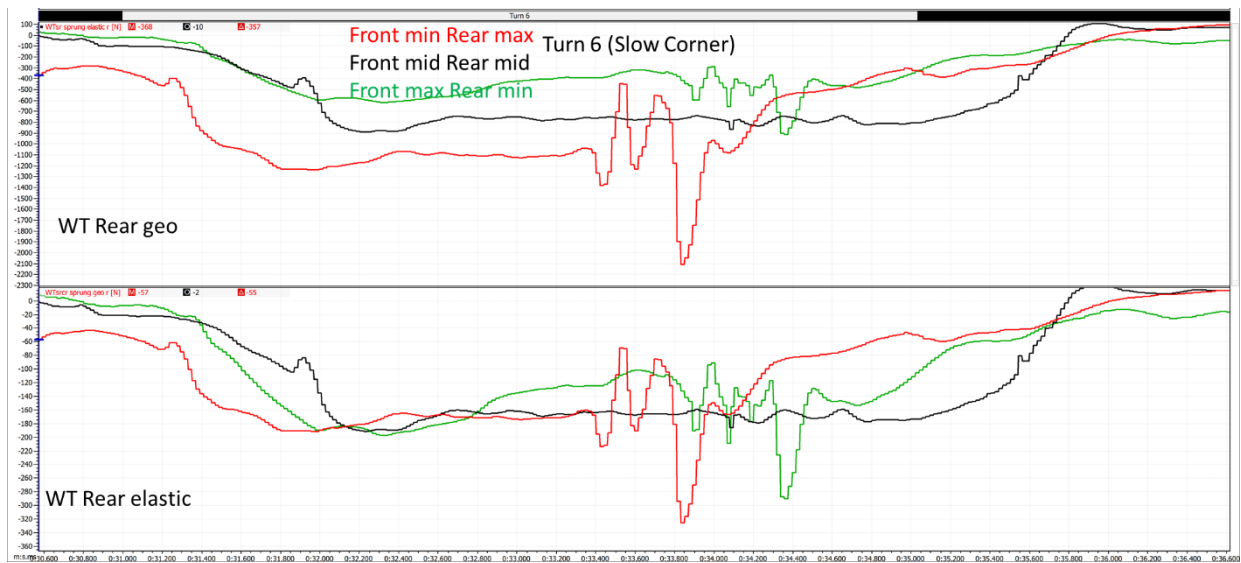


Figure 41 - Slow Speed Rear elastic and geometric load transfer ARB setups

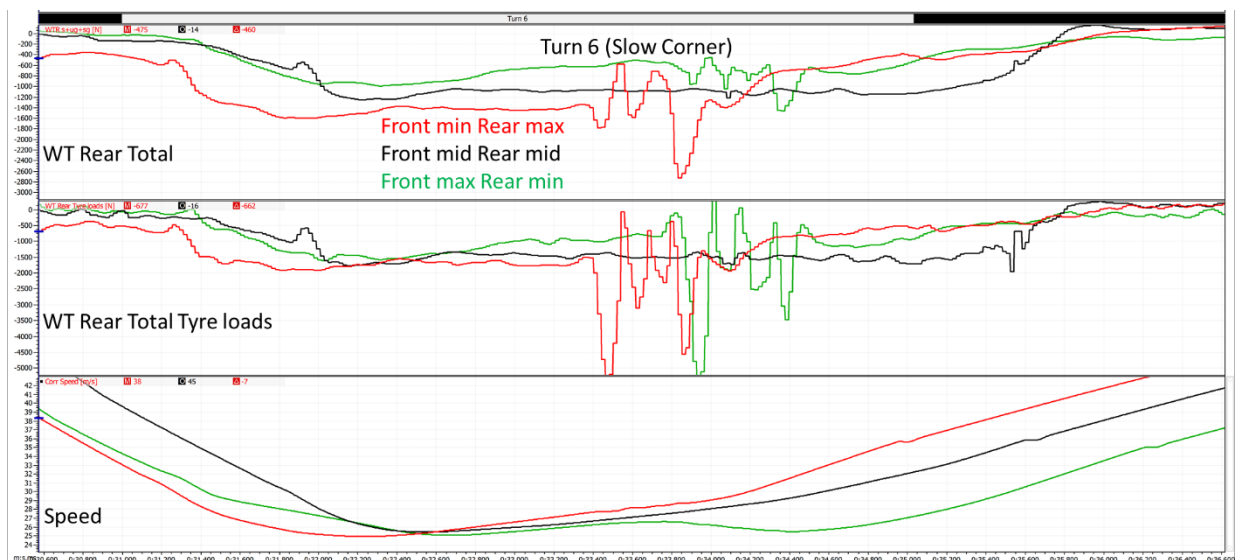


Figure 42 - Slow speed Rear total predicted and tyre load, load transfer ARB setups

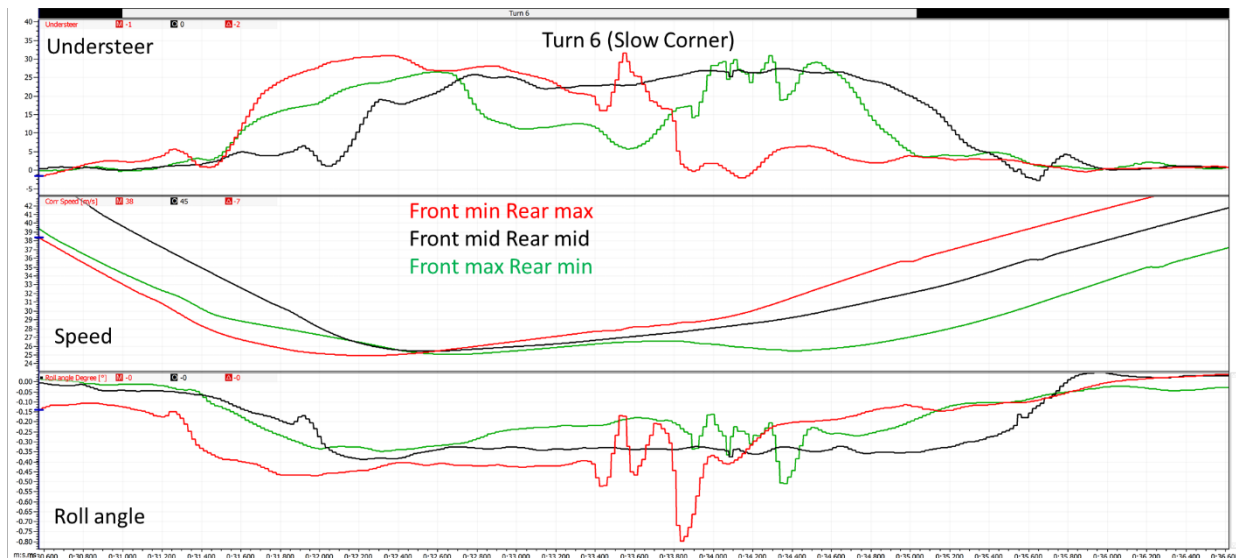


Figure 43 - Slow speed understeer, speed and roll angle, load transfer ARB setups

9.1.3 High Speed Corner (Turn 4) Spring changes

The “Front min Rear max” configuration experiences the highest loads on its rear axle during steady state cornering and exit (Figure 46,47), while on its front axle it experiences the highest loads on exit of the corner (Figure 44,45). This is due to the loss of grip on the rear tyres on the exit, making the front-end work harder to retain control.

The “Front mid Rear mid” configuration is between the two other setups, except on corner exit where it experiences less load transfer at the front and rear. Thanks to its balanced setup, it has less understeer (Figure 48).

