

Aerodynamic Vehicle Testing and analysis (F3 Car)

by Ehab Aziz Barsoum

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Bsc Automotive Engineering

Race Engineering

Aerodynamic Vehicle Testing and Analysis

(F3 Car)

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1. Abstract

Aerodynamics is the first topic to discuss in modern technology in the world related to all sort of transportation fields, two of these fields include Aerospace and Aerodynamic race Engineering. This project aims to analyse and evaluate racing car performance and behaviour through aerodynamic characteristics and vehicle reactions in different performance positions.

Racing vehicle performance is about maximum longitudinal, lateral and vertical acceleration. In addition, looking at where the racing car maintains a specific position on the track which is shown by data acquisition. The maximum possible tyre grip is also needed during racing time to show the maximum acceleration in the different direction.

Within this project, the aim is to understand how to achieve a successful level of car racing performance on the track. Firstly we record and set up data accuracy and fully understand the vehicle dynamics. These include its centre of pressure, weight transfer, camber change (in a certain time while racing), its total downforce on different axles rear or front, corner radius, theoretical steer, which time and area the vehicle is understeering or oversteering and finally the difference of the vehicle's rake angle and Aerodynamic efficiency (Sergers, 2014).

2. Acknowledgment

It is my pleasure and my gratitude towards Tim Tudor, was very willing to help me to finish this assignment at this good condition with special guidance and orientations at all times, with best regards, success, and success always.

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4. Introduction

Aerodynamics play a highly important role in successful race technology, because new developments challenging the industry such as aerodynamics, chassis design, materials, engine power and tyre adhesion. In addition, race engineering is covered by different commercial sponsorships, which create a battlefield for the giants of automotive manufacturing.

Progressively, technology is changing in motor racing. Aerodynamics has been revolutionary in its developments during the last ten years. This includes many changes in regulations for specific targets of reducing the costs, improving safety, limiting the track speed and engineering tools by using advanced sensor technology to check the track and (CFD) computational fluid dynamics.

With regards to Newton's third law, for every action, there is an equal and opposite reaction. Whilst the racing car moves on the track, it creates an opposing force against the vehicle, this is known as drag force. Aerodynamic force is the reaction to this and the shape of the vehicle itself will impact 100% upon the performance of the vehicle on the track.

Whilst the racing car is stationary it is evaluated and the results analysed accordingly. On static loads for example, on the two front and rear axle sides, when the car is moving with a constant speed at front and rear axle sides, the data acquisition will find that the Aerodynamic loads and balances which guide us to find (COP) centre of pressure while the car moves in different directions, will determine coast down data. These are the aerodynamic forces implied in a car and they determine its rolling resistance and deceleration force (Katz, 2006).

5. Performance analysis

The analysis and validation process is an important method to specify aerodynamics. However, it is not that easy to predict the wing's performance as intended during the flow area of the race vehicle event was conducted. For example, this is used in Formula 3, taking into consideration different sort of competition aspects such as conclusion of dynamic events (acceleration, skid pad, endurance, and autocross). For performance calculation purposes, there is a fixed value which will be listed such as wheelbase, Gf long, Gf lateral and others have been measured experimentally and related to first straight line laps (SAE, 2006).

Global parameters

Which are important values needed essentially to successfully complete the Aerodynamics investigation, such as tire co-efficient of lift, frontal area, weight, (COG) centre of gravity/mm, car co-efficient of drag (SAE, 2006).

Aerodynamic performance and downforce.

In the car race performance like accelerating, cornering and braking forces are created at the area which between the surface and wheels is called contact patch, this friction such as forces are strongly influenced by the vertical force utilized on the wheels are specified by the maximum friction coefficient, this occurs clearly when speeding up to maximum which you exceed the maximum limit of speed in this car will slide, this is the sign of exceeding the tire adhesion limits(friction coefficient).

So if we increase the tyre force (maximum friction), the cornering force will be increased too without any sort of sliding it might occur, there is one method to do this which is to increase the cars mass, but there will be some impact on the cars lateral acceleration which is known as the side force at the same average, thus, there will be no development in the car being heavier, particularly in the turn rate.

In spite of increasing the track speed and time, the most important benefits of aerodynamic downforce is an increase in cornering speed too, the significant increase in cornering limits in the 1970s which is the reason for using inverted wings. Moreover to progress the cornering speeds, the most aerodynamics are doing is to enhancement the high-speed braking and car stability as well. Which guide to quickest lap times. This might occur where you think aerodynamic drag increases with the addition of wings, decreasing the limit of straightaway speeds (which is designed on the track to show the level of downforce and drag) which in turn finally will show the drag reduction is the first concern in the cars as the breaking records of the car fuel efficiency (Katz, 2006).

6. Test plan

The aim of this test is to look at the car race behaviour on the track which consists of different sorts of concepts, such as front and rear wing position, brake reaction during the test time, what areas the vehicle experiences understeering or oversteering, where the (COP) centre of pressure is located when the car accelerates or decelerates during the race time. Here will show the test plan for what the rear wings and front wings positioning between 1 to 18 ratios.



Figure (1)

F= Front wing

R =Rear wing

RH= Rear Height

FH= Front Height.

