

Aerodynamic Vehicle Testing and Analysis

by Daniel Salathiel

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1.0-Introduction:

Aerodynamic theory is based upon the basic laws of motion, the two main forces of which are lift and drag. A competition car is a highly complex aerodynamic device. A car is always in close proximity to the ground meaning, the process for controlling air flow is complicated, and makes understanding what's going on difficult without the correct analysis tools (S.Mcbeath, 2006). The study of aerodynamic components for a race car demands that the performance gains must be significantly noticeable before the changes can be implemented (J.Bradford, et al. 2014). A race car's aerodynamics is subject to a number of variables, which introduce different types of aerodynamic performance characteristics that can affect a car's handling. These variables can include variables such as wing pitch, and ride height to name a few. (J.Bradford, et al. 2014). These variables will be extensively tested and analysed in this report. Studying the effect of the variation in the parameters that can affect the aerodynamic characteristics of the car, and how these variables can be altered to achieve a faster lap time, and a more aerodynamically stable vehicle.

2.0 Literature Review:

2.1- Aerodynamic Characteristics:

Lift and drag coefficients are relative measures of how much lift and drag a particular shape generates as stated by (S.Mcbeath, 2006). Each of these variables affect the cars handling regarding downforce.

Downforce is made up of two main factors; friction and grip. The coefficient of drag is governed by the nature of the vehicle, and the surface it rests upon (S.Mcbeath, 2006). From these factors its possible for a car to create substantial vertical forces to push the contact patch of the tyre into the ground using its passage through the air. These forces add or subtract from the vehicle weight, thus altering the frictional force that the cars tyres can generate, producing levels of grip. If the cars aerodynamic features generates positive lift, then the maximum frictional forces that can be generated are reduced, whereas if the cars design generates downforce, the maximum frictional forces are increased in correspondence (J.Bertin, 2009).

A car that generates downforce can accelerate, brake and corner with greater force than a car with no downforce or one that generates positive lift. This means a vehicle with a design that greats enough down force can offer greater performance regarding lap times and handling. Having said this nothing comes for free, there are inherent drag penalties due to the drag generated. This means there l a trade-off between the gains and the losses that occur This is referred to as a net benefit analysis. Adapted from (S.Mcbeath, 2006).

3.0 Methodology:

3.1- Coast Down Test:

To establish results for the cars aerodynamics regarding Coefficient of Lift and Drag, a straight-line coast down test can be utilised. The coast down test can be carried out using different Aerodynamic setups in relation to the vehicle's front splitter and the rear wing angles. For the testing of the Formula 3 car, the splitter and wing has varying degrees of adjustment.

Once the setups are established the car is sent out to carry out the test. The test consists of the driver driving up to the start line of the straight and proceeding to come to a complete stop. This will allow for the static tyre loads and ride height to be collected. Once the driver has stopped for a minimum of 5 seconds, the driver is to then accelerate up to the maximum speed of the car in 5th gear. The driver is to then hold the max speed for a minimum of 5 seconds to allow for the constant velocity tyre loads and ride height to be recorded.

The next step is critical to allow for the coefficient of lift and drag to be calculated, and the rolling resistance at the lower speeds. The driver should put the vehicle into neutral, and When carrying out the coast down, to keep accuracy at its highest; keep steering inputs to a minimum and their foot away from Accelerator pedal and the brake pedal. If safety is compromised, correct the car accordingly and reset the test if there is enough space left to do so.

The data from each run should be named and saved in a suitable location for future analysis.

3.1.1- Coast down test setup table:

Setup	Front Aero	Rear Aero
1) A Stint 2	Min 1	Min 1
2) B Stint 3	Min 1	Mid 9
3) C Stint 4	Min 1	Max 18
4) D Stint 5	Mid 9	Min 1
5) E Stint 6	Mid 9	Mid 9
6) F Stint 7	Mid 9	Max 18
7) G Stint 8	Max 18	Min 1
8) H Stint 9	Max 18	Mid 9
9) I Stint 10	Max 18	Max 18

Table 1: Session 1 Coast Down Test Aerodynamic Setups (Daniel Salathiel, 2019).

3.2- Pembrey Circuit Testing:

For the circuit test session Pembrey was selected for its limited change in elevation and average lap times for the Formula 3 car being tested. The elevation was a key point due to changes in gradient over crests would cause false readings in the data.

Five minutes are allocated for each aerodynamic setup, based on an average lap time of 57 seconds. This meant that each setup had been allocated a total of 5 minutes, meaning all the setups can be tested sufficiently within the hour time slot. Along side the lap time considerations, 2 minutes was allocated for setup changes and adjustments between each 5 lap session.

Six determined setups were chosen based on previous cost down data for a set list of setups to test, with a further five setups if time permitted. Each of which can be seen in table 2, in section 3.2.1 below.

3.2.1 Circuit Testing Aerodynamic setup table:

Setup	Front Aero	Rear Aero
10) A 1A	Min 1	Min 1
11) B 2A	Mid 9	Mid 9
12) C 3A	Max 18	Max 18
13) D Handful 4A	Max 18	Min 1
14) E 5A	Min 1	Max 18
15) F Best Compromise 6A	Max 18	Mid 9
16) G Added Lap 7A	Min 1	Mid 9
17) H Added Lap 8A	Mid 9	Min 1
18) I Added Lap 9A	Mid 9	Max 18
19) J Min Ride Height 10A	Max 18	Max 18
20) K Max Ride Height 11A	Max 18	Max 18

Table 2: Pembrey Circuit Aerodynamic Setup Table, (Daniel Salathiel, 2019).

4.1 Coast down data:

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD	BE	BF	BG	BH	BI	BJ	BK	BL	BM	BN	BO	BP	BQ	BR	BS	BT	BU	BV	BW	BX	BY	BZ	CA	CB	CC	CD	CE	CF	CG	CH	CI	CJ	CK	CL	CM	CN	CO	CP	CQ	CR	CS	CT	CU	CV	CW	CX	CY	CZ	DA	DB	DC	DD	DE	DF	DG	DH	DI	DJ	DK	DL	DM	DN	DO	DP	DQ	DR	DS	DT	DU	DV	DW	DX	DY	DZ	EA	EB	EC	ED	EE	EF	EG	EH	EI	EJ	EK	EL	EM	EN	EO	EP	EQ	ER	ES	ET	EU	EV	EW	EX	EY	EZ	FA	FB	FC	FD	FE	FF	FG	FH	FI	FJ	FK	FL	FM	FN	FO	FP	FQ	FR	FS	FT	FU	FV	FW	FX	FY	FZ	GA	GB	GC	GD	GE	GF	GG	GH	GI	GJ	GK	GL	GM	GN	GO	GP	GQ	GR	GS	GT	GU	GV	GW	GX	GY	GZ	HA	HB	HC	HD	HE	HF	HG	HH	HI	HJ	HK	HL	HM	HN	HO	HP	HQ	HR	HS	HT	HU	HV	HW	HX	HY	HZ	IA	IB	IC	ID	IE	IF	IG	IH	II	IJ	IK	IL	IM	IN	IO	IP	IQ	IR	IS	IT	IU	IV	IW	IX	IY	IZ	JA	JB	JC	JD	JE	JF	JG	JH	JI	JJ	JK	JL	JM	JN	JO	JP	JQ	JR	JS	JT	JU	JV	JW	JX	JY	JZ	KA	KB	KC	KD	KE	KF	KG	KH	KI	KJ	KK	KL	KM	KN	KO	KP	KQ	KR	KS	KT	KU	KV	KW	KX	KY	KZ	LA	LB	LC	LD	LE	LF	LG	LH	LI	LJ	LK	LL	LM	LN	LO	LP	LQ	LR	LS	LT	LU	LV	LW	LX	LY	LZ	MA	MB	MC	MD	ME	MF	MG	MH	MI	MJ	MK	ML	MM	MN	MO	MP	MQ	MR	MS	MT	MU	MV	MW	MX	MY	MZ	NA	NB	NC	ND	NE	NF	NG	NH	NI	NJ	NK	NL	NM	NN	NO	NP	NQ	NR	NS	NT	NU	NV	NW	NX	NY	NZ	OA	OB	OC	OD	OE	OF	OG	OH	OI	OJ	OK	OL	OM	ON	OO	OP	OQ	OR	OS	OT	OU	OV	OW	OX	OY	OZ	PA	PB	PC	PD	PE	PF	PG	PH	PI	PJ	PK	PL	PM	PN	PO	PP	PQ	PR	PS	PT	PU	PV	PW	PX	PY	PZ	QA	QB	QC	QD	QE	QF	QG	QH	QI	QJ	QK	QL	QM	QN	QO	QP	QR	QS	QT	QU	QV	QW	QX	QY	QZ	RA	RB	RC	RD	RE	RF	RG	RH	RI	RJ	RK	RL	RM	RN	RO	RP	RQ	RR	RS	RT	RU	RV	RW	RX	RY	RZ	SA	SB	SC	SD	SE	SF	SG	SH	SI	SJ	SK	SL	SM	SN	SO	SP	SQ	SR	SS	ST	SU	SV	SW	SX	SY	SZ	TA	TB	TC	TD	TE	TF	TG	TH	TI	TJ	TK	TL	TM	TN	TO	TP	TQ	TR	TS	TT	TU	TV	TW	TX	TY	TZ	UA	UB	UC	UD	UE	UF	UG	UH	UI	UJ	UK	UL	UM	UN	UO	UP	UQ	UR	US	UT	UU	UV	UW	UX	UY	UZ	VA	VB	VC	VD	VE	VF	VG	VH	VI	VJ	VK	VL	VM	VN	VO	VP	VQ	VR	VS	VT	VU	VV	VW	VX	VY	VZ	WA	WB	WC	WD	WE	WF	WG	WH	WI	WJ	WK	WL	WM	WN	WO	WP	WQ	WR	WS	WT	WU	WV	WW	WX	WY	WZ	XA	XB	XC	XD	XE	XF	XG	XH	XI	XJ	XK	XL	XM	XN	XO	XP	XQ	XR	XS	XT	XU	XV	XW	XX	XY	XZ	YA	YB	YC	YD	YE	YF	YG	YH	YI	YJ	YK	YL	YM	YN	YO	YP	YQ	YR	YS	YT	YU	YV	YW	YX	YZ	ZA	ZB	ZC	ZD	
	State/Loc										State/Ride Height										Constant Velocity/Loc										Constant Velocity/Ride Height										Aero Loads & Balance										Aero Lift/Coefficient										Countdown Data										Drag/Factor																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																
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The data collected from the coast down test was processed using an Excel Spread sheet seen in the

Figure 1: Coast down data collection, Excel. (Daniel Salathiel, 2019).

The figure above shows, both the tyre loads, and ride heights were collected for static and constant velocity. The rate of deceleration was also calculated. From these data sets the coefficient of lift (CL) and the coefficient of drag (CD) could be calculated for each aerodynamic setup.

This data can be used to create an excel setup sheet for the Motec data analysis software. The coefficient of drag can be inserted into the maths channels to allow different variables to be analysed for each aerodynamic setup, to analyse the performance of each when doing a lap of a chosen circuit.

4.1.1 Excel Colour grading chart for each setup:

For each setup a colour coded chart was created for the coefficient of drag and the coefficient of lift. These can be used to select the most likely setup to perform the best around the circuit testing in a theoretical manner. From the charts seen below in figure 2 and 3, the setup that balanced the greatest compromise between drag and lift values is 18 front, and 9 rear aerodynamic settings.

Aero Drag	1	9	18
1	-666.20	-710.06	-880.94
9	-730.51	-1176.36	-1000.80
18	-1030.67	-1000.80	-973.71

Figure 2: Aerodynamic Drag grading chart, (Daniel Salathiel, 2019).

Cl	1.00	9.00	18.00
1	-2.94	-3.21	-3.52
9	-3.23	-3.40	-3.71
18	-3.34	-3.61	-3.92

Figure 3: Aerodynamic Drag grading chart, (Daniel Salathiel, 2019).

4.2 Bench mark setup for comparison:

The setup that's going to be used for comparison, is the setup that provided the quickest lap time around the circuit. In this report, the front aerodynamic setting of 18 and the rear aerodynamic setting of 18 provided the quickest lap time. This was due to the setup providing the greatest total aerodynamic force of 9425 Newtons, and a stable platform that provided the most preferred handling characteristics. These points will be further analysed alongside the relevant figures below.