The “Front max Rear min” setup experiences higher front loads in comparison to the other two setups, while on the rear, it experiences the least load transfer. This is because the firmer front springs are aiding the car to turn more quickly while the softer rear springs grip the track more easily.

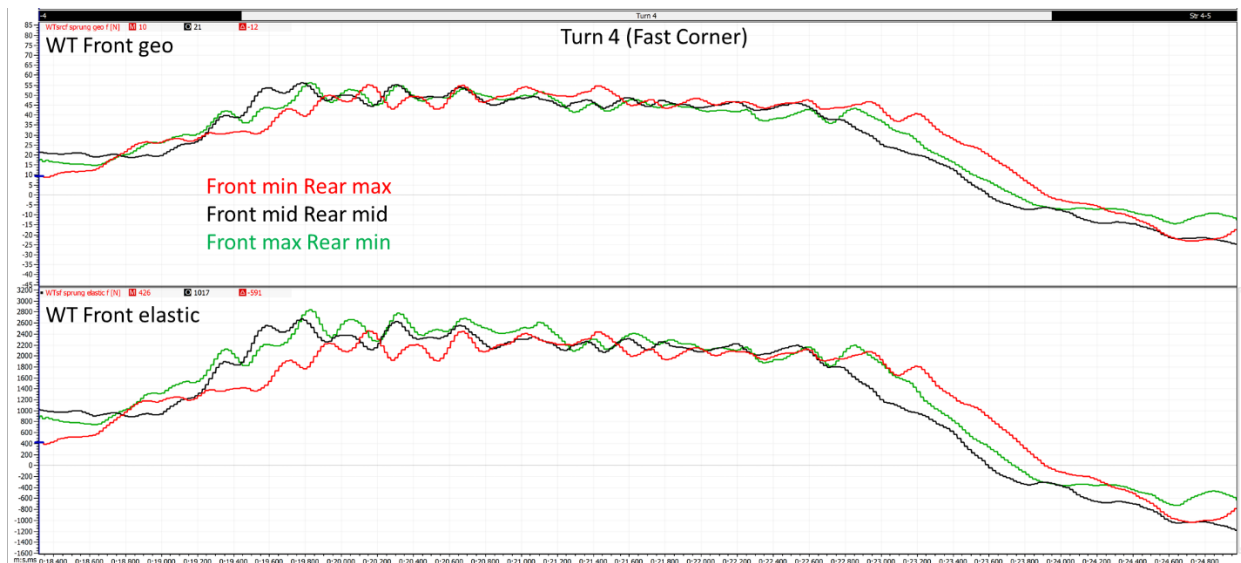


Figure 44 - High Speed front elastic and geometric load transfer spring setups

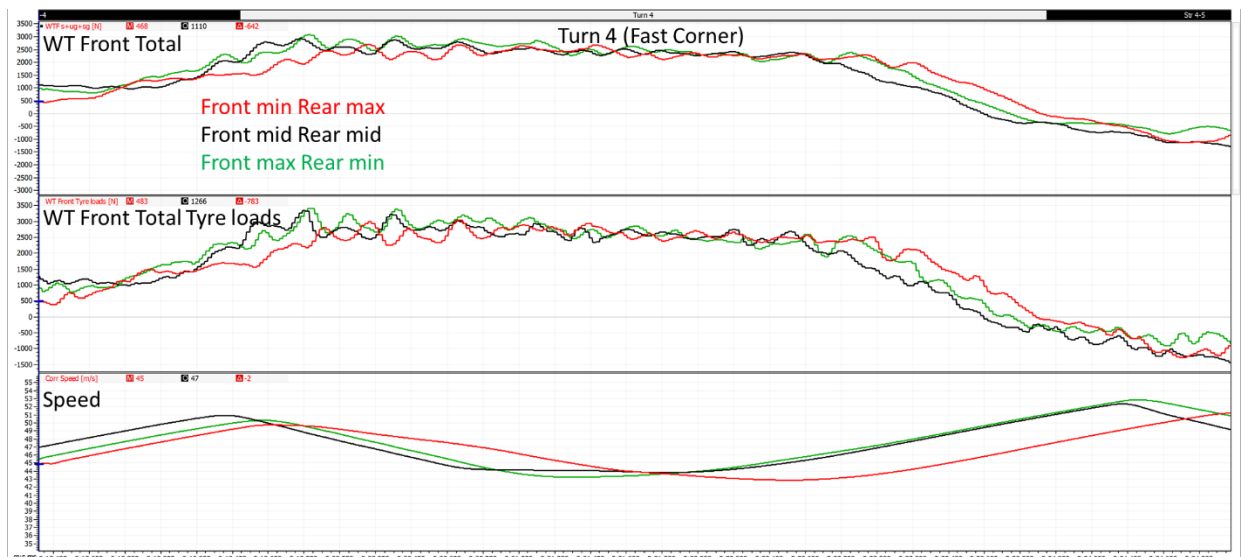


Figure 45 - High speed Front total predicted and tyre load, load transfer springs setups