Adjustments	Ratings	Feed back
Default (F11,R12) (FH 3, RH 5)	N/a	Fairly balanced, limited grip, low speed okay, slight under steer.
F1,R1 (FH 3, RH 5)	N/a	Slightly more grip, oversteer slightly, slightly more stable.
F18,R18 (FH 3, RH 5)	6	Loads of grip, lot more stable, good front end, touch the apex much better.
F9,R9 (FH 3, RH 5)	7	Slight less stable, more to over steer. (no phone record)
F18,R1 (FH 3, RH 5)	8	Very oversteery, brakes okay (worst setup so far)
F9,R1 (FH 3, RH 5)	6.5	Slightly less oversteer
F1,R18 (FH 3, RH 5)	4	Slightly under steer, safe to drive as always find the limit on the grip, low speed understeer.
F1,R9 (FH 3, RH 5)	5	Nice balance good confidence in car high speed, understeer low speed corner.
F1,R6 (FH 3, RH 5)	4.8	Best setup, so far loads of grip, very stable slightest understeer.
F1,R12 (FH 3, RH 5)	4.8	Slight understeer, high speed still stable, top out at a higher speed.
F1,R10 (FH 3, RH 5)	4.5	Balance good, slight understeer, less grip overall, didn't feel good when planted at high speed corner.
F2,R12 (FH 3, RH 5)	5	Perfect balance, slight understeer low speed corner, felt very planted.
F3,R12 (FH 3, RH 5)	4.5	Balance very good, not as much grip as previous, low speed understeer, high speed corner scrubbing across track as not enough grip.
F2,R12 (FH 2CM, RH 4CM)	4	Felt more understeer, general good grip overall, low speed corner responded well to inputs.
F2,R12 (FH 2.5, RH 4.5)	4.8	Tiny bit understeer, flat out very good high speed through corner which couldn't previous low speed felt good.
F2,R12 (FH 2.7, RH 4.7)	4.8	Almost identical to previous, more understeer low and high speed

Figure (2) the figure show where the F1 R1 the wings in front and rear position angle also shows the drive feedback for each lap. This laps is been done in Silverstone track.

7. Total aerodynamic lift coefficient (CL)

Name	Summary
Expressions	
☒ speed [m/s]	(Corr Speed [km/h]*1000)/(60*60)
☒ Long WT [N]	(MASS [kg]*G Force Long [G]*G [m/s/s]-1*CoG [m])/Weelbase [m]
☒ Front Aero [N]	(Tire Load - FL [N]+Tire Load - FR [N])-(FLO [N]+FRO [N])*Long WT [N]
☒ Rear Aero [N]	(Tire Load - RL [N]+Tire Load - RR [N])-(RLO [N]+RRO [N])*Long WT [N]
☒ Total Aero [N]	(Front Aero [N]+Rear Aero [N])
☒ Centre Of Pressure [ratio]	(Front Aero [N]/Total Aero [N])*100
☒ Aero Drag Force [N]	(0.5*Air Density [kg/m3]*CD*(speed [m/s]*speed [m/s]))
☒ Corner Radius [m]	(speed [m/s]^2)/(G Force Lat [G]*9.81)
☒ Ackerman wheel steer angle [rad]	(Weelbase [m]/Corner Radius [m])
☒ Ackerman steer % [%]	Ackerman wheel steer angle [rad]*(28.60/0.1073)*1
☒ Under steer % [%]	abs(Steering Wheel Pct [%])-abs(Ackerman steer % [%])
☒ Aero Drag [N]	0.5 * Air Density [kg/m3] * Cd * (speed [m/s])^2
☒ Downforce [N]	(Front Aero [N]+Rear Aero [N])
☒ Aero efficiency [%]	(CL [N]/Cd)
☒ Rake Angle [deg]	atan((Ride Height FL [mm] + Ride Height FR [mm])/2 - (Ride Height RL [mm] + Ride Height RR [mm])/2) / (Weelbase [m])
☒ CL [N]	((Downforce [N])/(0.5*Area [m2]*Air Density [kg/m3]*speed [m/s]^2))
Constants	
☒ Air Density [kg/m^3]	1.223
☒ Area [m^2]	1.2
☒ CoG [m]	0.23
☒ FLO [N]	1163
☒ FRO [N]	1163
☒ G [m/s^2]	9.81
☒ MASS [kg]	560
☒ RLO [N]	1580

Figure (3)

Co-efficient of lift (CL) is term to show what downforce reaction divided by 0.5 x air density x front area x speed m/s².

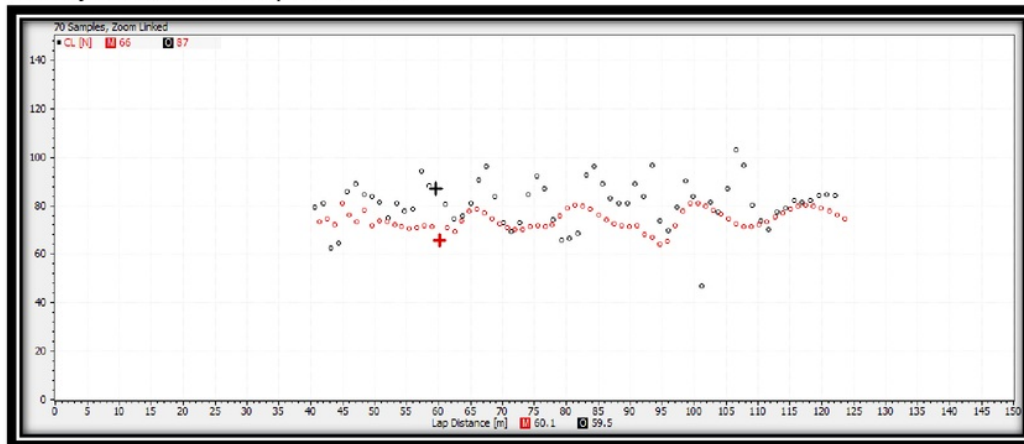


Figure (4)

As the figure shows CL between red setup lap = 66 and black set up is = 87 different due to high speed for black setup which is 237.0 km/h and the red set up speed is 216.9 km/h also if we look at front aero for red = 2461N and black front aero = 3623N. So to summarise this case the position of wings plus the speed will make huge impact at the co-efficient of lift practically is appear in the front aero values.