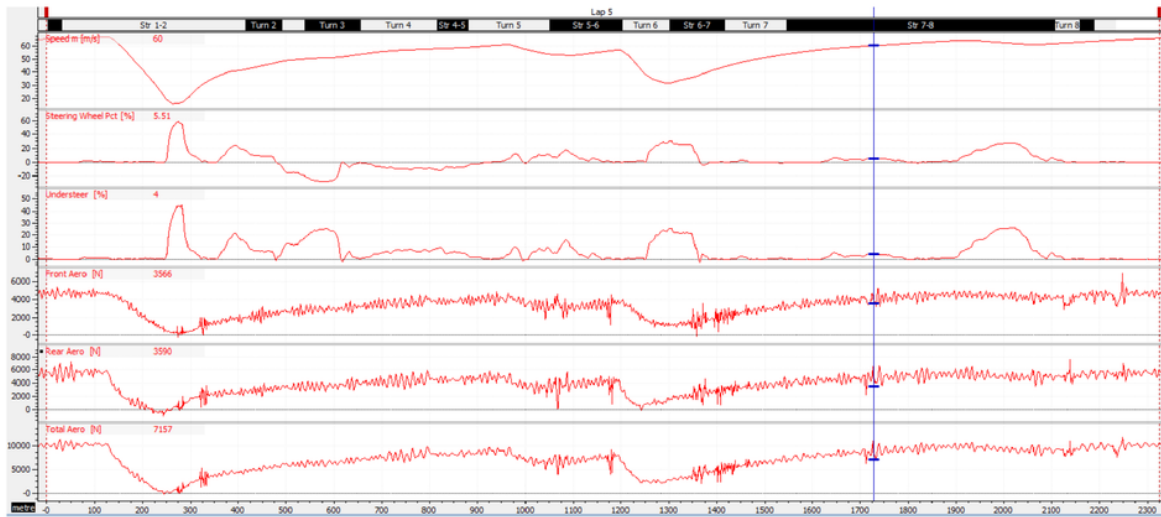


Figure 4: Setup 18_18 Data trace fastest lap, (Daniel Salathiel, 2019).

The data from the Motec software provides a benchmark for comparison for the other setups, the datum can be used to show where the slower setups lose time when directly compared with the fastest data. For this setup the data shows that the car provides a stable aerodynamic package, while generating the greatest amount of aerodynamic force. Both these factors can be seen in figure 5 and 6 below. The centre of pressure shows a confined result around the centre of the car, favouring a more rearward position due to the rear wing generating greater force than the front. As supported by (B. Hai-Toa, 2011). This can be seen in the front aerodynamic force graph in the appendices, appendix 14.

4.2.1: Bench Mark comparison of the three main setups:

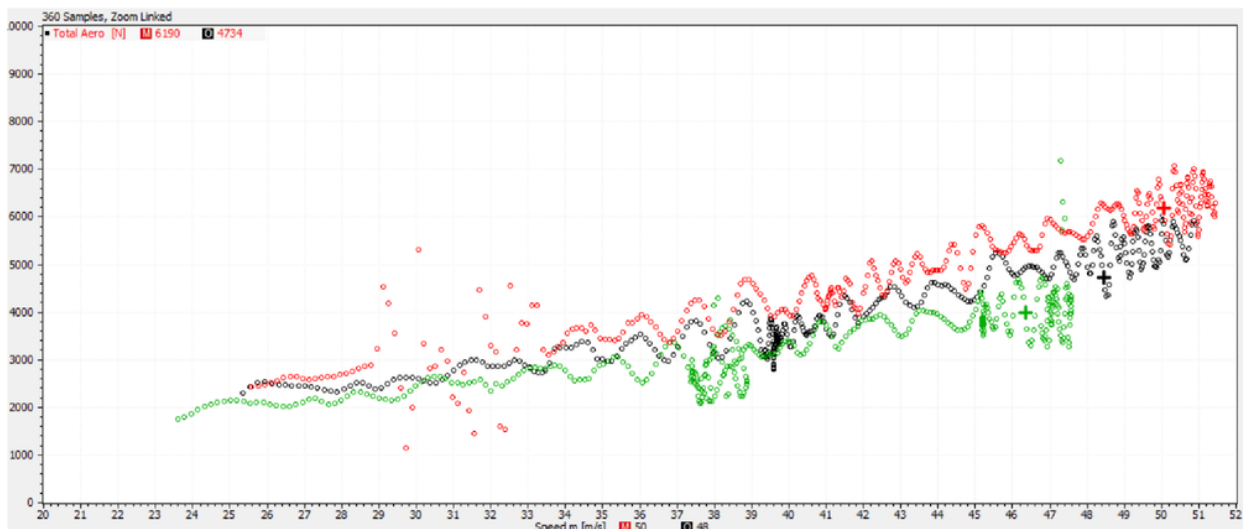


Figure 5: Overlay comparison of the three main setups, (Daniel Salathiel, 2019).

The figure above shows the three main setup total forces, each of these will be analysed individual in this report. The forces above show a brief outlook of how each setup functioned during the laps. The red trace is the 18_18 quickest lap, the black representing the 9_9 setup and the green representing the 1_1. The remaining setup graphs and maths channels to achieve them will be included in the appendices.

The data shows a direct positive correlation between speed, and the aerodynamic force produced by the car's wings, but also the direct relationship between the angle of the wings and the amount of force generated.

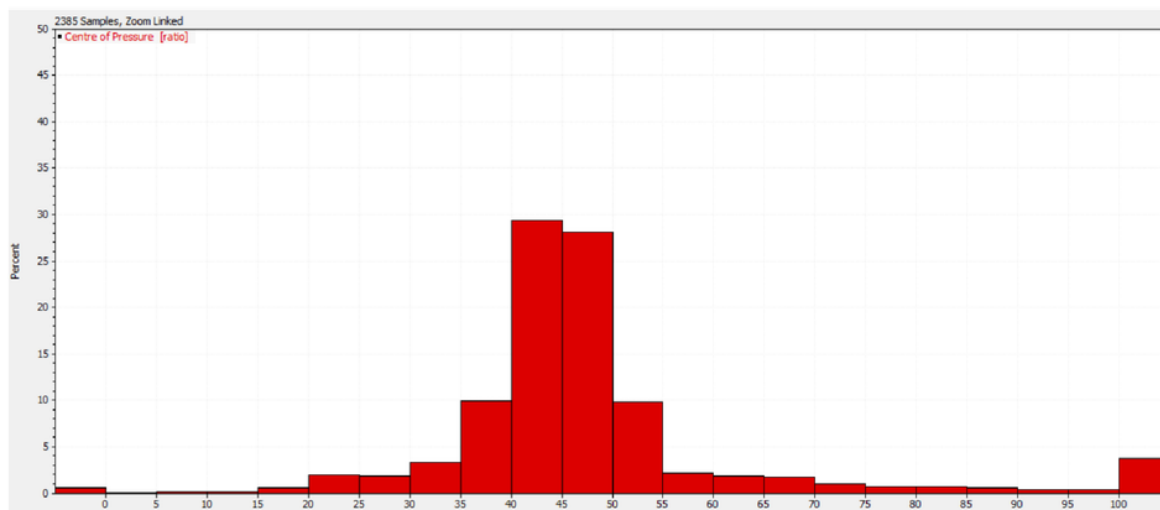


Figure 6: 18_18 Centre of Pressure Histogram, (Daniel Salathiel, 2019).

4.3 Setup 1 front and 1 rear data comparison:

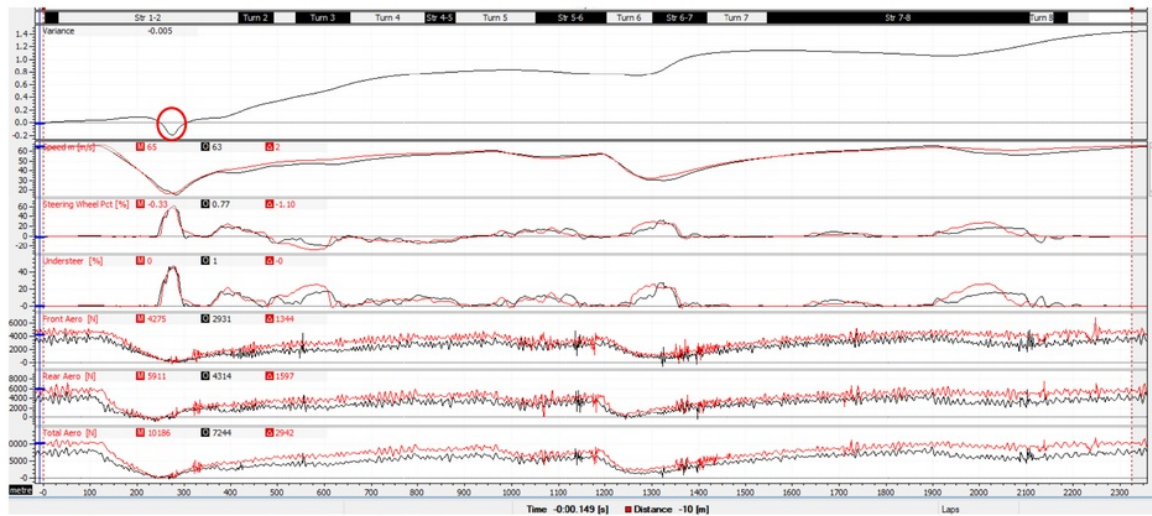


Figure 7: Setup 1_1 compared to fastest lap, (Daniel Salathiel, 2019).

The datum in the figure above shows how setup 1_1 compares to the fastest setup 18_18 in terms of time lost and gained at each section. The point highlighted by the circle shows where the setup gains time along the first straight. This can be attributed to the decreased drag displayed by the setup, allowing the car to accelerate quicker into the first corner. Along the straight this can be seen by in figure 7, showing a lower peak of total aerodynamic force, meaning decreased drag along the straight. If the car creates increased down force, the maximum frictional forces are correspondingly increased (S.Mcbeath, 2006).

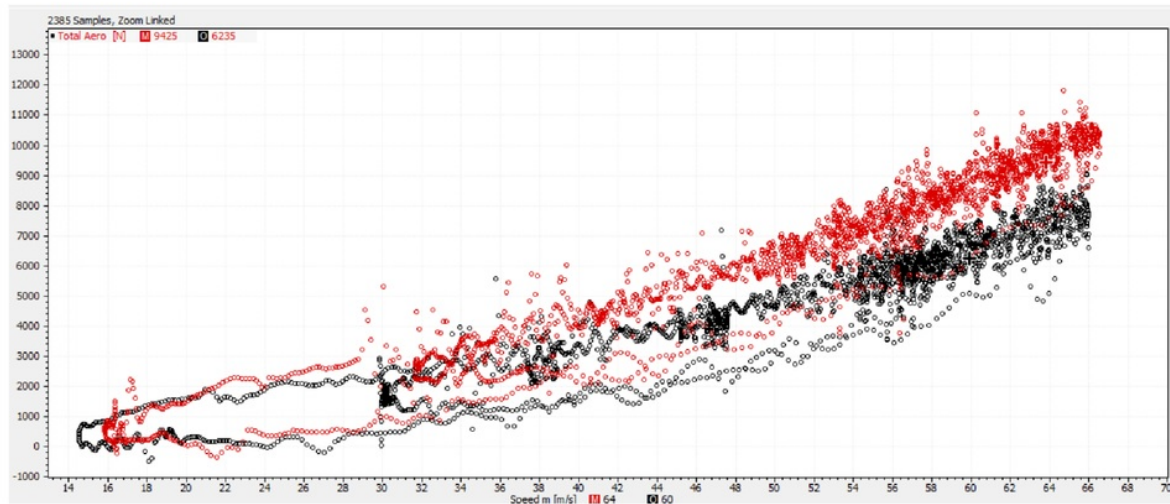


Figure 8: Aerodynamic Setup 1_1 Total Aero force (N), (Daniel Salathiel, 2019).

The peak force achieved by this setup is 6235N, this means it achieves 3190N less force than the higher 18_18 setup. This means that down the straight this provides an advantage due to decreased drag, but this time is lost throughout the rest of the lap due to lower cornering speeds being achieved. This can be seen in the data trace between turn 2 through to turn 5 on the datum plot. The lower total aerodynamic forces being experienced means there is decreased downforce, leading to a decrease in the ability for the driver to carry higher cornering speeds.

The decrease in aerodynamic force seen by the current setup means that less speed could be carried through the corners leading to time being lost due to the driver not being able to carry speed through the apex of the corner, losing 6 m/s through the corner and consequently leading to decreased exit speed and maximum speed reached along the following straight. This can be seen in the figure below highlighted by the red box.