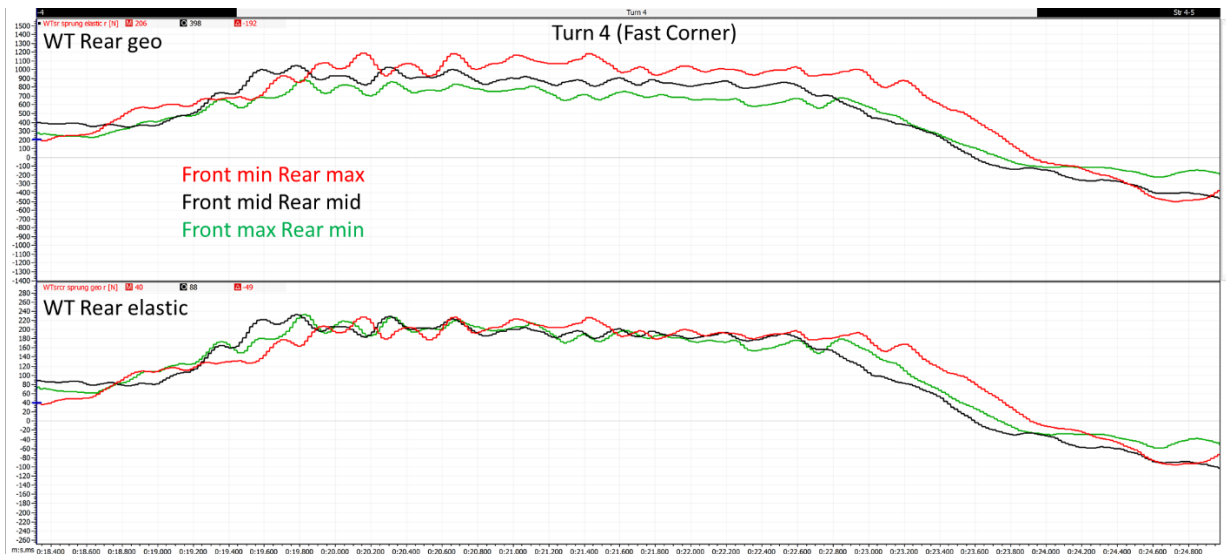


Figure 46 - High Speed Rear elastic and geometric load transfer spring setups

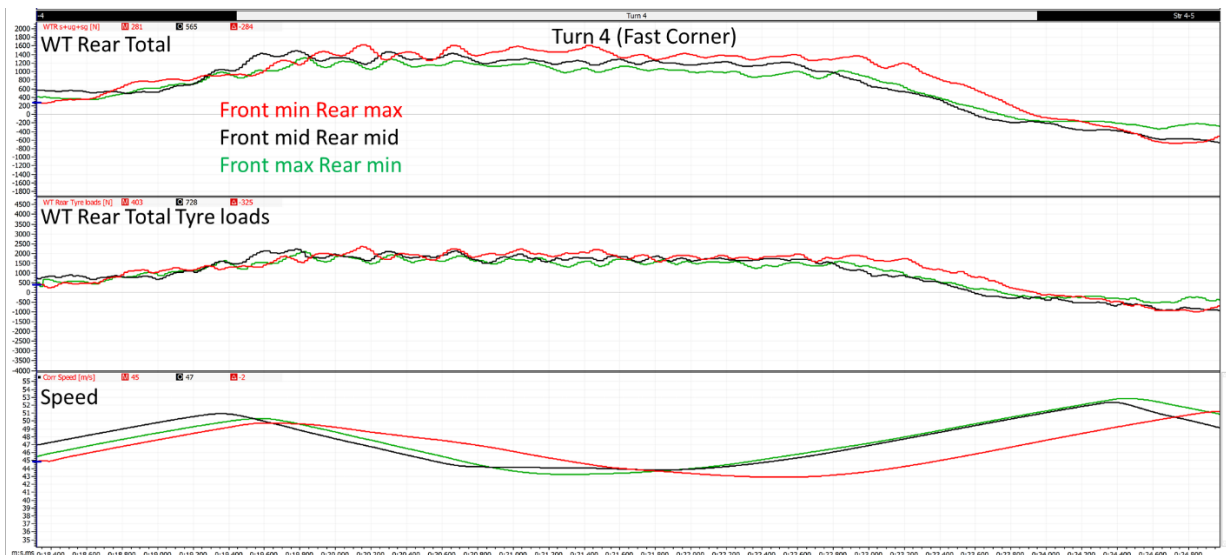


Figure 47 - High speed Rear total predicted and tyre load, load transfer springs setups

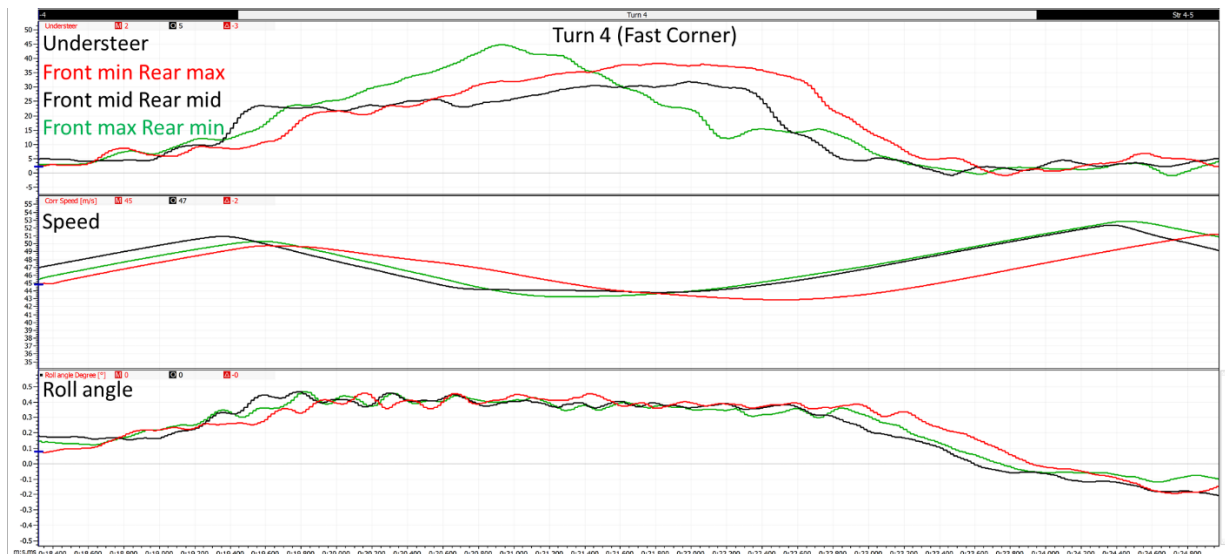


Figure 48 - High Speed understeer, speed and roll angle, load transfer springs setups

9.1.4 High Speed Corner (Turn 4) ARB changes

At corner entry, configuration “Front max Rear min” experiences higher load transfers to the two other setups on its front axle (Figure 49,50), during steady state and corner exit it has the least roll angle of the three (Figure 53). Furthermore, it experiences a large spike of understeer in comparison to the other setups on entry of the corner but is lower at corner exit (Figure 53) The high understeer at the start of the corner is due to the high front ARB rate, which under load makes the car slip and be more unstable on corner entry. On the other hand, on corner exit the higher front ARB rate helps the car turn more efficiently once the understeer is managed.

The “Front min Rear max” configuration has the slowest corner entry of the setups, it experiences the highest load transfer on its rear axle at corner entry and apex, and low transfer loads on its front axle. Due to this, it experiences the least understeer out of the two setups overall. On the other hand, the roll angle at corner entry and apex is higher than the other two, this is due to the low front ARB rate.

The “Front mid Rear mid” setup, experiences the least amount of roll at corner entry, thanks to its balanced setup, while at corner exit it experiences the most roll as it doesn’t have enough rear ARB to counteract understeer.