Spreadsheet works

	Sonic Load				Concentricity Load				Aerodynamic Balance				Aerodynamic Coeff				Coast down				Dry Forces																
Setup	LF	RF	LR	RR	Wt/Kg	F	FR	LR	RR	AerF	AerR	AerT	OCF	Vs/m/s	CL	CD	Y	V2	Q	V3	G	V4	K	a	a2	Descent	Rolling	Per	AerDrag	Ca	Wing	in	Alt2	Plan	MaxDist	MaxCos	
F1R1	161	162	678	581	220	2777	2765	3324	322	326	345	674	0.48	81.17	1.22	-1.45	23524	55.95	48.32	55.98	45.5	1381	34.32	0.7778	0.93	-0.30	-58.52	-166.67	165.6	-0.07	550	53.76	12	1.223	553.2	0.4533	
F7R10	161	163	680	583	220	2763	2763	3340	326	346	672	0.48	81.17	1.21	-1.45	23508	55.95	38.11	57.03	38.22	2.0833	23.32	15	0.5333	-2.08	-4.09	-166.67	-162.52	-104.47	-4.41	550	53.76	12	1.223	553.2	0.4533	
F9R9	161	164	682	679	218.2	2807	2807	3329	406	476	804	0.47	80.87	1.43	-1.75	31945	55.93	40.37	57.97	42.51	1.9811	13.54	1333	15.43	2.70	-0.39	-65.55	-65.1	174.47	0.70	550	53.76	12	1.223	553.2	0.4533	
F17R10	161	163	680	583	221.2	282	282	3333	406	476	804	0.47	80.87	1.43	-1.75	31905	55.93	37.12	57.97	37.27	1.722	25.92	1393	17.3	-2.04	-0.39	-65.55	-64.39	-1425.33	-4.81	550	53.76	12	1.223	553.2	0.4533	
F13R	161	165	682	679	220	2835	2835	330	335	347	676	0.48	81.17	1.24	-1.45	23944	55.93	39.2	55.93	41.9	1.467	0.833	0.93	-2.27	-0.39	-62.73	-164.93	-107.74	-4.46	550	53.76	12	1.223	553.2	0.4533		
F7R7	161	161	678	580	220	2844	2844	3323	330	332	347	679	0.48	81.17	1.25	-1.45	278	57.52	42.44	57.25	42.57	2.3778	23.73	1722	15.75	-2.74	-0.39	-165.53	-167.3	-107.16	-4.43	550	53.76	12	1.223	553.2	0.4533
F7R7	161	163	681	580	218.9	2843	2843	3326	335	343	679	0.51	81.05	1.29	-1.44	27288	55.93	40.2	58.36	40.42	2	24.77	1.97	19.05	-2.38	-0.45	-102.22	-164.72	-167.51	-4.46	550	53.76	12	1.223	553.2	0.4533	
F7R7	161	161	678	582	218.9	2843	2843	3302	330	335	343	678	0.51	81.05	1.28	-1.44	27228	55.93	38.37	58.33	38.38	1.444	24.47	0.861	13.33	-2.65	-0.31	-140.14	-171.03	-108.45	-4.53	550	53.76	12	1.223	553.2	0.4533
F1R12	161	163	680	583	220.7	2765	2765	345	345	367	670	0.48	81.05	1.21	-1.50	27078	55.93	37.88	57.47	37.83	1.033	24.46	1353	15.3	-1.61	-0.39	-165.03	-167.83	-154.43	-4.38	550	53.76	12	1.223	553.2	0.4533	
F1R13	161	165	682	679	218.5	2764	2764	3545	345	345	367	702	0.44	80.97	1.30	-1.56	27025	57.36	37.37	57.41	2.472	18.39	1.97	2.8	-2.38	-0.39	-166.33	-164.61	-109.85	-4.47	550	53.76	12	1.223	553.2	0.4533	
F1R13	161	161	678	582	218.1	2803	2803	336	342	400	705	0.47	80.65	1.32	-1.50	23947	58.70	38.43	57.32	38.45					-2.08	-0.39	-162.23	-164.43	-167.87	-4.33	550	53.76	12	1.223	553.2	0.4533	
F1R13	161	160	684	684	218.1	2857	2857	332	332	374	423	0.47	80.73	1.35	-1.5	3014	59.3	37.35	57.22	37.43					-2.07	-0.39	-163.23	-164.43	-164.10	-4.38	550	53.7	12	1.223	553.41	0.4533	
F1R13	162	163	680	583	218.5	2805	2805	3328	346	448	841	0.47	80.634	1.38	-1.70	3038	57.31	38.38	57.38	37.42					-1.61	-0.39	-163.23	-164.43	-168.83	-4.33	550	57.7	12	1.223	553.2	0.4533	
F1R13	165	161	678	583	218.2	2802	2802	3339	3497	3475	3955	7333	0.47	80.973	1.38	-1.55	23388	58.388	38.72	55.833	37.05					-1.61	-0.39	-162.73	-164.47	-170.36	-4.34	550	59.1	12	1.223	553.31	0.4533