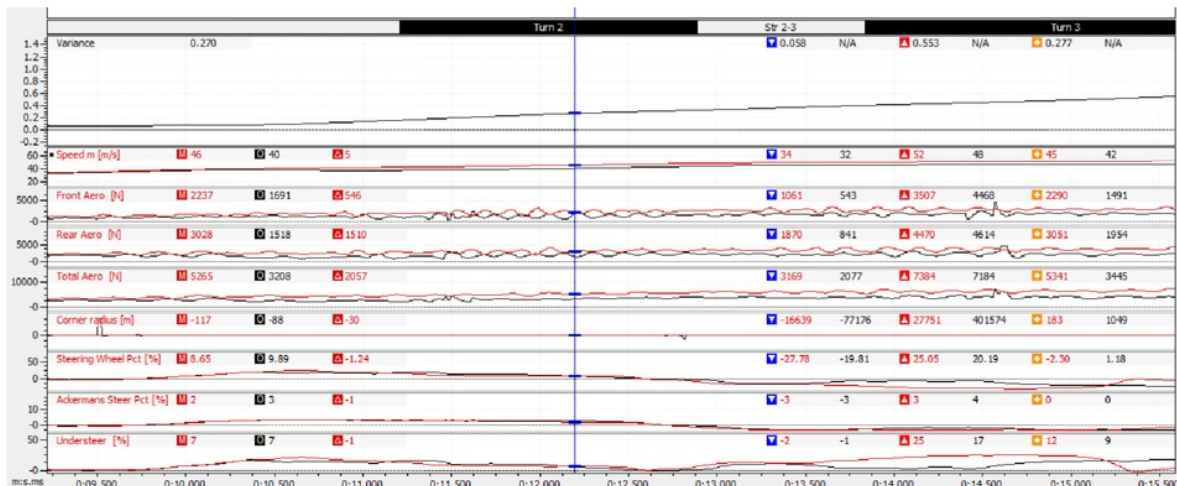


Figure 9: Turn 2 cornering speed comparison, (Daniel Salathiel, 2019).

The decrease in cornering speed seen in figure 7 can also be attributed to other factors that effect the cars handling performance. One such factor is the centre of pressure of the vehicle. The comparison for both setups can be seen in the figure below. The centre of pressure of the car for this setup can be seen to be more towards the rear of the car than the front but can be seen to be largest at 45%. The closer the centre of pressure is towards the centre of the car, the more stable the handling performance. The figure shows that the setup concentrated around the centre of the histogram, this shows that the setups change in centre of pressure is minimal providing predictable handling regarding understeer and oversteer.

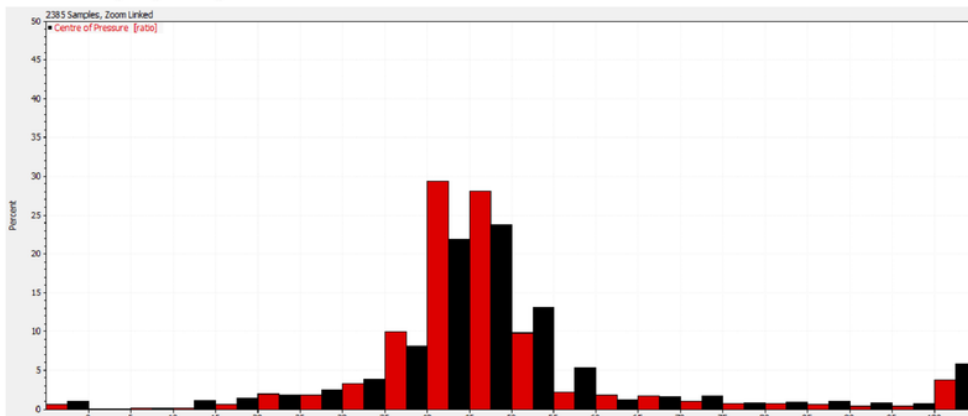


Figure 10: Setup 1_1 Centre of Pressure Histogram, (Daniel Salathiel, 2019).

4.4- Setup 9 front and 9 rear data comparison:

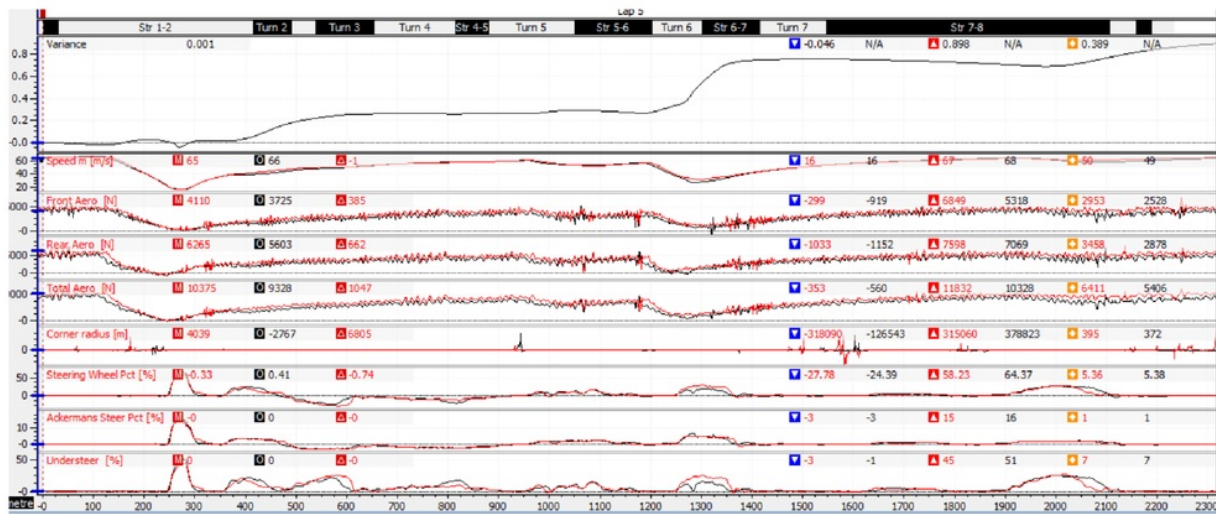


Figure 11: Setup 9_9 Lap data screen shot comparison, (Daniel Salathiel, 2019).

The figure above shows the data recorded for the 9 front and 9 rear aerodynamic setup. The lap time set for this setup was 0:46:596 seconds. This means this aerodynamic setup was 0.902 seconds slower than the quickest time set by the 18_18 setup.

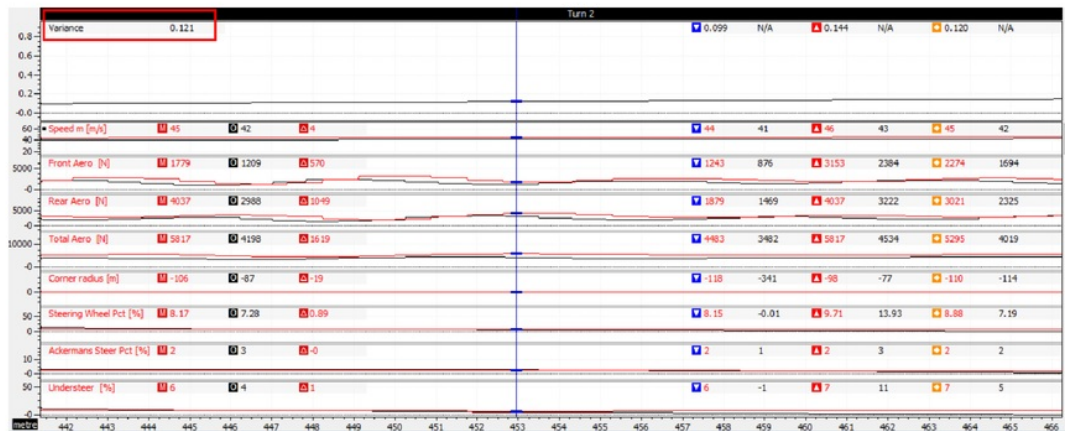


Figure 12: Setup 9_9 turn 2 data trace analysis, (Daniel Salathiel, 2019).

Time was lost through turn 2 shown in figure 10 above as shown by the datum highlighted. The setup lost 0.121 seconds through this corner due to the fastest setup gaining a speed advantage of 4 m/s cornering speed. The reason for the setup carrying less cornering speed was because of the decrease in total aerodynamic force being generated, this is due to the setup having decreased wing angle, meaning less downforce could be generated. The resulting loss in force meant 1049 newtons was lost in comparison to the faster setup, meaning less downforce was produced, thus less grip.

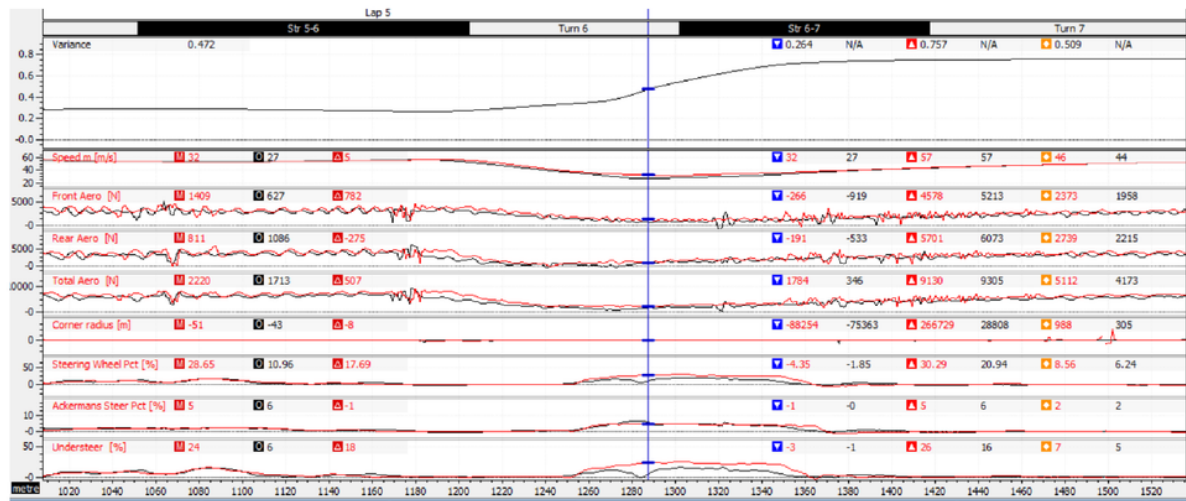


Figure 13: Setup 9_9 turn 6 data trace analysis, (Daniel Salathiel, 2019).

Further time loss can be seen through turn 6 displayed in figure 13 above. A loss of 0.621 can be seen by the end of the corner when compared to setup 18_18, and a further 0.110 seconds was lost due to the driver being able to carry 5 m/s more speed through the corner and accelerate a lot sooner when exiting the corner.

The downforce channel can be used to determine the speed loss through this corner. When compared to the faster lap, this setup generated 507N less aerodynamic force in total. This led to understeer occurring, as shown by the understeer channel in the figure above, and the steering percentage channel, where the driver can be seen to straighten out mid corner. This is a key indication of understeer. Further factors for understeer can be seen in section 4.3.1.

4.4.1 Weight transfer analysis:

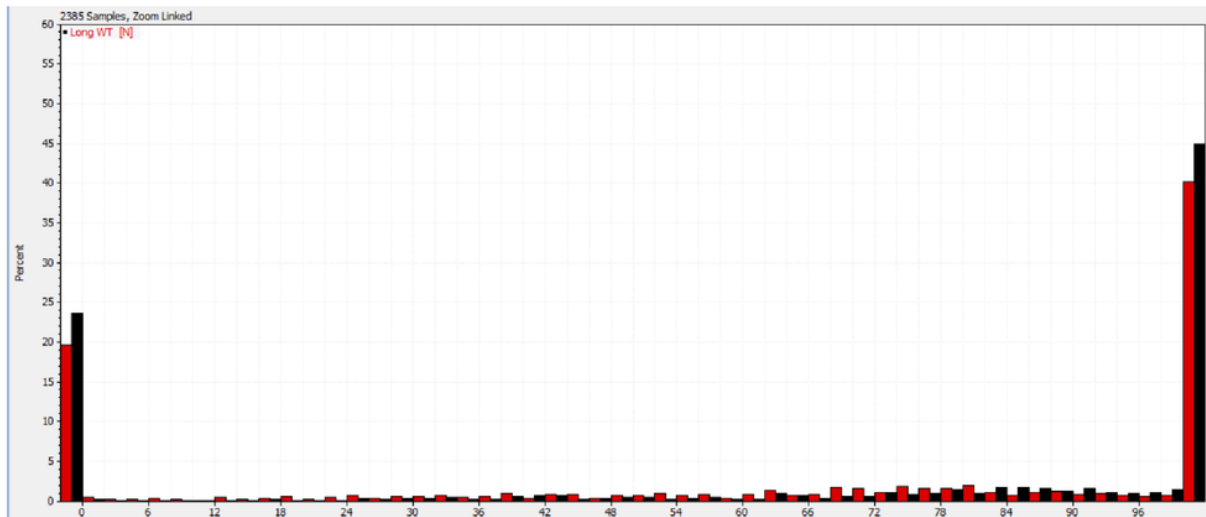


Figure 14: Longitudinal Weight Transfer Histogram setup 9_9, (Daniel Salathiel, 2019).