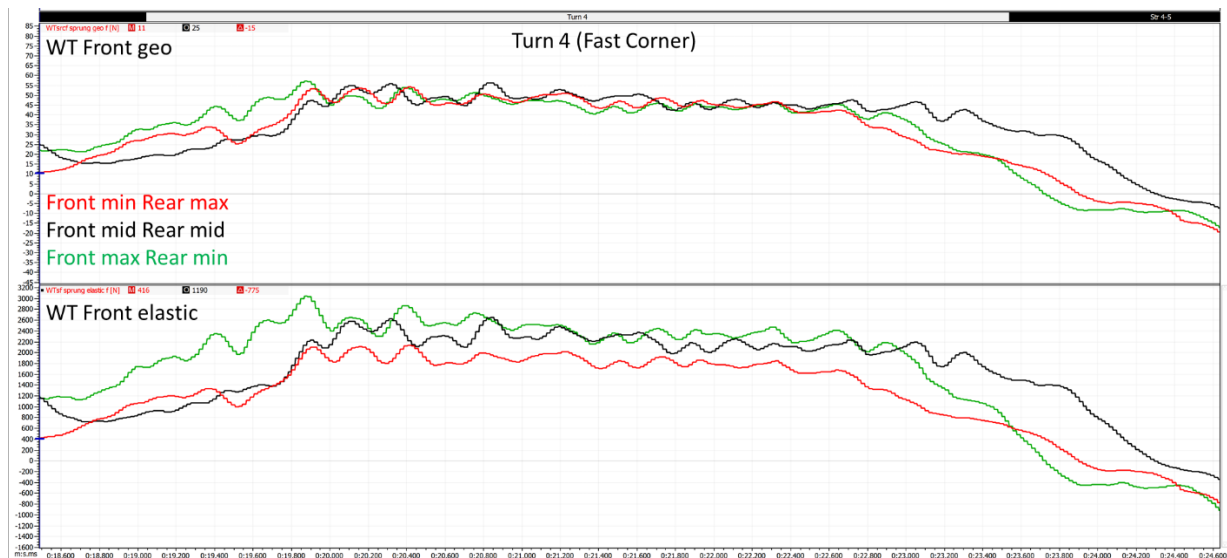


Figure 49 - High Speed front elastic and geometric load transfer ARB setups

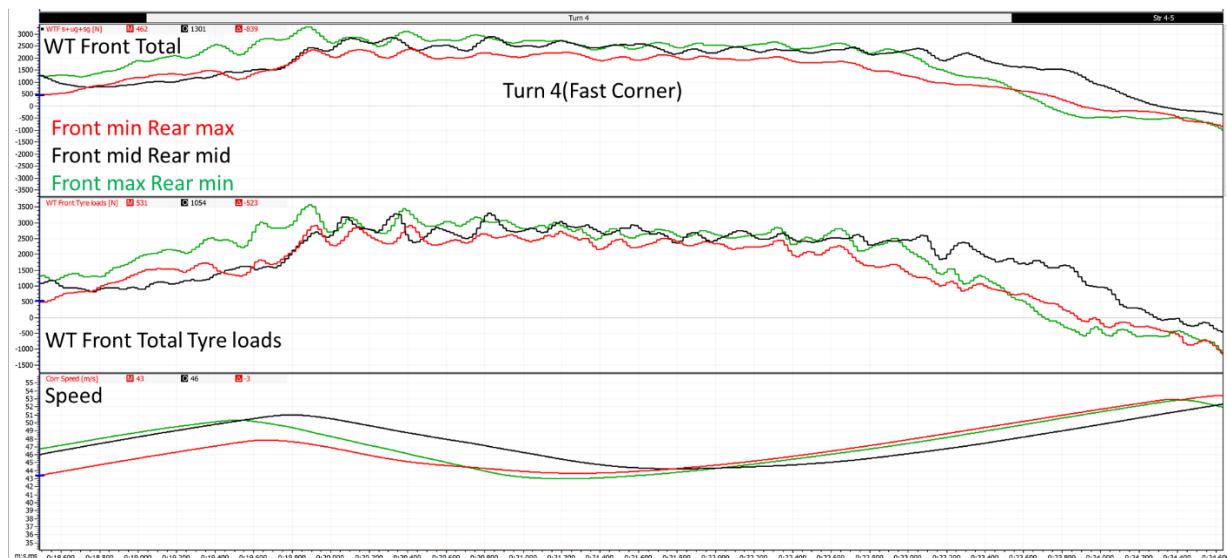


Figure 50 - High speed Front total predicted and tyre load, load transfer ARB setups

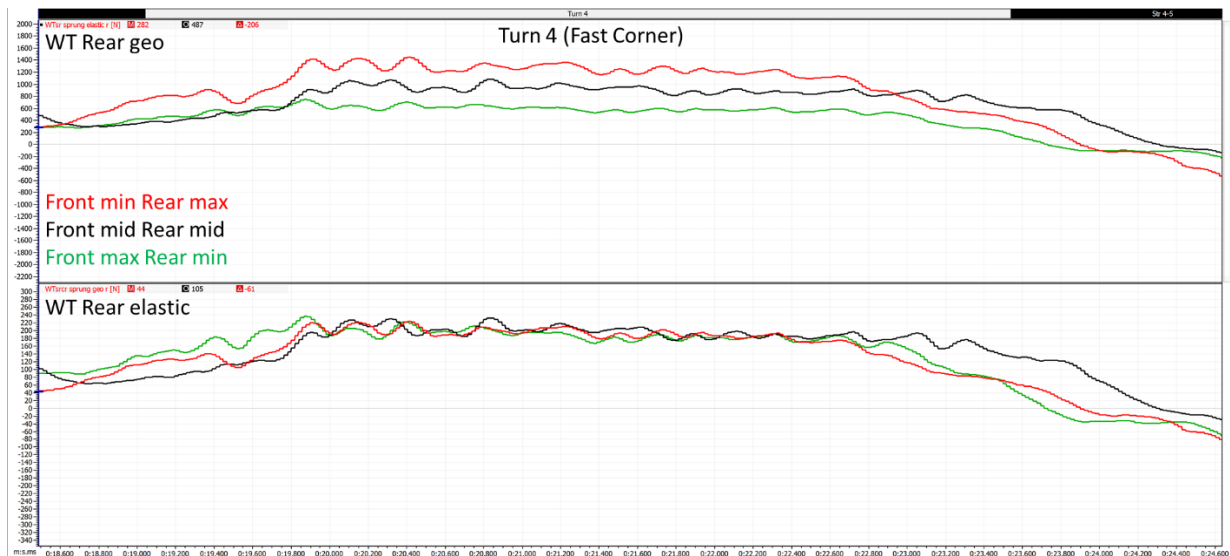


Figure 51 - High Speed Rear elastic and geometric load transfer ARB setups

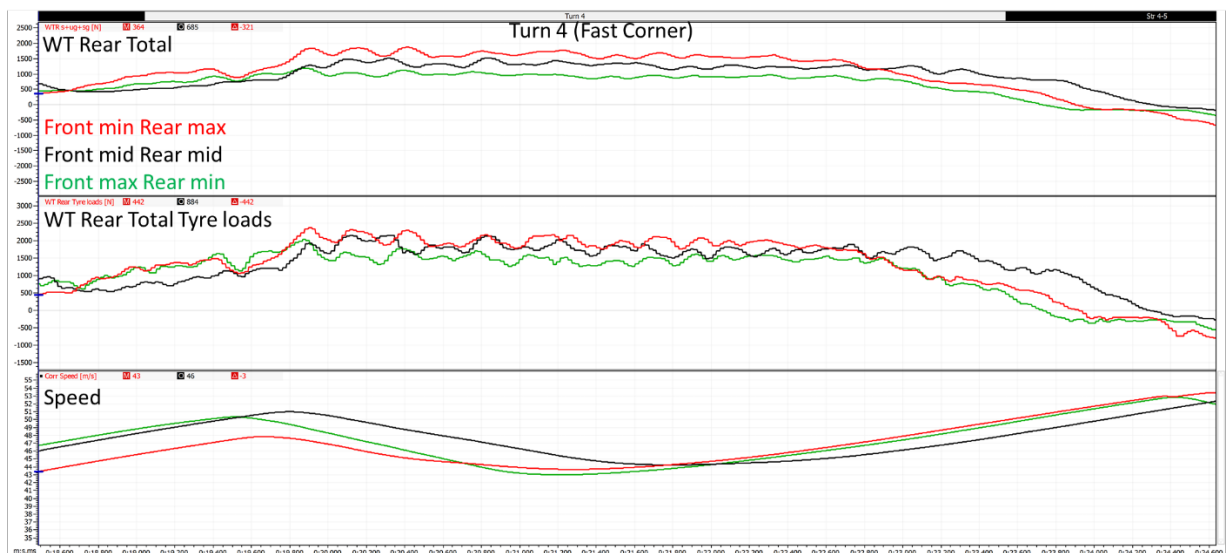


Figure 52 - High speed Rear total predicted and tyre load, load transfer ARB setups