Figure (5)

Chosen Good laps

At this section will chose good wing angle for front and rear from previous straight line coast down test and applied in the aero Silverstone track test, the chosen ones are

1. Max wing configuration **F18 R18** at time roughly 14:05 and its colour in Motec will be **black**.
2. Medium wing configuration **F9R9** at time 14:08 with colour **green**.
3. Minimum wing configuration **F1R1** at time 14:01 with colour **red**.

8. Total lift and Drag

In this section I will chose the finest two laps that been made in Pembrey circuit , the standards to choose which two is good it dependent on what (CD) Co-efficient of

A. Total lift and Drag varies

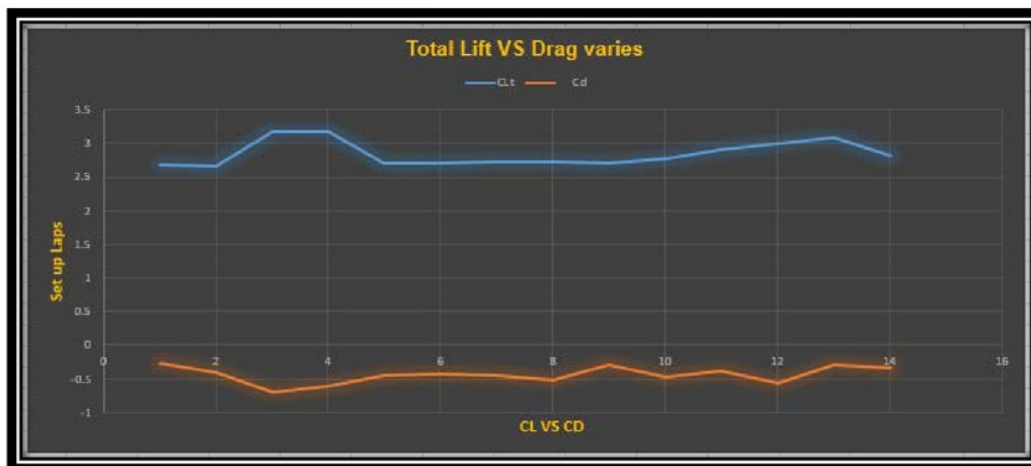


Figure (6)

According to Joseph Katz, the vehicles stability and handling can be changed by different normal forces on the front or rear aero downforce, So the high performance of race car in increasing the drag force which also affects the handling , the stability and braking front and rear wheel too. The figure shows the total lift blue line in certain time when the drag force is decreased, this occurs due to front splitters and rear wing angle producing drag force which is increasing aero front and rear. So if the total lift is negative that mean downforce it is works and push the car down to increase the grip and stability (Katz, 2006).

Silverstone laps

Hide Values	Date	Time	Wing/Conrod	Wheelbase	Wheelbase Left	Wheelbase Right	Track Front	Track Rear	Total Weight Front	Total Weight Rear	Static Ride Height Front	Static Ride Height Rear	Static Weight FL	Static Weight FR	Static Weight PL	Static Weight PR	Adelman Factor	Cd	Supracon Conrod	Rol Bar Rate Front	Rol Bar Rate Rear	Spring Rate FL	Spring Rate FR	Spring Rate PL	Spring Rate PR	Spring Rate RL	Spring Rate RR
Set																											
Set																											
Difference			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F1 R1	28-Feb-19	14.00.00															0.27										
F18 R18	28-Feb-19	14.03.00															0.7										
F9 R9	28-Feb-19	14.07.00															0.39										

Figure (7)

This figure shows the transferred laps between the straight line test to Silverstone circuit.

Total Lift and Drag force channels

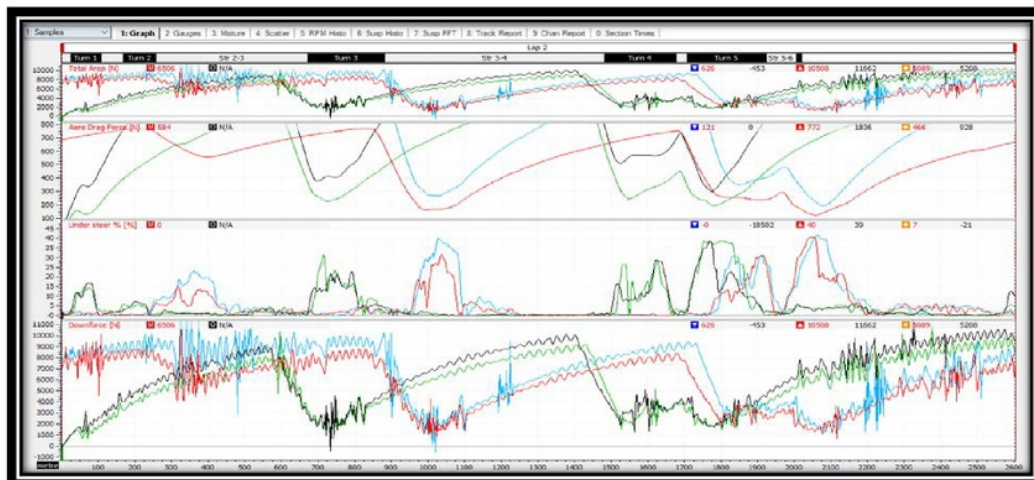


Figure (8)