The longitudinal weight transfers for this setup can be seen to show a higher distribution to the rear of the car. The resulting effect on a cars handling performance if under heavy cornering loads is understeer as seen in the section above. Understeer results from a lack of traction at the front wheels. The levels of grip at the front wheels will be reduced due to the rear weight transfer. Adapted from (DrivingFast, 2019).

When compared with the faster setup, the weight transfer is greater. This means that the setup has reduced grip under weight transfer due to the lower levels of aerodynamic forces being produced, leading to the front wheels losing traction because of the reduced force pushing them into the ground, and the lifting effect of the greater weight transfer to the rear of the car.

4.5- Setup 18 front and 9 rear data comparison:

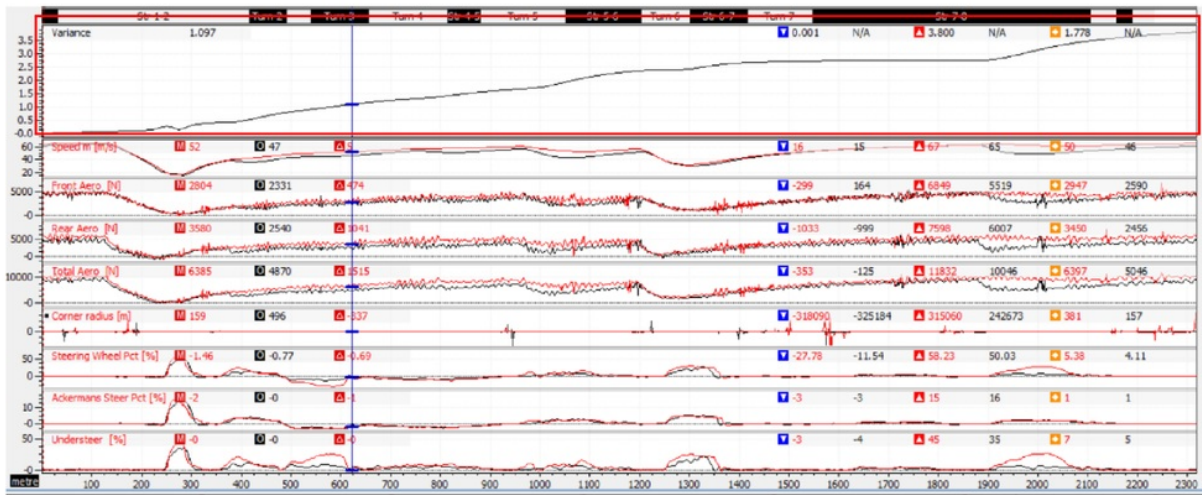


Figure 15: Setup 18_9 Motec data analysis screenshot, (Daniel Salathiel, 2019).

Over all this setup in comparison to the quickest time lost 3.5 seconds over the duration of the lap. To see why this setup was slower, the different factors such as aerodynamic force, weight transfer and centre of pressure will be analysed. The cornering performance can be seen to be decreased when compared to the quickest setup, as shown by the datum line highlighted above.

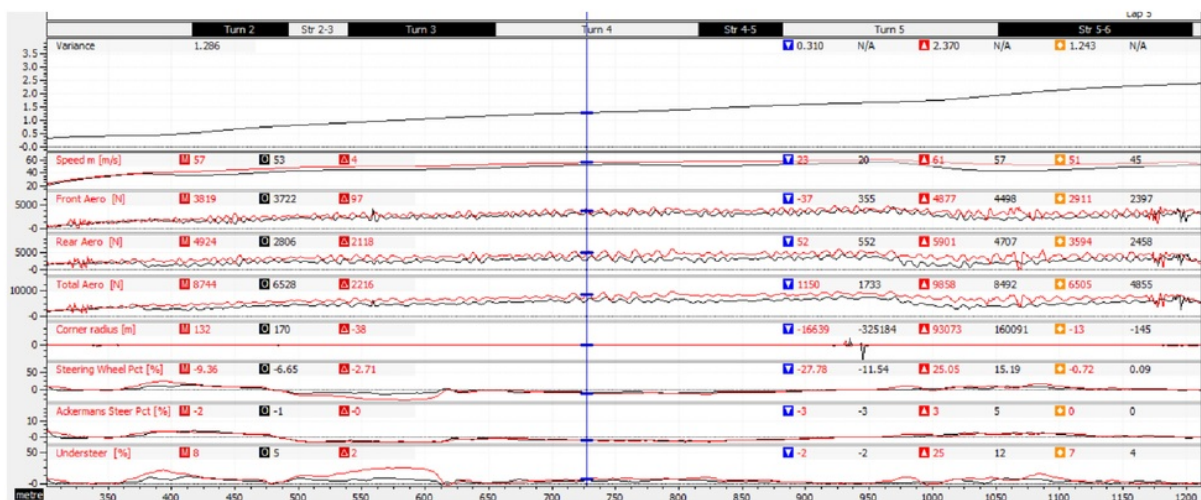


Figure 16: Turn 2- turn 5 data analysis setup 18_9, (Daniel Salathiel, 2019).

This setup was on average 5 m/s slower through turns 2 to 5. By turn 4, 1.283 seconds was lost due to the decrease in cornering speed being carried when compared to the 18_18 setup. The 18_9 setup was selected due to it showing the best compromise between the coefficient of Drag and the coefficient of lift. This can be seen in section 4.1.1 of this report, figures 2 and 3.

The setup generated a total of 6528 newtons of aerodynamic force, 2216 newtons less than the quickest setup. This is due to the rear only generating 2118N of force due to the decreased wing angle. This will be further analysed in the next section, highlighting the handling characteristics that result from this data.

4.5.1- 18_9 Rear Aerodynamic and weight transfer analysis:

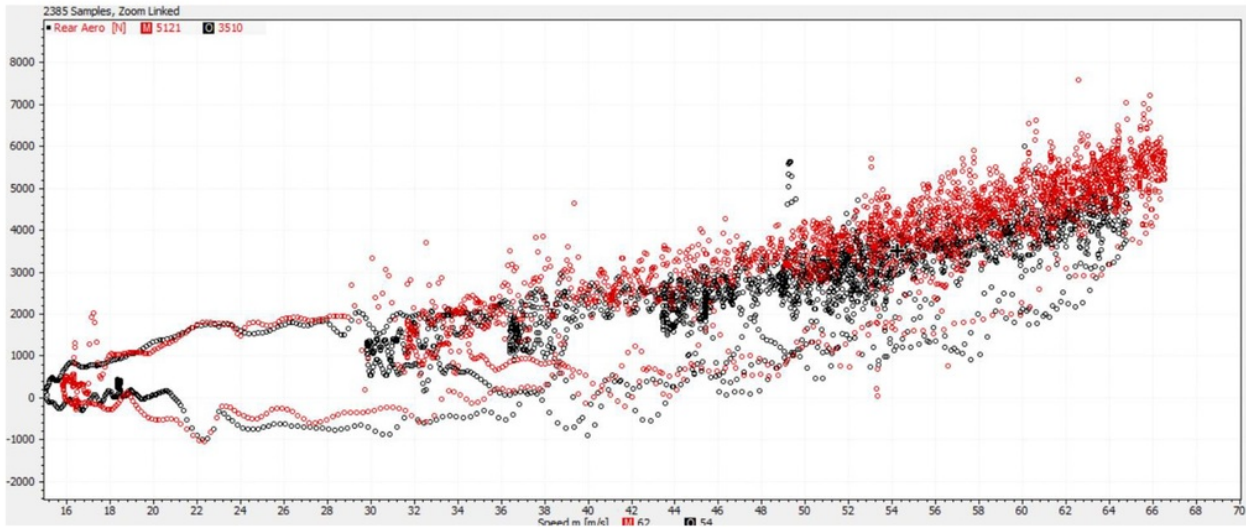


Figure 17: Setup 18_9 Rear Aerodynamic Force Scatter Graph Analysis, (Daniel Salathiel, 2019).

The rear can be seen to generate less aerodynamic force than the quicker, higher angled wing of the 18_18 faster setup. The rear wing for this setup generates 1611N less force, resulting in the rear of the car generating less grip than the front in comparison seen in figure 16 below due to the centre of pressure moving towards the front of the car resulting in reduced grip at the rear tyres. When the rear of the car has reduced grip in comparison to the front wheels, the resulting performance characteristic is oversteering. (Drivefast, 2019).

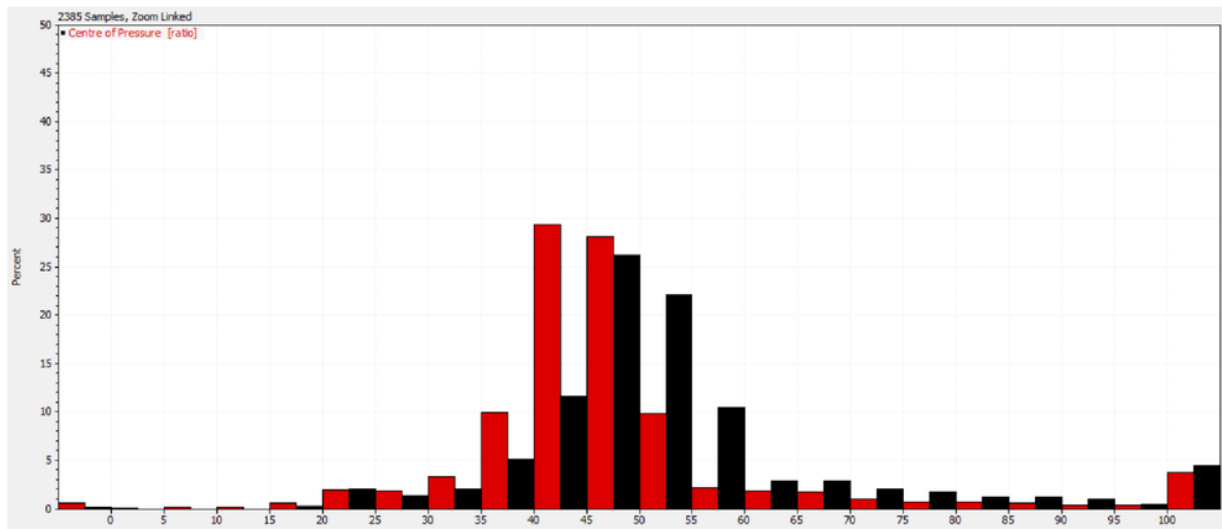


Figure 18: 18_9 Centre of Pressure histogram analysis, (Daniel Salathiel, 2019).

The centre of pressure seen in the figure above when compared to the 18_18 setup can be seen to be more forwards, shown by the data forwards of the 50% marker. The resulting effect of the centre of pressure being more towards the front of the car with reduced aerodynamic force at the rear, is oversteer as previously discussed. The results shown in the histogram above were to be expected, due to the higher aerodynamic setting at the front, leading to higher forces being generated at the front of the car, causing the centre of pressure to shift forward. In comparison to the 18_18 setting in red, where the centre of pressure can be seen to be more balanced around the centre point, and favouring the rear due to the lower percentages shown in the figure.

5.0 Conclusion:

The quickest lap time was set with the setup utilising the 18 front wing position, and the 18 rear wing position. This setup suited the track due to it balanced handling characteristics regarding and shown by the centre of pressure and weight transfer graphs when analysed.

It also allowed the driver to carry more cornering speed through the corners due to the setup providing and generating a much higher total aerodynamic force when compared to the other setups tested. On a track with larger straights, the setup may lose time along the duration of a lap when compared to the other setups analysed. The key attribute of this setup though is the stability and force produced by the wings when set to their maximum position. Thus, allowing the driver to carry greater speed through the corner, which means the car can accelerate a lot sooner due to the forces being generated increasing grip. This means the setup produces a predictable aerodynamic handling package, increasing the handling and performance of the F3 car throughout the duration of the laps around the circuit.