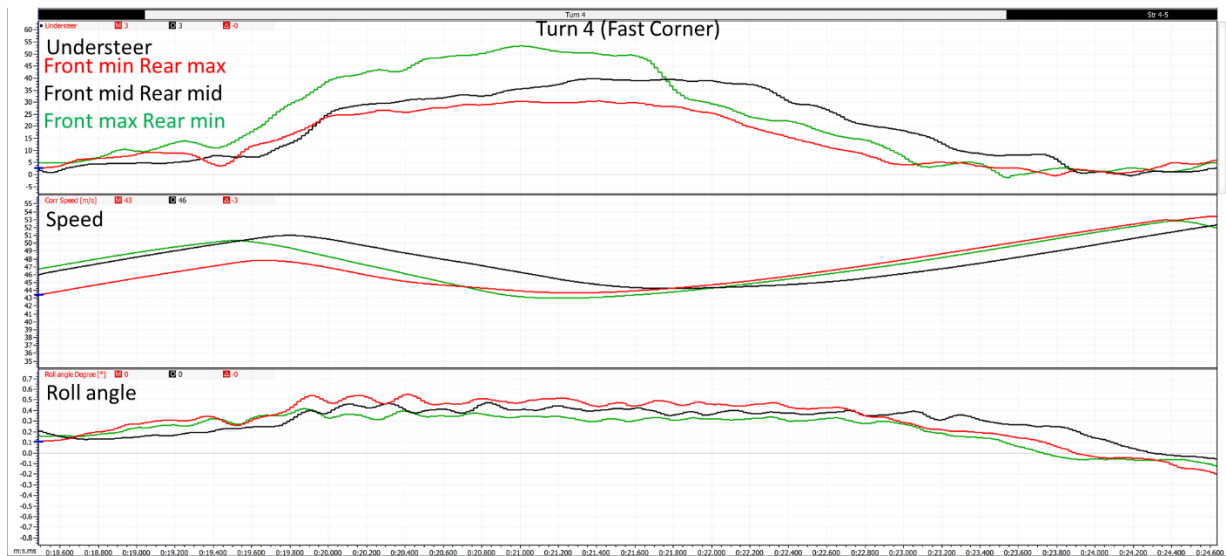


Figure 53 - High Speed understeer, speed and roll angle, load transfer ARB setups

10. Dampers

While springs produce force through displacement, dampers produce force through velocity. Using this a graph can be done to compare the different Low and high-speed Bump and Rebound setups on a car. A point to make is that dampers do not control weight transfer, they control the rate of weight transfer.

Figure 54 and 55 are graphs showing the force vs velocity, it tells the reader how force increases with velocity. In Figure 54, the Bump is being tuned, therefore the setup with the most “clicks” will develop more force with speed and vice versa. The same goes for the rebound in Figure 55.

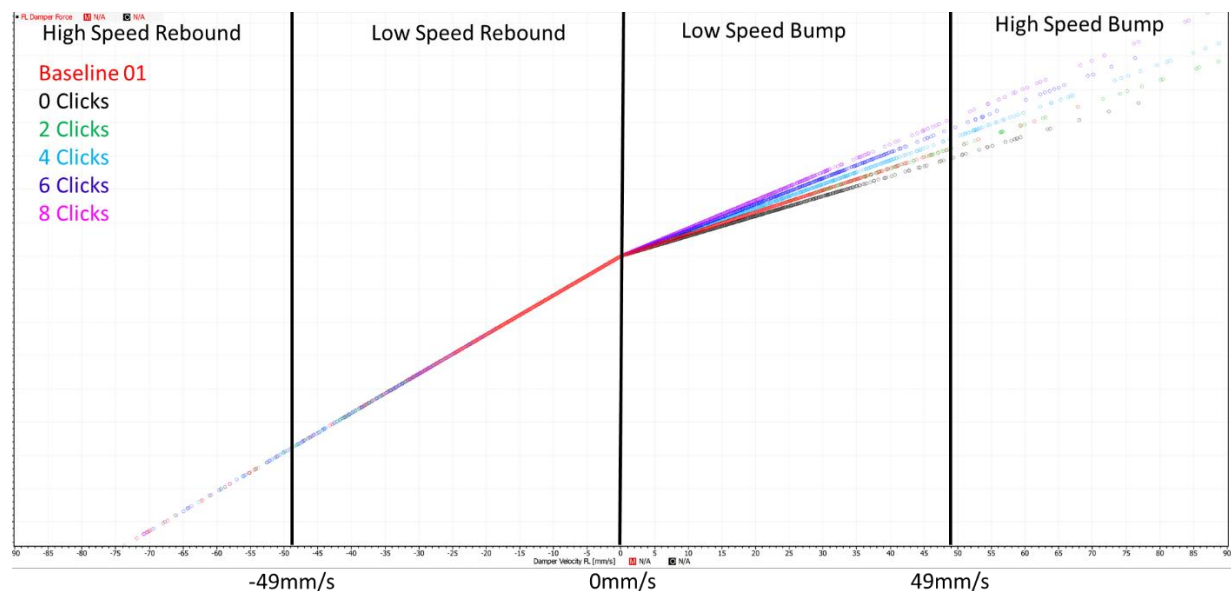


Figure 54 – Low Speed Bump setups

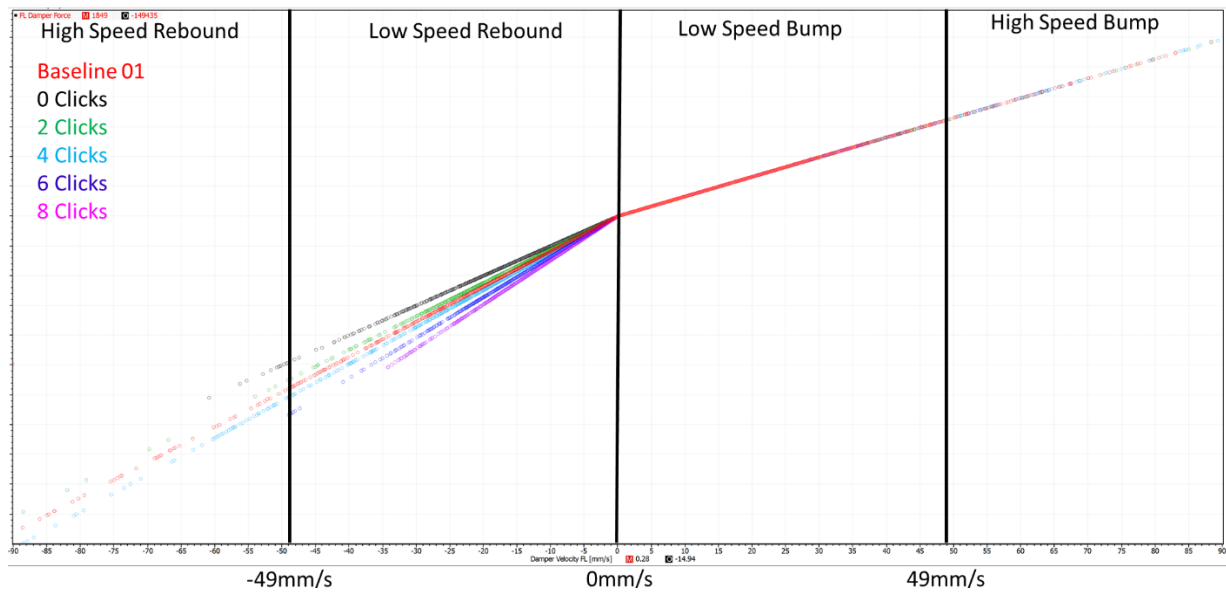


Figure 55 – Low Speed Rebound setups

10.1 Histograms to assess damper settings overall

The “zero bin” is the bar which separates the bump and rebound areas, most of the time the dampers are in their low speed zone. Looking at the height of the “zero bin” it can be assessed if a damper needs further tuning.

In Figure 56 the rear axle is balanced with a 19% RL and 20% RR, on the other hand the front axle has a 2.5% difference between the two, meaning that either one is underdamped or the other is overdamped. Looking at these histograms, it is also possible to see the percentages of low speed bump and low speed rebound, on the Right of the “zero bin” in Figures 56 57 and 58, the bump speed is located while on the left the rebound is located. Both sides can be compared for fine tuning the damping system to make them symmetrical. Something to take into consideration is that the rebound of the car on high downforce vehicles can be used to influence the pitching. Consequently, it is possible for the bump and rebound not to be symmetrical.