As the driver starts to build up the speed also will build up the drag force and total aero in front and rear wing. But here the front wing F9 with speed 221KMH the same comparison speed to the previous lap it is reduced the total lift to 8060N, Aero drag=901N. Which is very good results at this speed. So the next step is to move the cursor to another location. The same speed for the previous lap is 112.2KMH, the total lift is 352N and the aero drag force 79N. Which shows the R9 impact on the aero drag and total lift in the same speed (McBeath, 2011).

Conclusion F1 R1 & F9 R9, F18 R18

Lap description	Speed KMH	Total lift N	Aero Drag Force N	Understeer
F1R1	241.0	7745	740	6
F9 R9	174.7	4686	561	1
F18 R18	177.0	5536	1034	0

Table (1)

The figure shows the three laps with differences, same distance and time, high speed in the F1R1 created little difference in total lift and aero drag which produce high understeer in the curve, if reduce the speed to be like 176KMH gives perfect results, which will show the configuration of the laps related to wing angle. Which done huge different of boundary layers separation, for purpose to creates some turbulence under the car which deal with rake angle, also to work with the rear to enhance COP which played an important role in increasing the grip and car stability during braking in corners if it is required (Schuetz, 2016).

9. Total lift versus Speed X& Y Plot

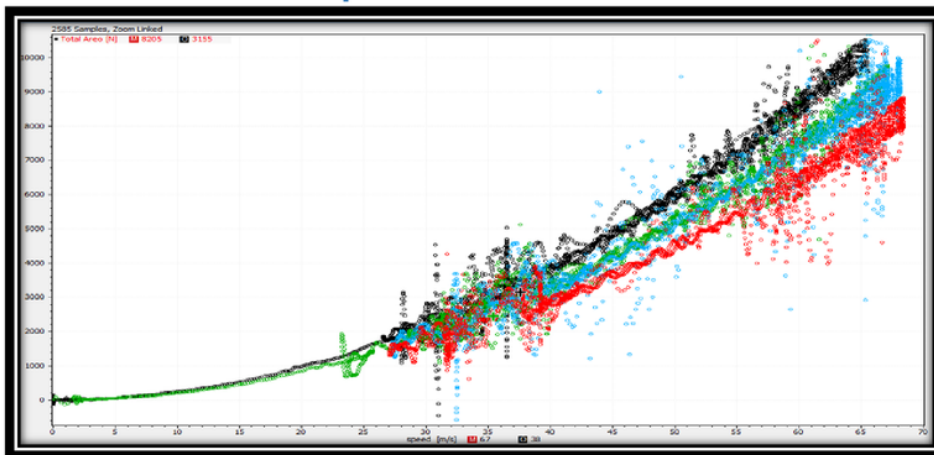


Figure (9)

As the car speeds up the total aero increased, The correct of position angle for rear wing and front splitter is very important to manage the different aero force around the vehicle.

Wing configuration	Total Lift	Speed	CL	Understeer
F1R1	5339	219.9	60	7
F9 R9	5607	188.8	73	1
F18 R18	6745	191.3	86	1

Table (2)

The table shows the total aero lift in the front and rear versus speed, each lap is different time on the track, CL shows how this coefficient of lift in F1 R1 is less than the F18 R18 that makes stability for the body structure on the wheels, other point related to F1 R1 speed it increases the understeer percentage which gives attention to go back to manage the stability of the car when the next curve is coming. Also F18 R18 it shows good results for understeering which is 1% and this shows a sign of great stability on the road surface (Sergers, 2014).

Wing configuration	G force Lat	Speed	Front Aero	Rear Aero	Roll Angle
F1 R1	1.483	245.7	3981	4132	0
F9 R9	-1.448	149.4	1638	2006	-1
F18 R18	-0.726	144.9	1726	2155	-0

Table (3)

The table shows the values of G force lateral for three laps and F1 R1 is value which F1 R1 G force lateral is 1.483 N which means this force is push in different sides of the tracks corners, the Rear Aero acts more than front because air layers create turbulence which pushes the car down to the road surface, also when frontal aero is increased that makes the car understeer which is known as a positive number and negative number for oversteer (McBeath, 2011).