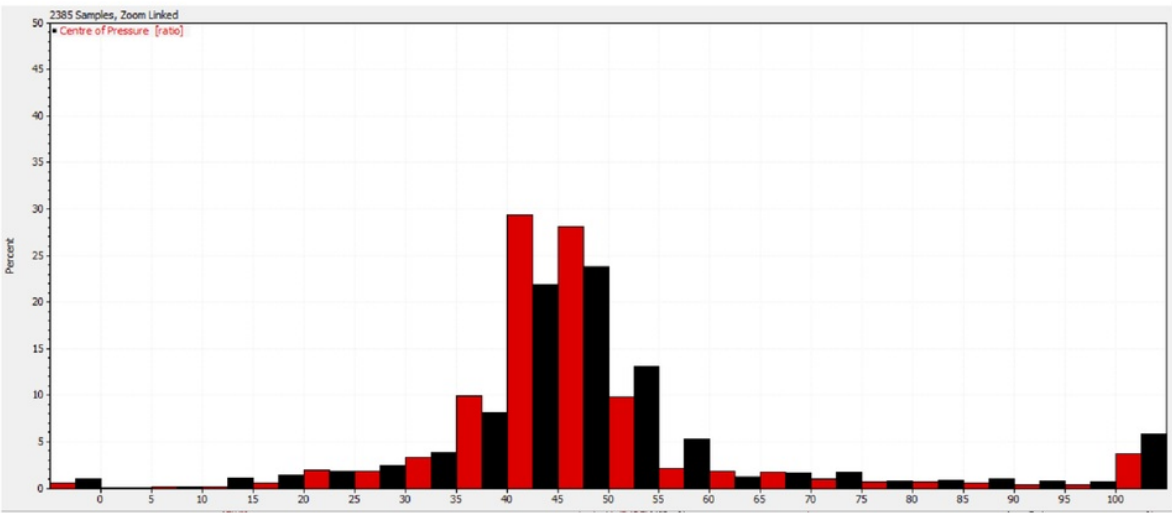
6.0 Appendices

Appendix 1- Motec Maths Channels:

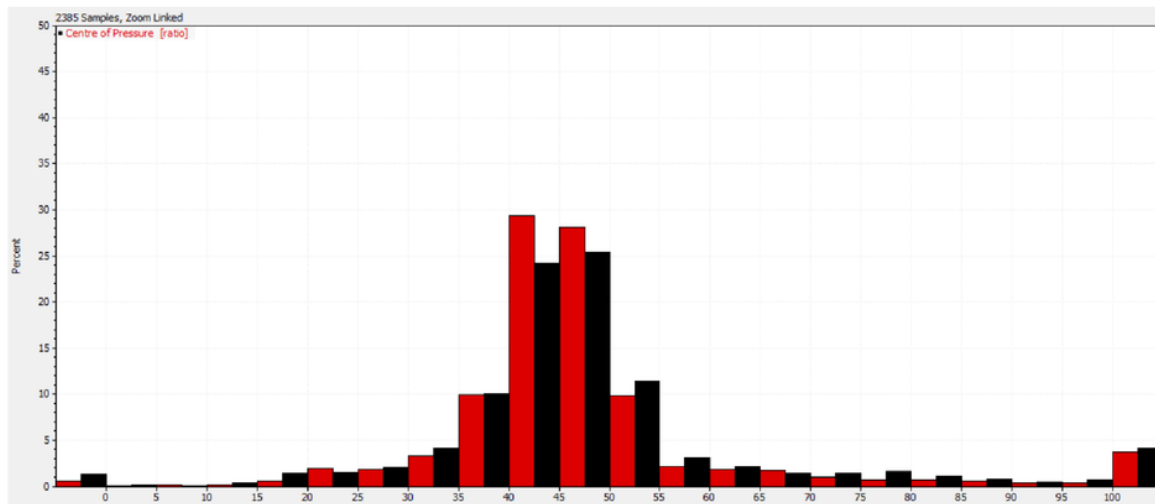
Name	Summary	
Expressions		
☒ Long WT [N]	(Mass' [kg])*G Force Long' [G]*G' [m/s/s]*-1*cog' [m]/wheel base' [m]	Add Expression...
☒ Front Aero [N]	(Tire Load - FL' [N]+Tire Load - FR' [N])-(FL' [N]+FR' [N])*Long WT' [N]	Add Scale/Offset...
☒ Speed m [m/s]	Corr Speed' [km/h]*1000/(60*60)	Add Filter...
☒ Front Aero [N]	(Tire Load - FL' [N]+Tire Load - FR' [N])-(FR0' [N]+FL0' [N])*Long WT' [N]	Add Plugin...
☒ Rear Aero [N]	(Tire Load - RL' [N]+Tire Load - RR' [N])-(RL0' [N]+RR0' [N])*Long WT' [N]	Add 2D Table...
☒ Total Aero [N]	(Front Aero' [N]+Rear Aero' [N])	Add 3D Table...
☒ Centre of Pressure [ratio]	(Front Aero' [N]/Total Aero' [N])*100	Add Constant...
☒ Aero Drag Force [N]	(0.5*Air Density' [kg/m3]*Cd*1.2*(Speed m' [m/s]*Speed m' [m/s]))	Delete
☒ Corner radius [m]	(Speed m' [m/s]*Speed m' [m/s])/(G' [m/s/s]*G Force Lat' [G])	Edit...
☒ Ackemans angle [rad]	(wheel base' [m]/Corner radius' [m])*-1	Move Up
☒ Ackemans Steer Pct [%]	(Ackemans angle' [rad])*(10.80/0.1208)	Move Down
☒ Understeer [%]	abs(Steering Wheel Pct' [%])-abs(Ackemans Steer Pct' [%])	
Constants		
☒ Air Density [kg/m³]	1.223	
☒ cog [m]	0.23	
☒ FL0 [N]	1161	
☒ FR0 [N]	1165	
☒ G [m/s²]	9.81	
☒ Mass [kg]	560	
☒ RL0 [N]	1582	
☒ RR0 [N]	1578	
☒ wheel base [m]	2.73	

(Daniel Salathiel, 2019).

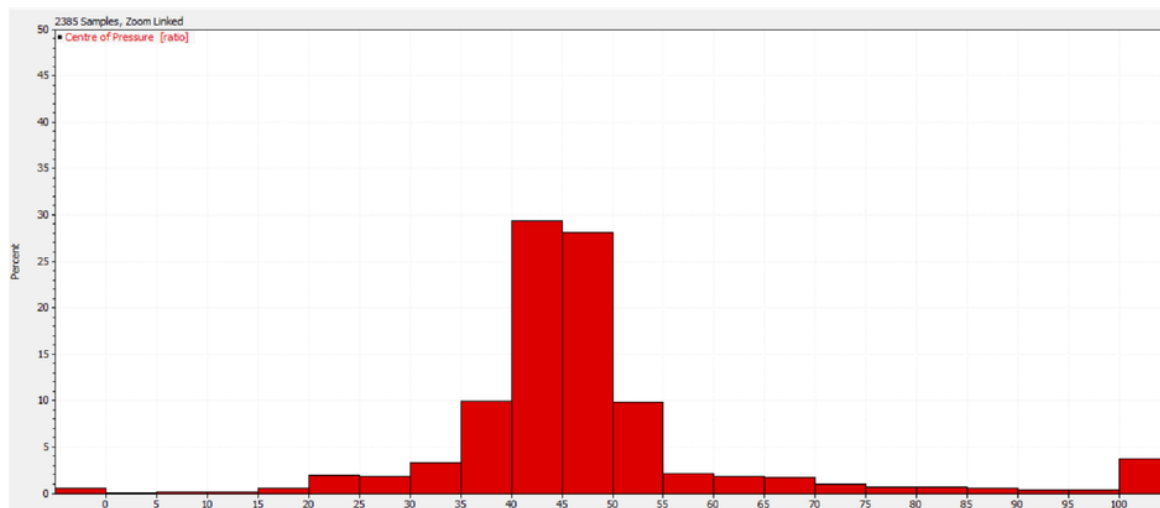
Appendix 2 Centre of Pressure Screen shots 1 1 setup:



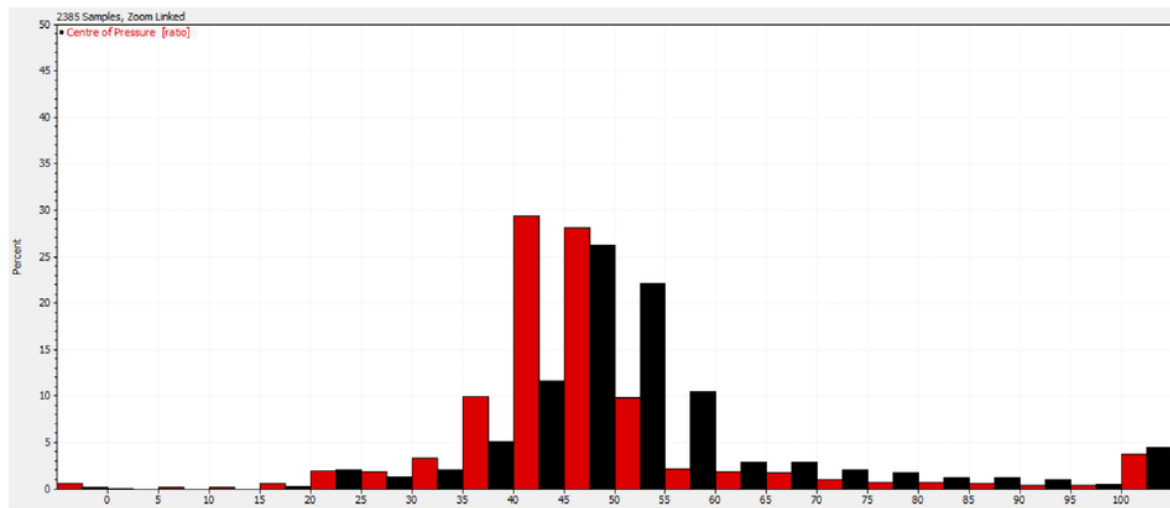
Appendix 3 Centre of Pressure Screen shots 9_9 Setup:



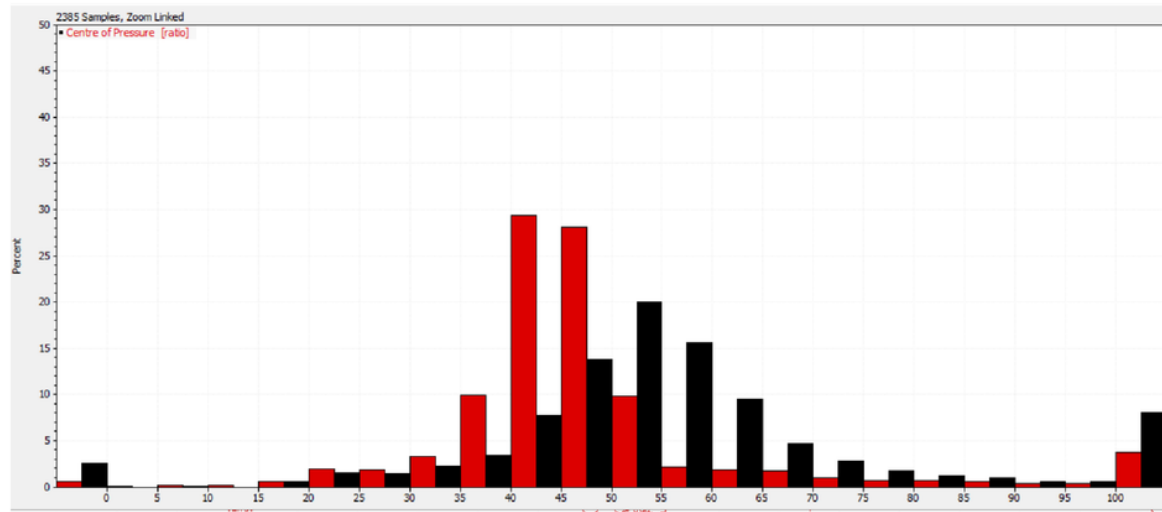
Appendix 4 Centre of Pressure Screen shots 18_18:



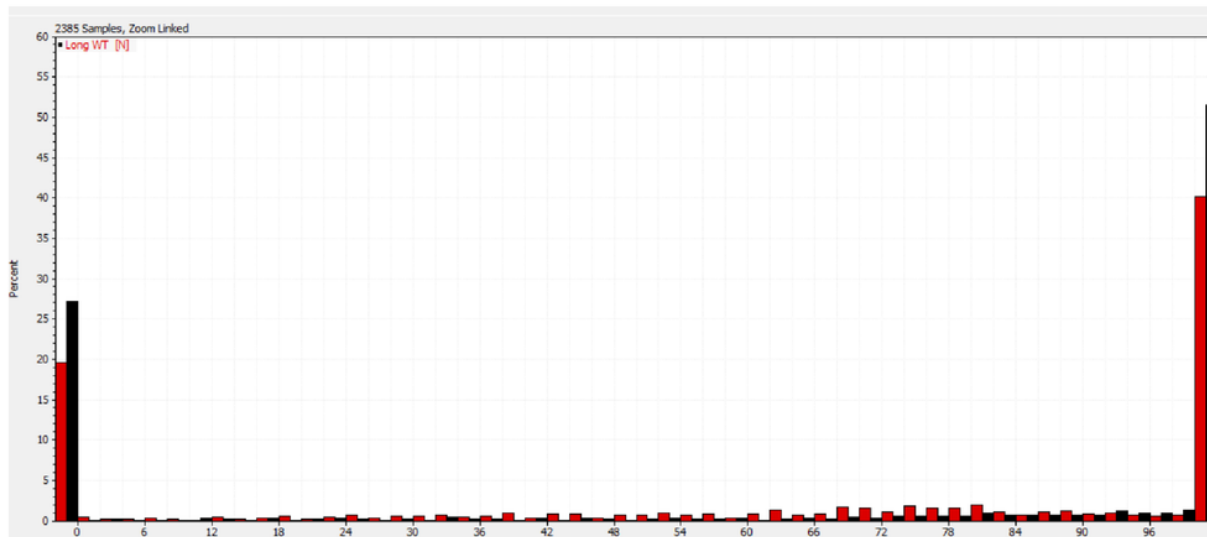
Appendix 5 Centre of Pressure Screen shots 18_9



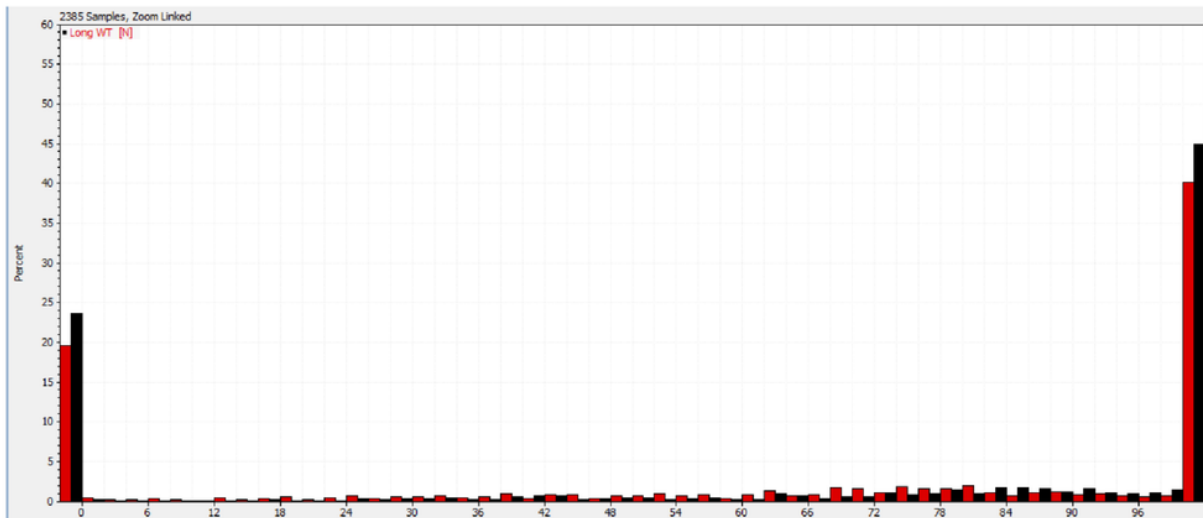
Appendix 6 Centre of Pressure Screen shots 18 1:



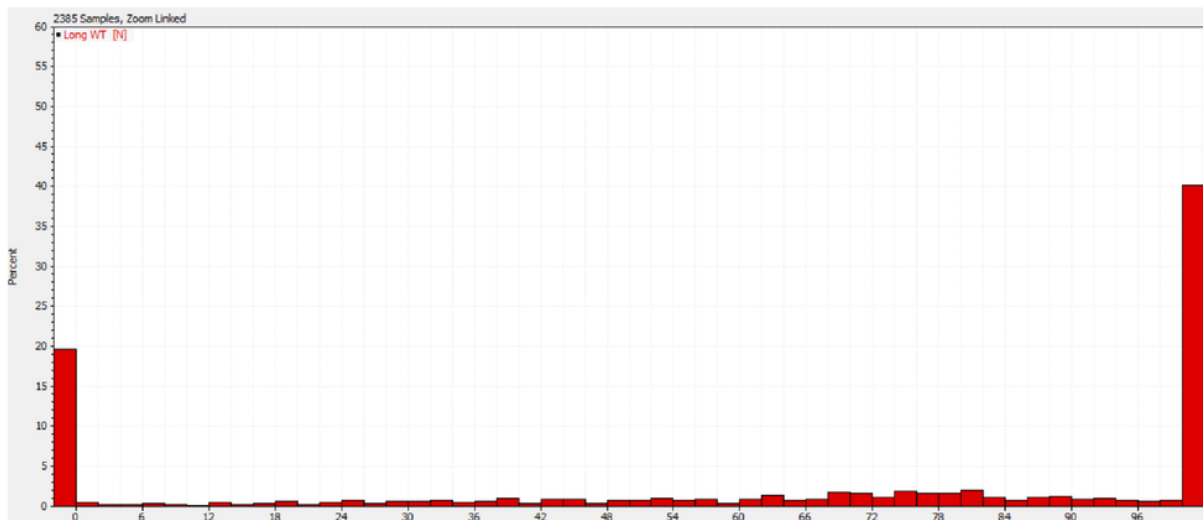
Appendix 7 Longitudinal weight transfer Screen shots 1 1 setup:



Appendix 8 Longitudinal weight transfer Screen shots 9_9 setup:



Appendix 9 Longitudinal weight transfer Screen shots 18_18 Setup:



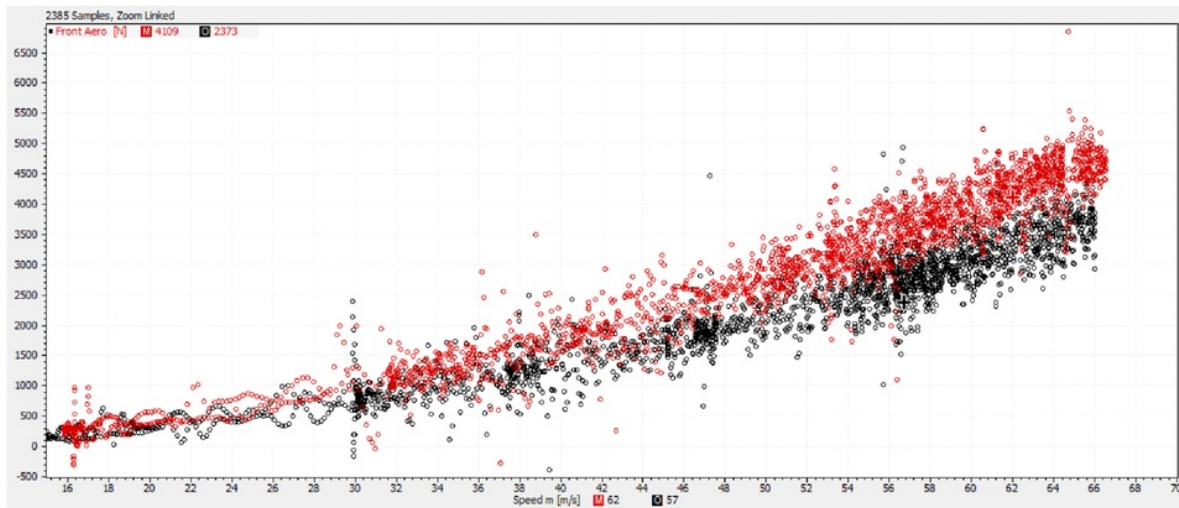
Appendix 10 Longitudinal weight transfer Screen shots 18 1 Setup:



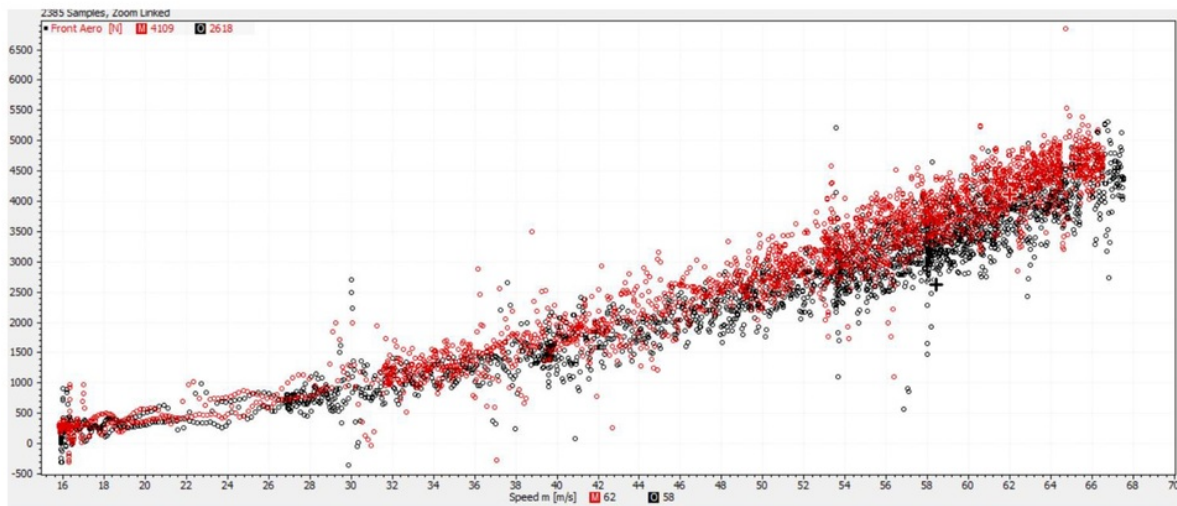
Appendix 11 Longitudinal weight transfer Screen shots 18 9 setup:



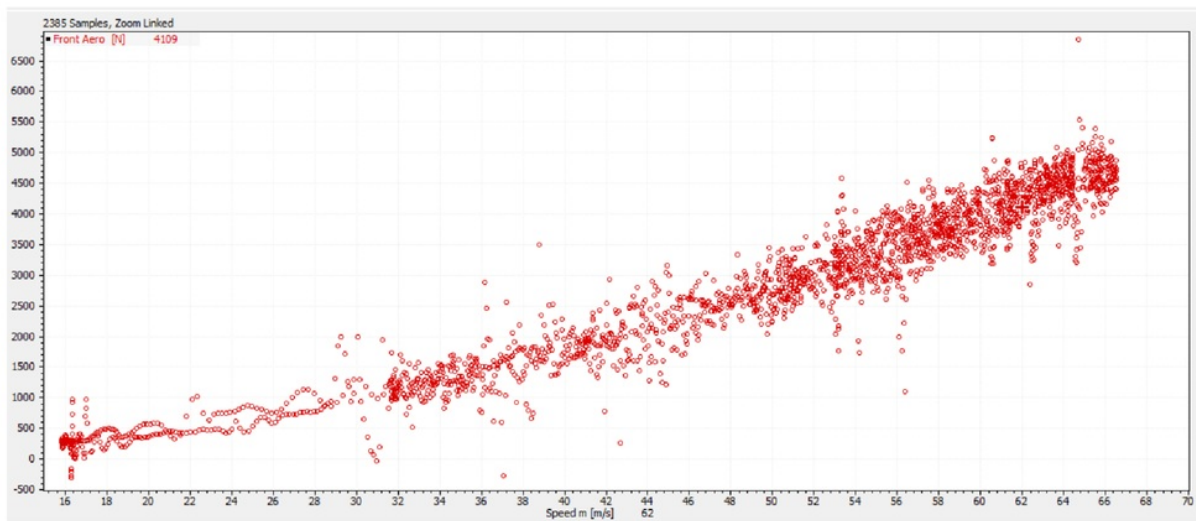
Appendix 12 Front Aerodynamic force graph Screen shots 1 1 Setup:



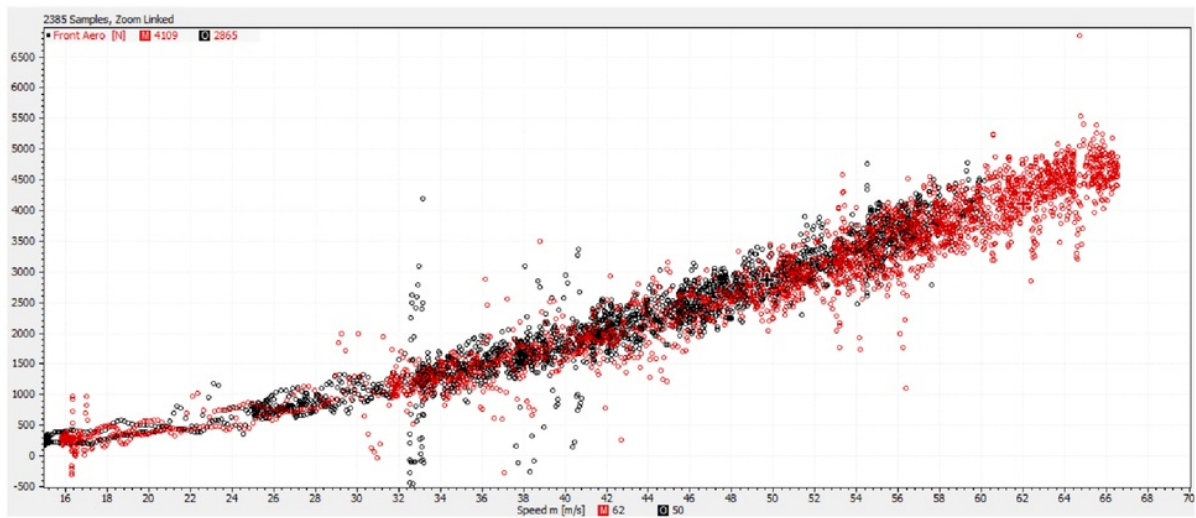
Appendix 13 Front Aerodynamic force graph Screen shots 9 9 Setup:



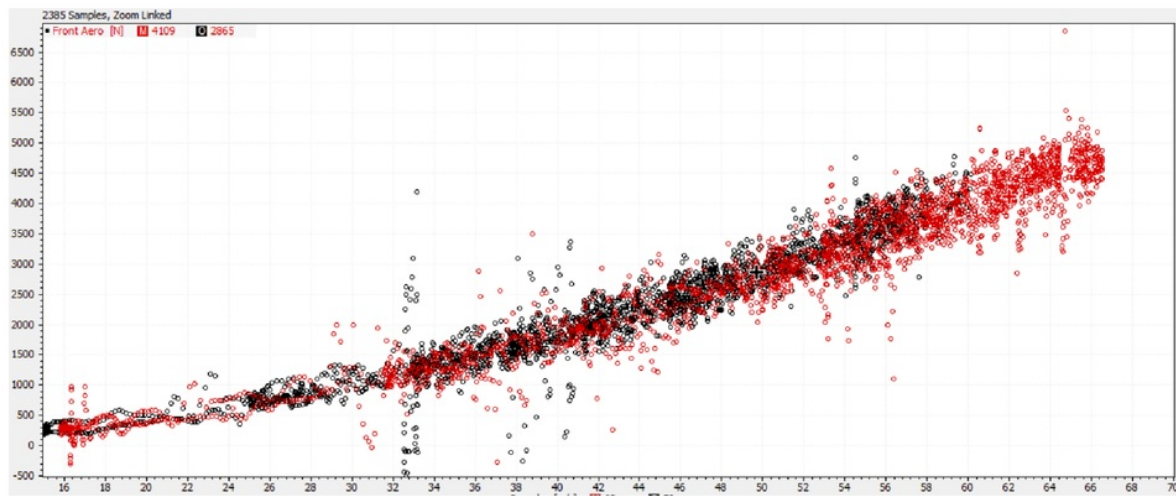
Appendix 14 Front Aerodynamic force graph Screen shots 18_18 Setup:



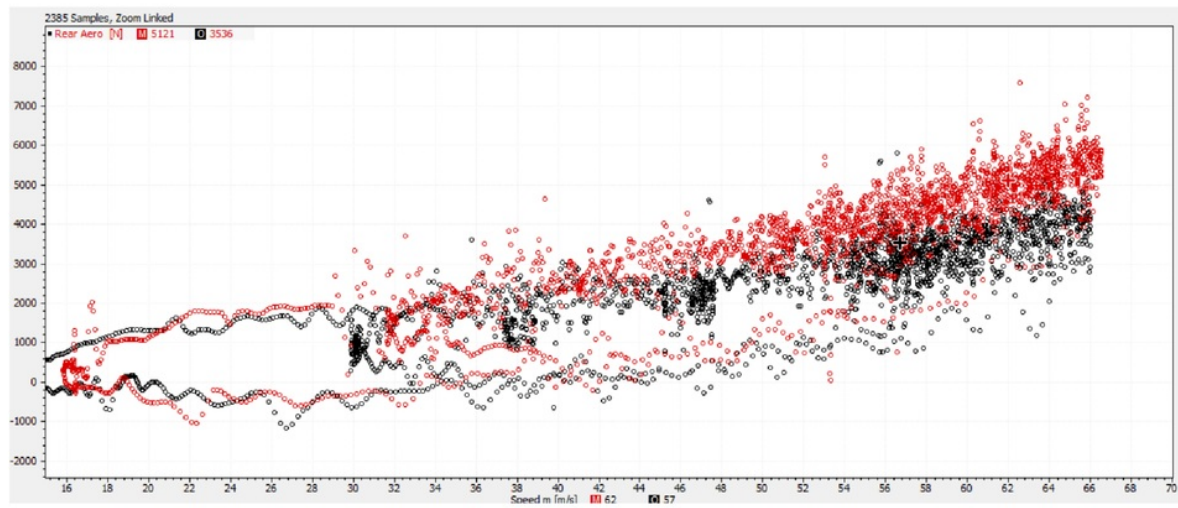
Appendix 15 Front Aerodynamic force graph Screen shots 18_1 setup:



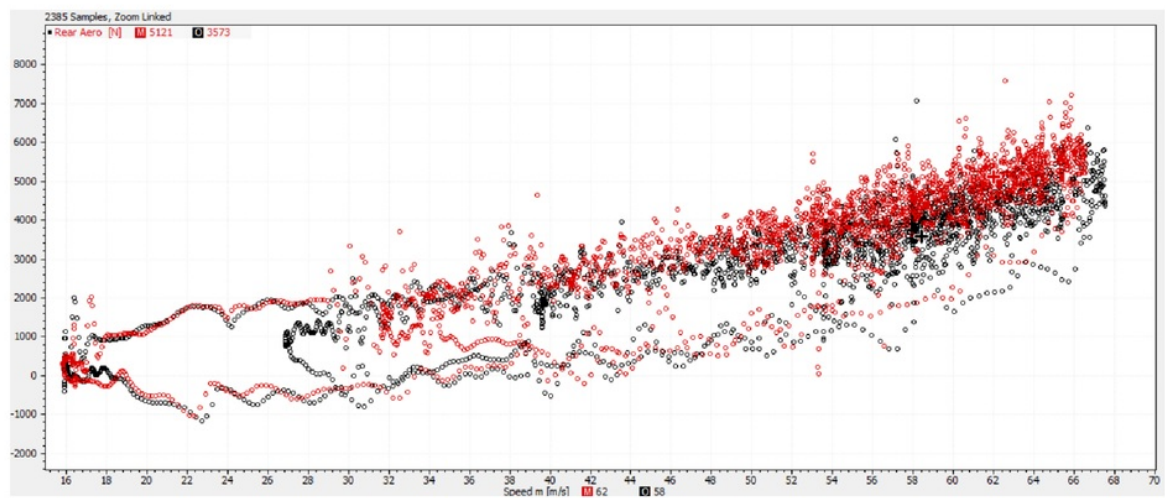
Appendix 16 Front Aerodynamic force graph Screen shots 18_9:



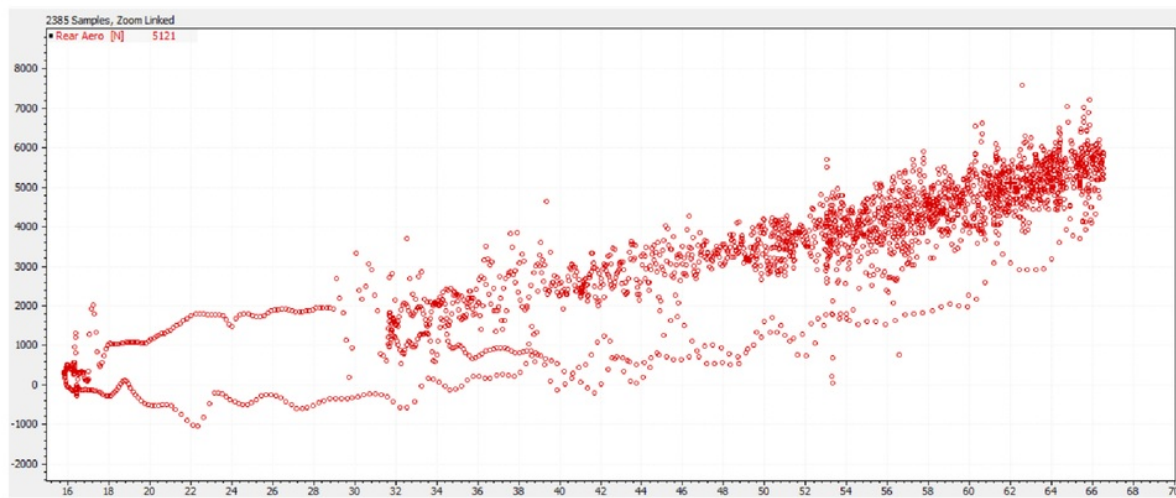
Appendix 17 Rear Aerodynamic force graph Screen shots 1 1 Setup:



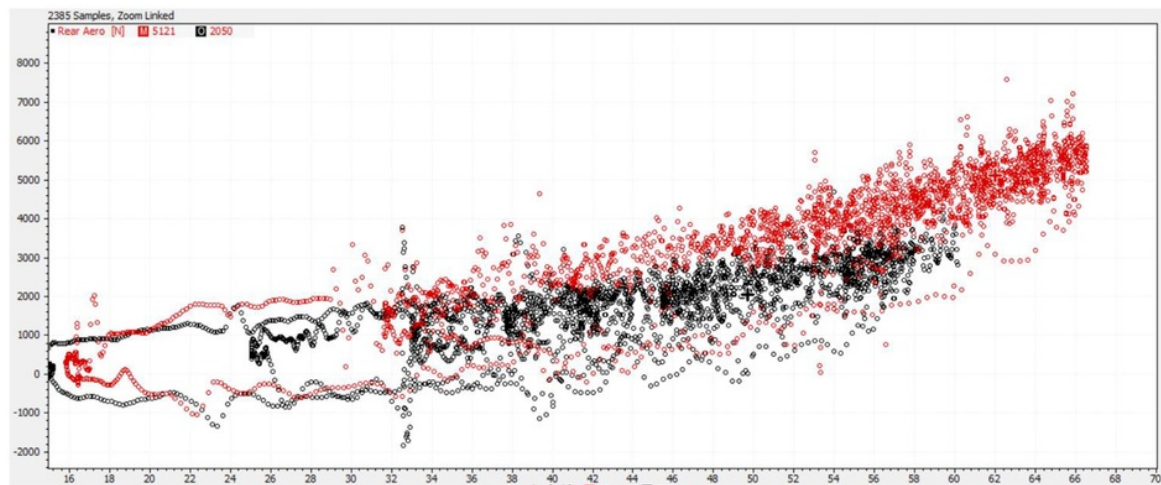
Appendix 18 Rear Aerodynamic force graph Screen shots 9 9 Setup:



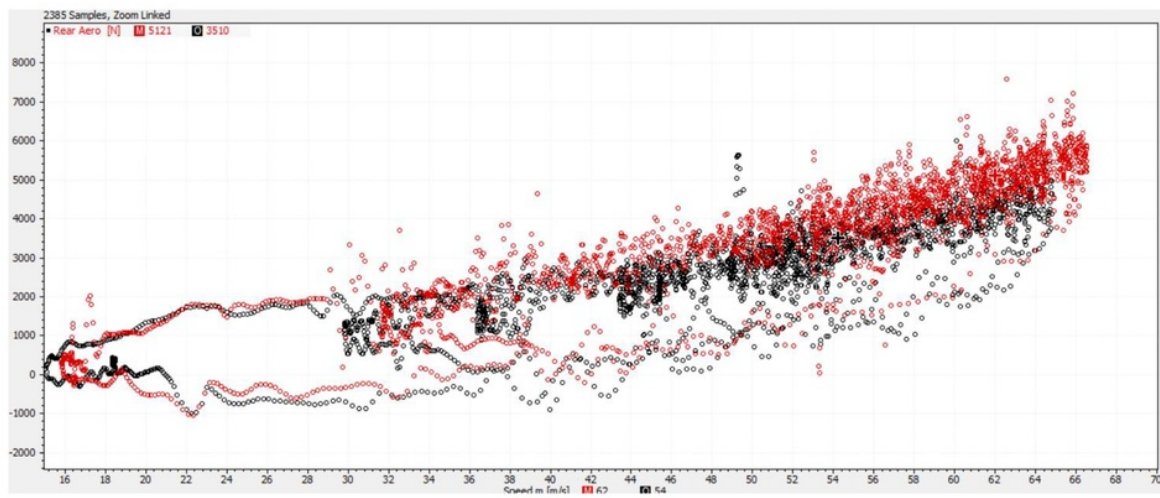
Appendix 19 Rear Aerodynamic force graph Screen shots 18 18:



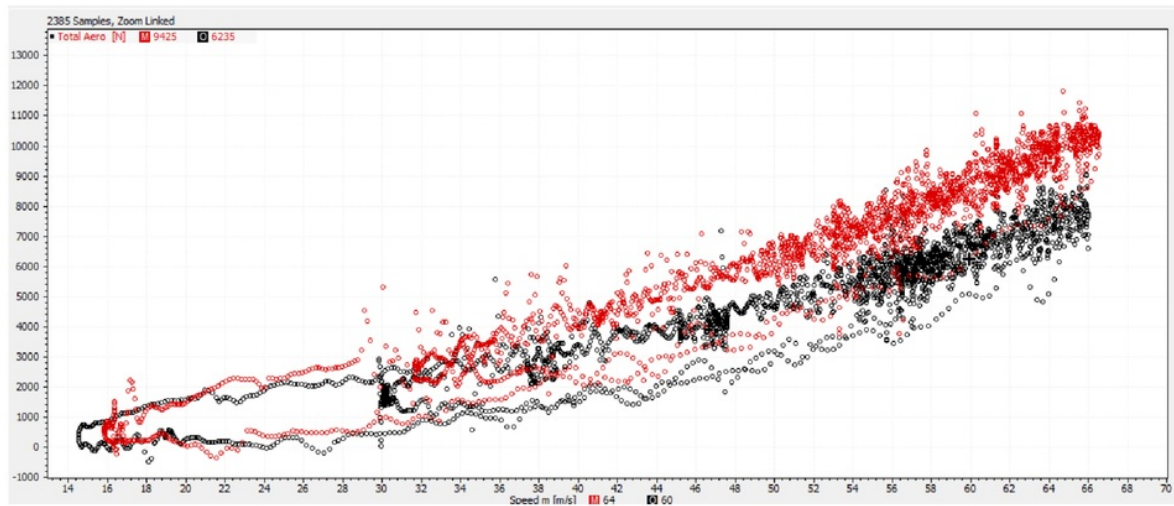
Appendix 20 Rear Aerodynamic force graph Screen shots 18 1:



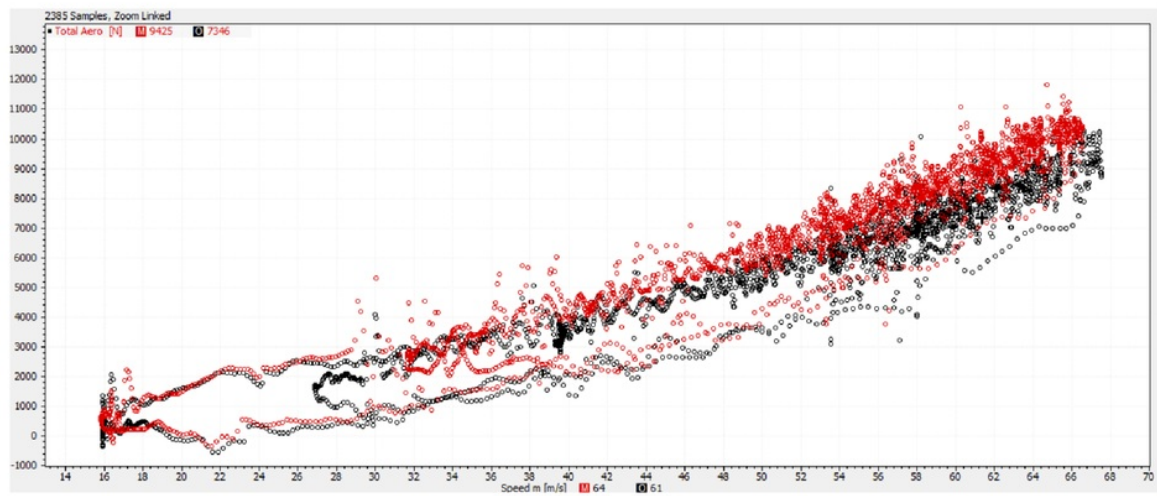
Appendix 21 Rear Aerodynamic force graph Screen shots 18 9:



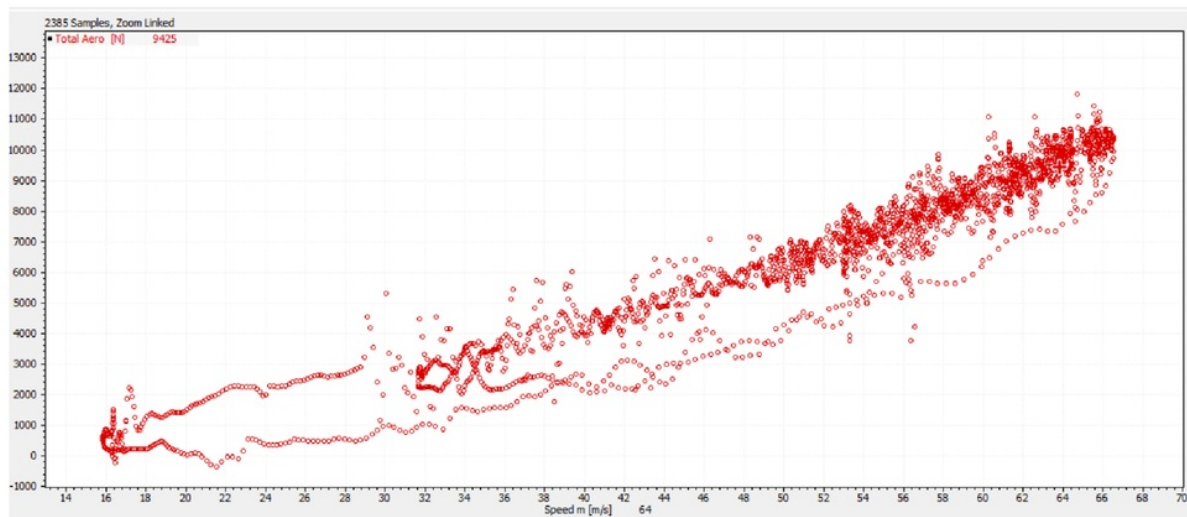
Appendix 22 Total Aerodynamic force graph Screen shots 1_1 Setup:



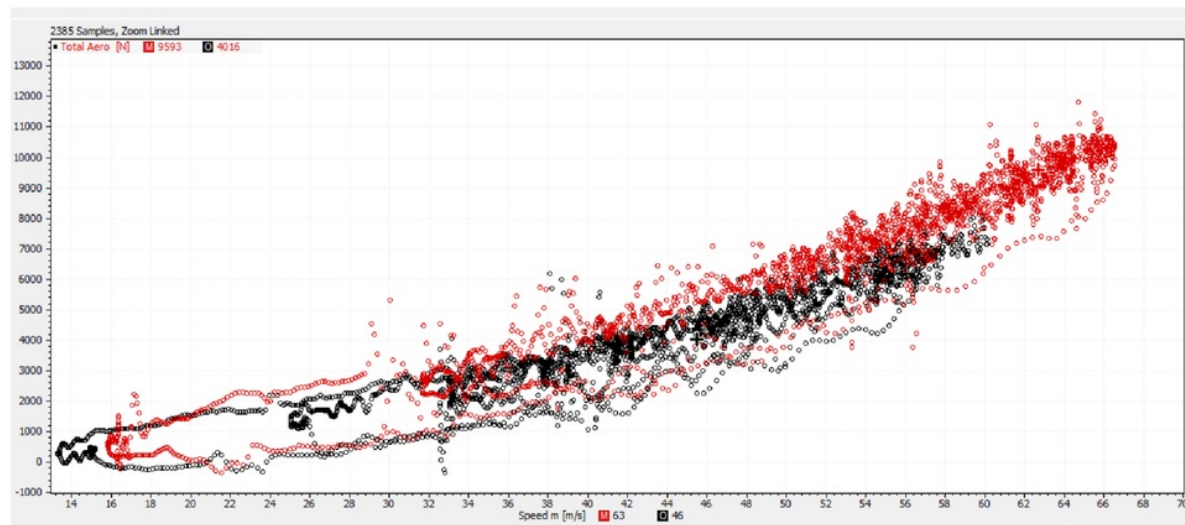
Appendix 23 Total Aerodynamic force graph Screen shots 9_9 Setup:



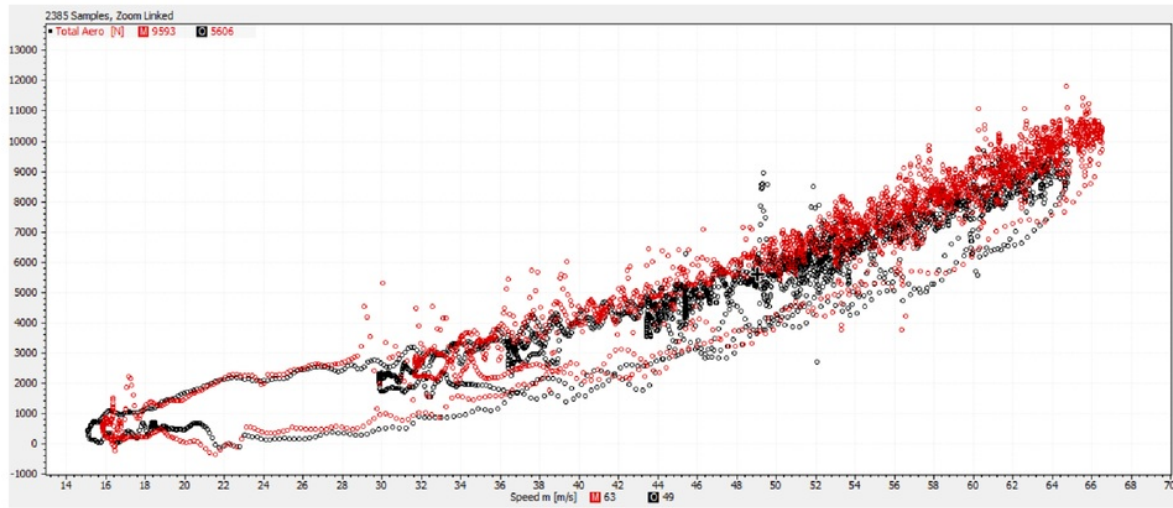
Appendix 24 Total Aerodynamic force graph Screen shots 18_18 Setup:



Appendix 25 Total Aerodynamic force graph Screen shots 18_1 setup:



Appendix 26 Total Aerodynamic force graph Screen shots 18_9 Setup:



7.0 Bibliography:

Bertin, J. and Cummins, R. (2009). *Aerodynamics for Engineers*. 6th ed

Book- Van Valkenburgh, P. (2000). *Race car engineering and mechanics* (Rev. ed.). Seal Beach, Calif.: Paul Van Valkenburgh.

Drivingfast.net. (2019). [online] Available at: <https://drivingfast.net/weight-transfers/> [Accessed Mar. 2019].

ieeexplore-ieee-org.ezproxy.uwtsd.ac.uk. (2019). [online] Available at: <https://ieeexplore-ieee-org.ezproxy.uwtsd.ac.uk/document/6028679> [Accessed Mar. 2019].

Journals-sagepub-com.ezproxy.uwtsd.ac.uk. (2019). [online] Available at: <https://journals-sagepub-com.ezproxy.uwtsd.ac.uk/doi/full/10.1177/0954407013514396> [Accessed Feb. 2019].

McBeath, S. (1999). *Competition car downforce*. 2nd ed. Yeovil: Haynes.

SAGE Journals. (2019). *Uncertainty quantification and race car aerodynamics*. [online] Available at: <https://journals.sagepub.com/doi/10.1177/0954407013514396#> [Accessed Mar. 2019].