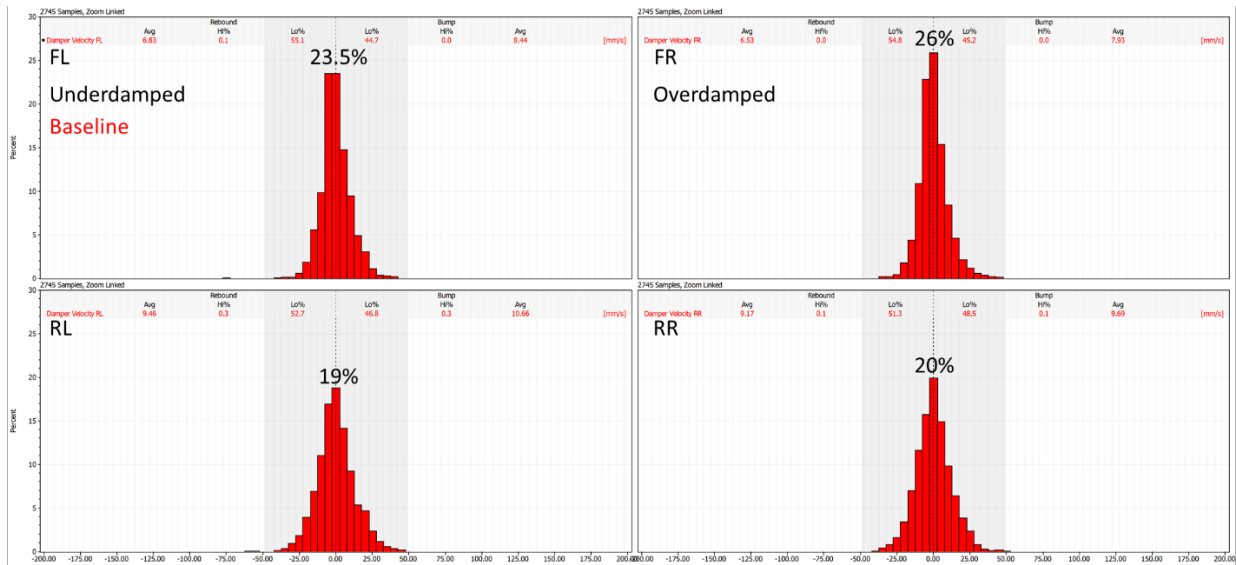


Figure 56 – Baseline histogram

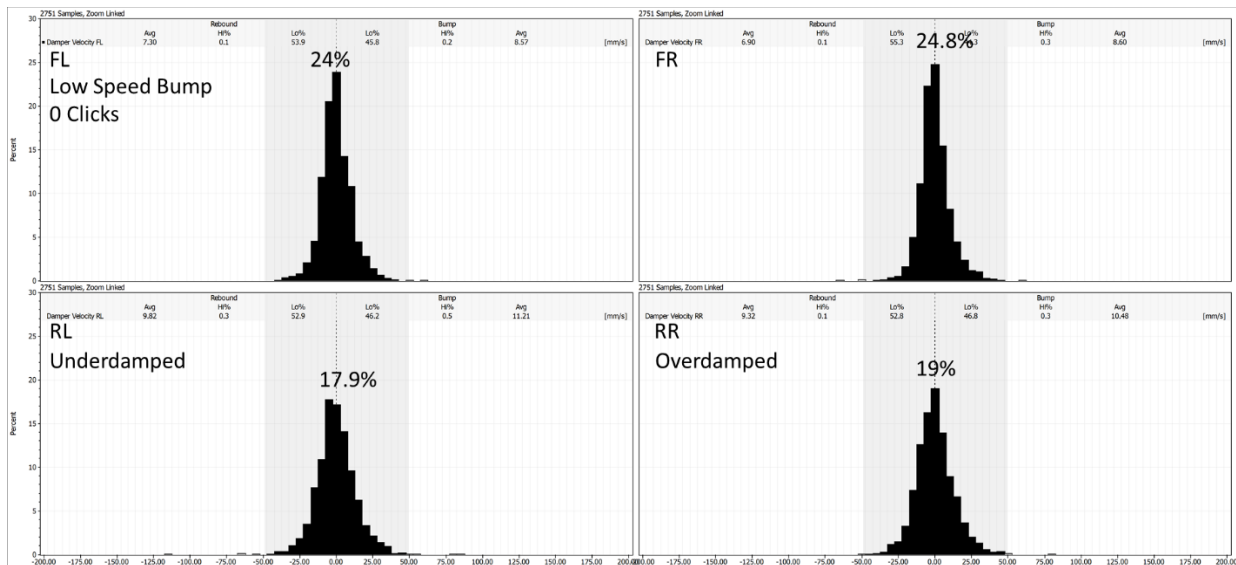


Figure 57 – Low Speed Bump 0 Clicks Histogram

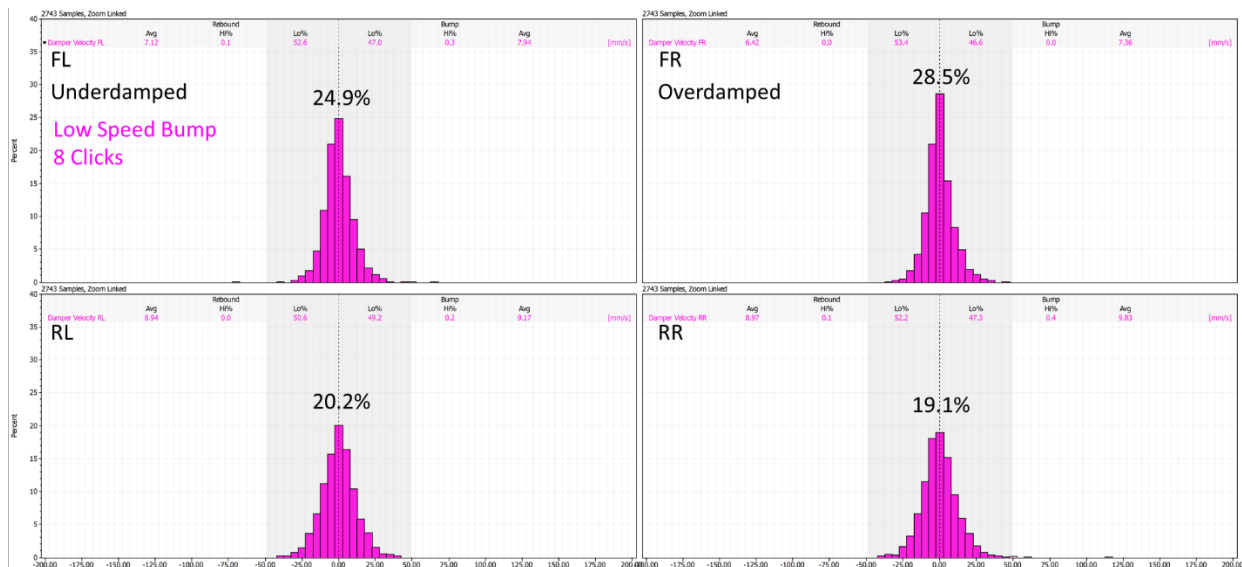


Figure 58 – Low Speed Bump 8 Clicks

10.2 Damper Setup transient handling

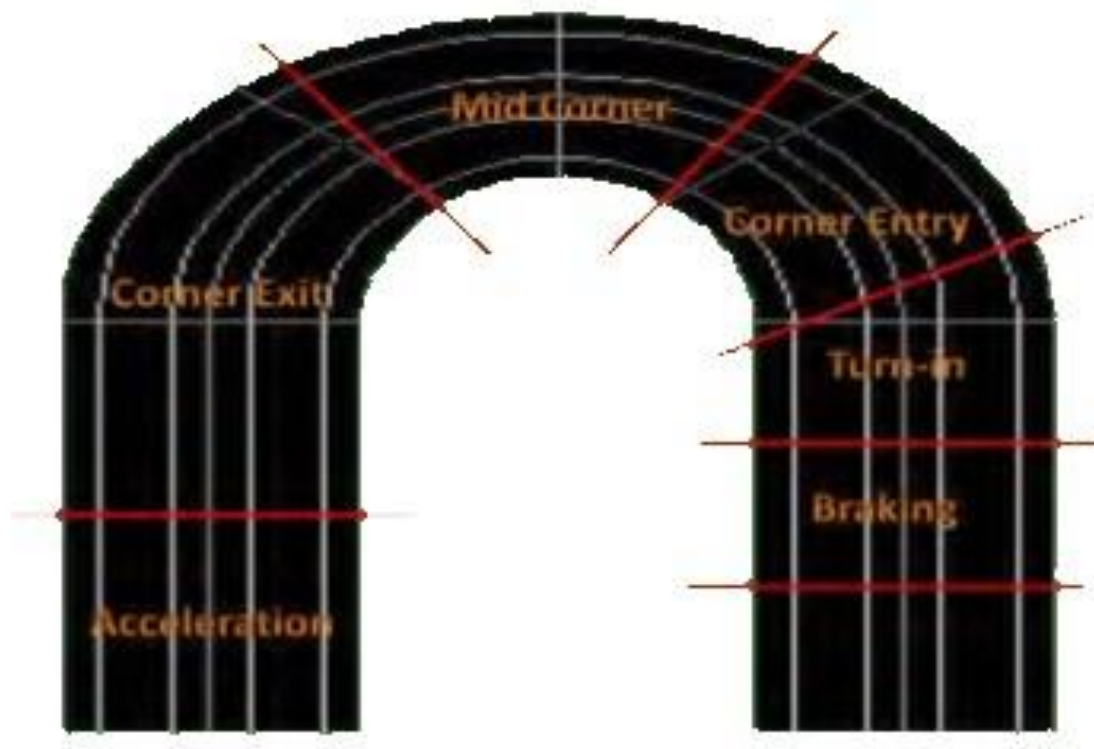


Figure 59 – Corner sections (Tudor, 2019)

- **Braking:**

Dampers control the rate weight transfer from the rear to the front. If the weight transfer is too fast the front tyres won't be able to take the additional loads and lose grip. If the weight

transfer is too slow, the driver will have to delay the turn in to the corner and will overshoot the corner. If too much rear rebound is placed on the vehicle it tends to lift the rear tyres of the ground, therefore losing grip. (Kasprzak, 2011)

- **Turn in:**

The compression of the outside wheels can be used as dynamic springs. Using the dampers, it is possible to quickly load the outside wheels as soon as the vehicle begins to roll. Consequently, this will give the car a good turn in response. Too much damping would overload the tyre and produce understeer, too little and the steering won't be fast and precise. The dampers are still controlling the rate of weight transfer, especially on rear rebound, if there is too much this will produce oversteer. (Kasprzak, 2011)

- **Corner entry:**

Weight transfer is still happening from the rear to the front, as well as to the outside wheels. The compression on the outside wheels can be used to control the rate of weight transfer. Less compression speed rate, more compression to slow it. If the car is losing control increasing the rebound on the inside wheels will help. (Kasprzak, 2011)

- **Mid corner:**