Lateral acceleration versus Speed X & Y Plot

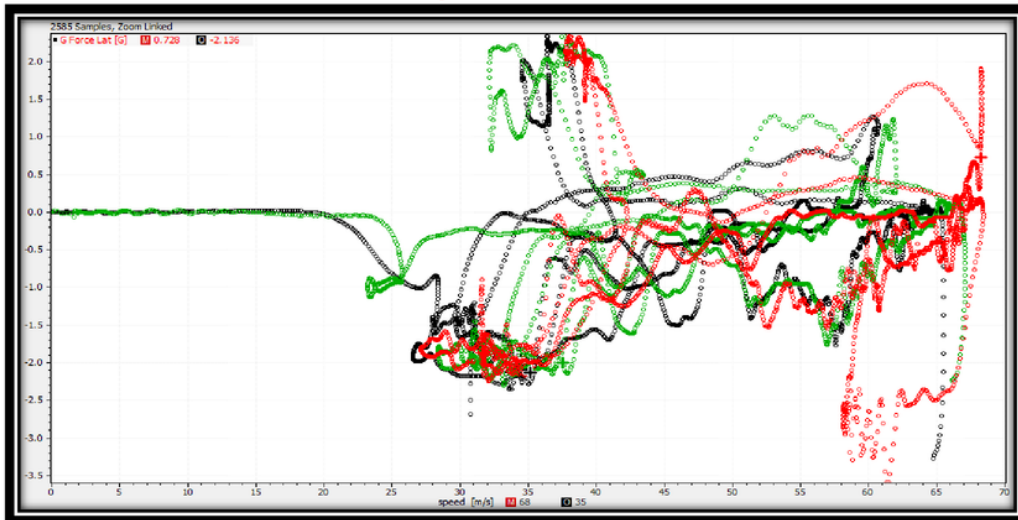


Figure (10)

Figure (10) shows the four better laps F1 R1 & F9 R9, F18 R18 and F2R12, Each one is dealing with curves and bends differently, F1 R1 from splitter is sharp angle which facing the drag force moves the air drag force to face the rear wing which causes the COP to move back, when the rear wing the front aero understeer and oversteer in different curves, the dark red and dark black dots it means a lot of lateral acceleration is occurring during the increasing the speed.

Negative G force Lat in **F9 R9 & F18 R18** which means the car is oversteering in this section.

The rake angle

Is the angle from the front axle and rear axle height, can be calculated by a sum of right height front lift &right divided by 2 subtract from rear left and right ride height divided by wheel base (Formula One World Championship Limited, 2019).

10. Downforce Lift at rear and frond axes

Name	Summary
Speed [m/s]	(Car Speed) [m/s]*1000/(60*60)
Long WT [N]	(MASS) [kg]*G Force Long [G]*G [m/s/s]*1-1*CoG [m]/Wheelbase [m]
Front Aero [N]	(Tire Load - FL) [N]*Tire Load - FR [N]*(FLO) [N]*FRO [N]*Long WT [N]
Rear Aero [N]	(Tire Load - RL) [N]*Tire Load - RR [N]*(RLO) [N]*RRO [N]*Long WT [N]
Total Aero [N]	(Front Aero) [N]+(Rear Aero) [N]
Centre Of Pressure [ratio]	(Front Aero) [N]/(Total Aero) [N]*100
Aero Drag Force [N]	(0.5*Air Density [kg/m3]*CD*Speed [m/s]*Speed [m/s])
Corner Radius [m]	(Speed [m/s]^2)/(G Force Lat [G]*9.81)
Akerman wheel steer angle [rad]	(Wheelbase) [m]/Corner Radius [m]
Akerman steer % [%]	Akerman wheel steer angle [rad]/(28.60/0.1073)*1
Under steer % [%]	abs(Steering Wheel Plt [rad]-abs(Akerman steer % [rad])
Aero Drag [N]	0.5 * Air Density [kg/m3] * Cd * (Speed [m/s])^2
Downforce [N]	(Front Aero) [N]+(Rear Aero) [N]
Aero efficiency [%]	(CL) [N]/(Cd)
Rake Angle [deg]	atan(((Ride Height FL [mm] + Ride Height FR [mm])/2 - ((Ride Height RL [mm] + Ride Height RR [mm])/2) / (Wheelbase [m]))
CL [N]	((Downforce) [N]/(0.5*Area [m2]*Air Density [kg/m3]*Speed [m/s]^2)
Roll angle [deg]	(Cym Roll Angle) [rad]/(180/3.14)
New Long WT	((New Mass) [kg]*G Force Long [G]/(G [m/s/s]/(1-1*CoG [m]/Wheelbase [m]))
New Front Aero [N]	(Tire Load - FL) [N]*Tire Load - FR [N]*(FLO) [N]*FRO [N]*New Long WT
New Rear Aero [N]	(Tire Load - RL) [N]*Tire Load - RR [N]*(RLO) [N]*RRO [N]*New Long WT
New Down Force Lift [N]	(New Front Aero) [N]+(New Rear Aero) [N]
Constants	
Air Density [kg/m3]	1.223
Area [m2]	1.2
CoG [m]	0.23
FLO [N]	1163
FRO [N]	1163
G [m/s/s]	9.81
MASS [kg]	560
New Mass 85% [kg]	476
RLO [N]	1583
RRO [N]	1583
Wheelbase [m]	2.73

Figure (11)

The figure above shows the new mass which is 85% of the total mass of 560 and the result will be the new mass = $0.85 \times 560 = 476$ kg.

The next step will go through Long WT to setup the new mass and start calculating the new Long WT and then New Aero in front axle and rear axle, and then finally will calculate the total New Downforce Lift as the figure above showing (Schuetz, 2016).

10.1 Long WT



Figure (12)

Longitudinal force which pushing the car forward or to rear, the total car mass as known is split at front and rear, so when the front aero splitter angle is 1 the coefficient of drag will be small and the rear wing angle is 18 so that moves COP back and increasing the turbulence behind the wing which may pull or suck the car back to make negative WT (Sergers, 2014).

11. Front Aero Vs Lap Distance

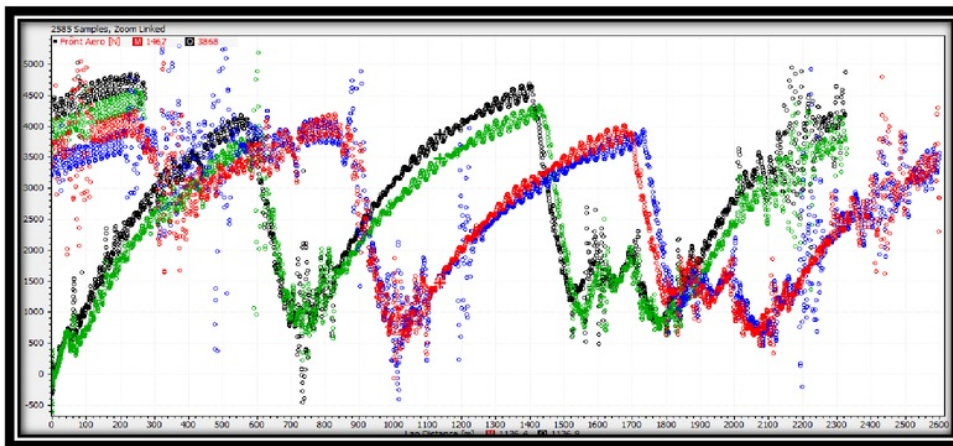


Figure (13)

This figure includes the chosen four laps of F1R1 & F9R9 & F18R18, F2 R12 The perfect Aerodynamic force load on the front axle is in F2R12, F18 R18 is higher than three colours which means it gives a sort of heavyweight in the front which stops the traction force if the car front drive and if its rear-drive increase the weight on the rear aero is not quicker and gives a low distance, F2 R12 the first good lap in distance the front aero force is reasonable because the splitter angle allows some air drag force to go under the car and works with air boundary layers with the Rear wing R12 air

pressure to push the car down which allows a further distance to be travelled in less time. Thus COP is moved in the rear to push the car down and increase the grip and stability of the car. When the front aero is with an acceptable splitter angle to let some air balance between the air on the top and bottom of the car surfaces (Sergers, 2014).

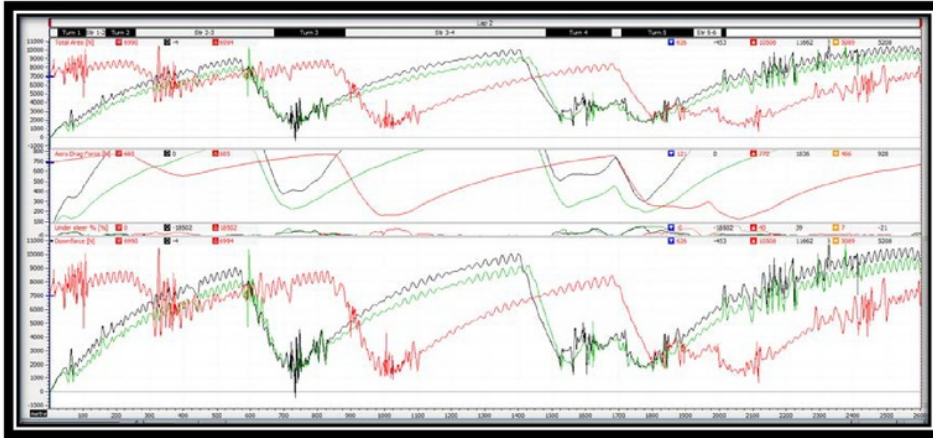


Figure (14)

This figure shows the lap F1 R1, F9 R9, F18 R18 and F2 R12 which shows the aero in different areas increased and decreased relative to the splitter and rear wing angle, when the front aero is increased that pushes it to understeer in specific curves, but the wing position gives extra stability when some air goes under the wheel (Sergers, 2014).

Rear Aero Vs Lap Distance

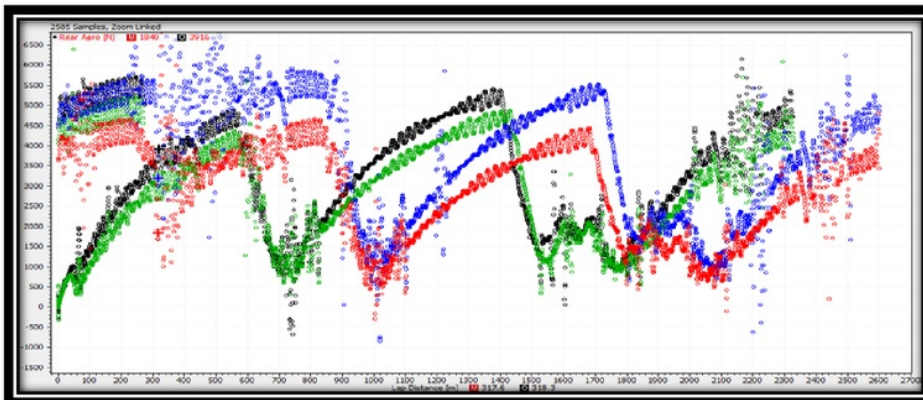


Figure (15)

Rear Aero in blue colour which is F2R12 is the good one because highest Aero force on the rear it gives extra weight to help pin down the car on the road surface and increase the grip and stability, also it doesn't waste the time like the other three laps, when speed is increased the required air pressure to create the weight on the rear, there is no issue in the braking because it increases the feeling of grip while braking in certain areas such as climbing the hills or going down in the slopes (SAE, 2003).