Dampers essentially don't have any handling effects on this section, apart for any bumps.

- **Corner exit:**

Transition from turning to acceleration. Weight transfer will begin to go from the front to the back. Rear compression can be used to support the back end of the car, too much rear compression will make the car oversteer. To counteract oversteer, softening the rear compression will increase load transfer to the rear or increasing front rebound will increase the rate of weight transfer to the rear.

If the car is understeering on corner exit, it means that the load is being taken away from the front tyres too quickly, causing loss of grip. Increasing front rebound and rear compression will limit understeer, but too much rear compression can produce oversteer. (Kasprzak, 2011)

- **Acceleration:**

Front to Rear weight transfer rate is controlled by the dampers. Increasing rear compression to maximize acceleration can be made, but too much rear compression will translate into a loss of traction, so tuning the front rebound to counteract loss of traction can be made. (Kasprzak, 2011)

10.3 Low Speed Bump Setups

Straight away from looking at Figure 60 and 61 it is apparent the larger Bump setting in green, is helping the car on corner exit, by limiting understeer. The extra bump does make the car oversteer on exit briefly, but it levels out soon after.

On the other hand, the lower bump setting from the low bump configuration in black in Figure 60 and 61, develop large amounts of understeer on corner exit. As it experiences large amounts of weight transfer from one end to the other, to counter this increasing bump at the rear of the car will help counteract understeer.

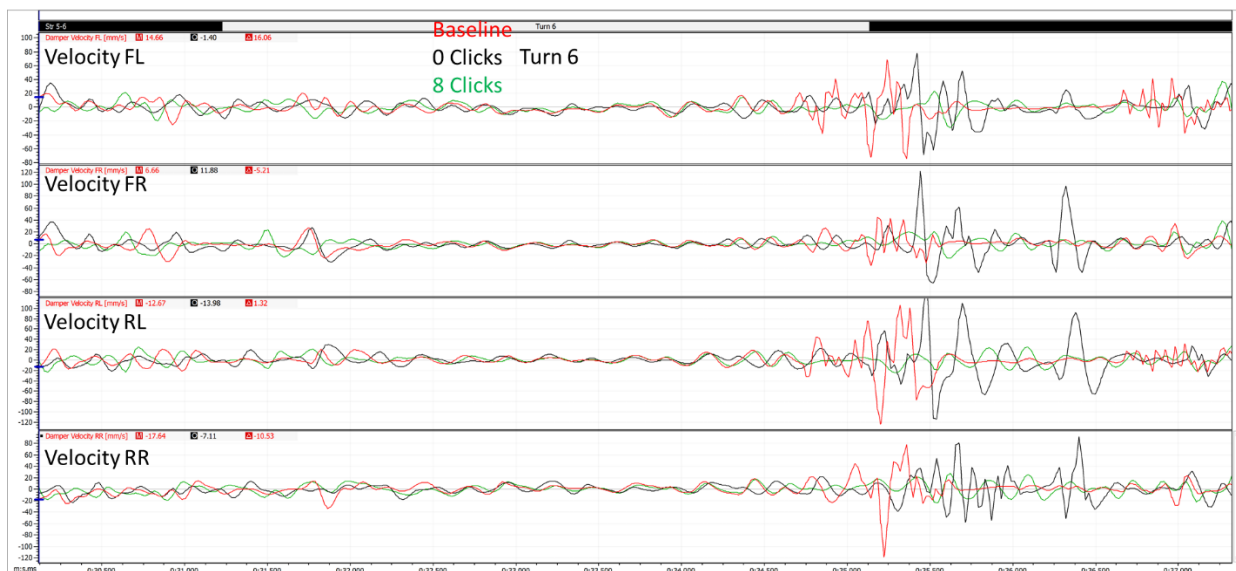


Figure 60 – Damper Velocity Bump and Rebound, low speed bump settings.

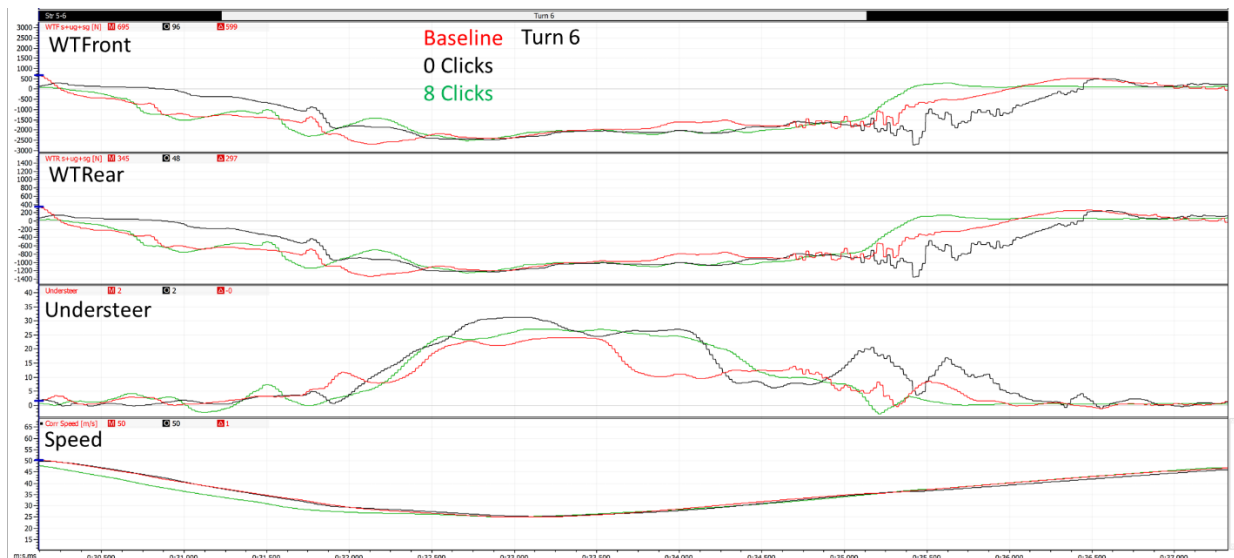


Figure 61 – Weight Transfers and Understeer, low speed bump setting.

10.4 Low speed Rebound Setups

The green 8 clicks configuration at corner entry, due to its high damper rate, understeers a lot more in comparison to the other 2 setups, on the other hand on corner exit it understeers the least as the weight transfer is balanced nicely by the dampers.

The black 0 clicks configuration, thanks to its low rebound setting, understeers the least on corner entry but at steady state it steadily understeers and at corner exit it oversteers slightly.

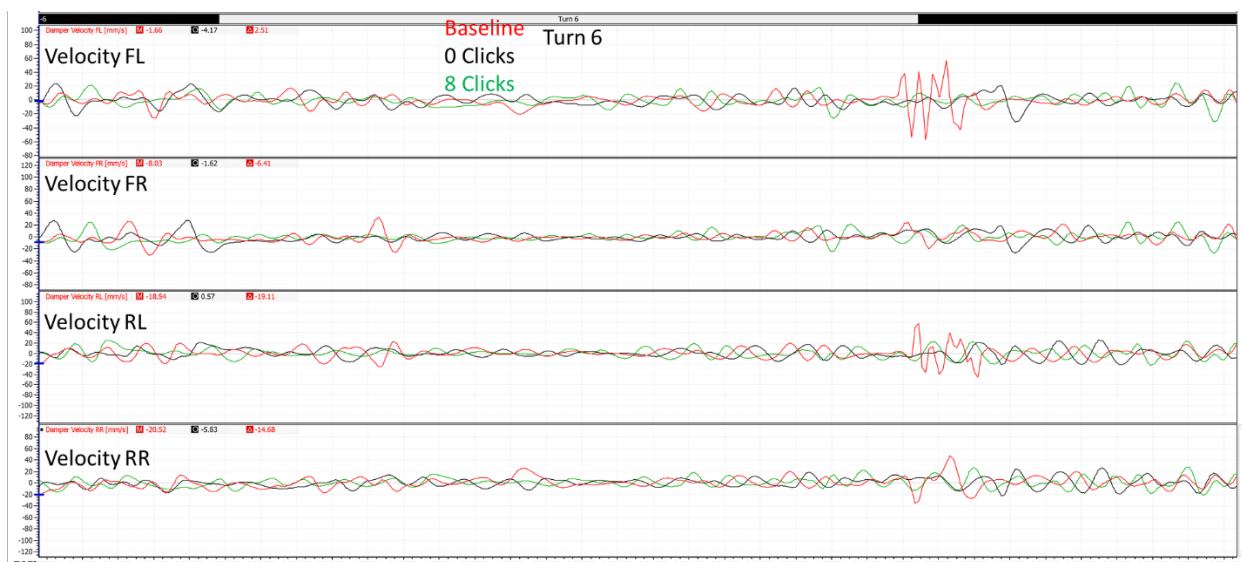


Figure 62 -- Damper Velocity Bump and Rebound, low speed rebound settings.

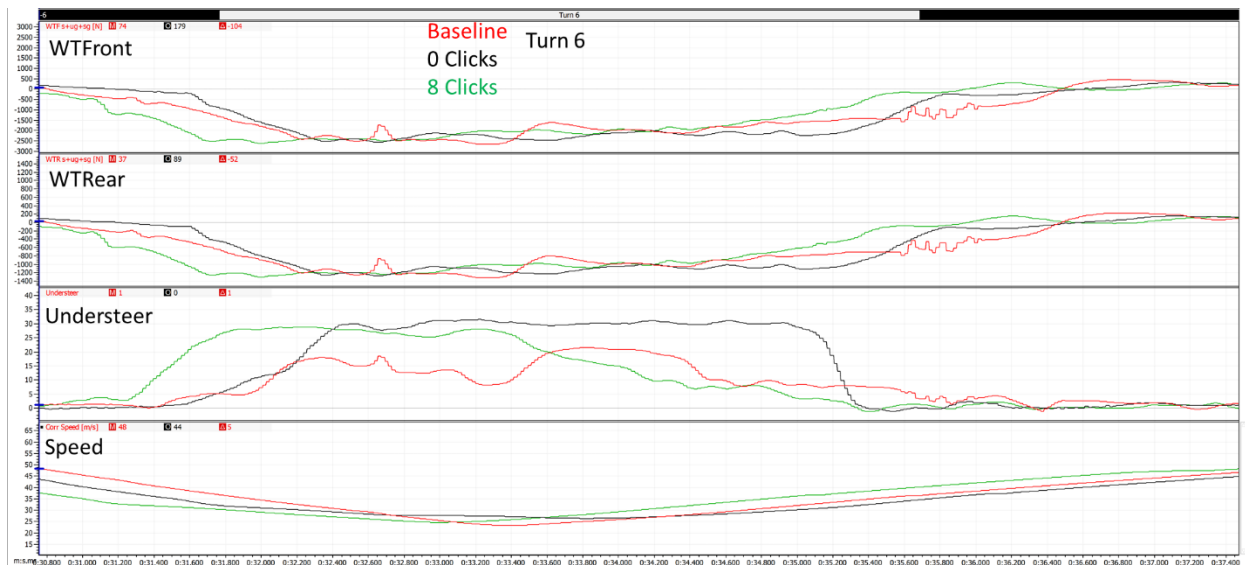


Figure 63 – Weight Transfers and Understeer, low speed rebound setting.

11. Conclusion

A better test plan with constant speed testing in a straight line for each aerodynamic setup, as well as coast down data for each aerodynamic setup, should have been done. For meeting the 2-hour deadline sacrificing some damper setups in favour for this kind of testing would have been more fruitful, as well as producing more laps with each setup till consistent lap times are achieved.

Aerodynamically, the Pembrey circuit with its short straights is very much a high downforce track, therefore the setups with high front downforce capitalize.

Dampers can be tuned to achieve the best weight transfer rates around corners, with low speed bump and rebound being the most present and hardly any high-speed bump and rebound sections.

12. References

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