12. COP over all

In this section will calculate the centre of pressure for each setup in Silverstone circuit.

1. FI1R1

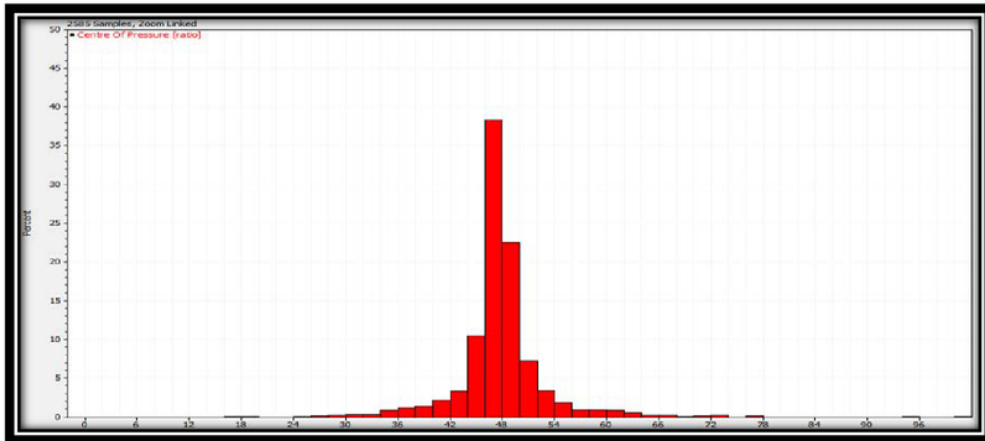


Figure (16)

The figure shows the COP is fixed close to the centre of car more slightly to the rear side more than the front, this happened because the air pressure under the car is lifting the car up but the rear wing respond to this by pushing the car down due to rear wing angle, which increases the grip and stability of the car (Formula One World Championship Limited, 2019).

2. F18 R18

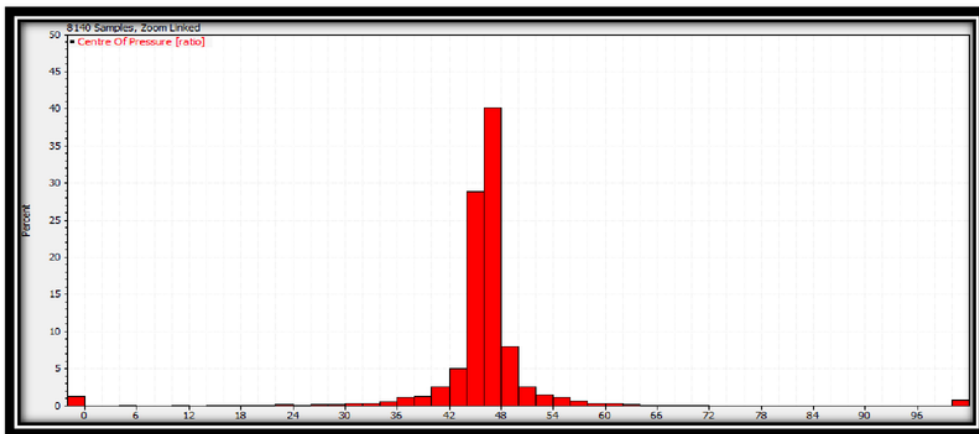


Figure (17)

COP here is typical style because the front and rear of the car has more balance with the drag force which is going under the car and the air boundary layers on the top of the cars surface. COP is in a good area which increases the grip loads and stability of the car on the track (J.Bertin, 2002).

3. F9 R9

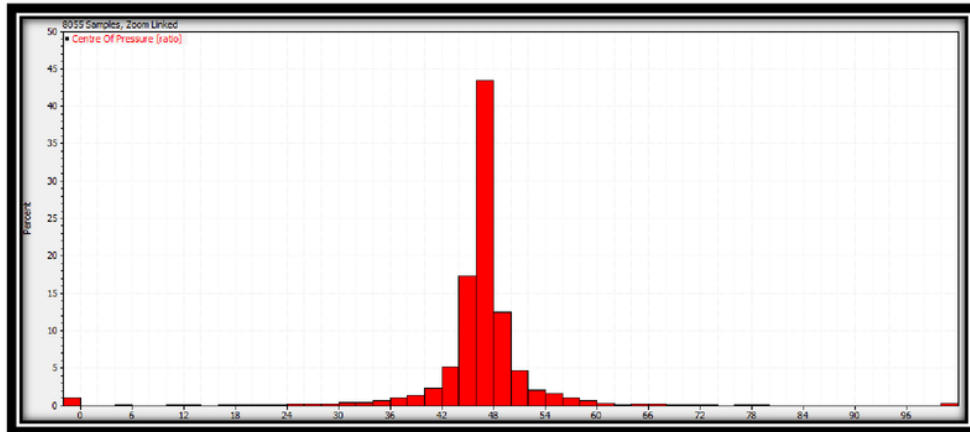


Figure (18)

This figure shows aero force in the front area is increased which is guide to less stability due to increasing the air pressure therefore the weight in the front , this also passes air boundary layers under the car which lifts it up and with high speed around the corner makes oversteering which happened due to Air Dissipation, under the car and on top of the car which is known as downforce which has an important role to keep the car with good grip (Sergers, 2014).

4. F18 R1

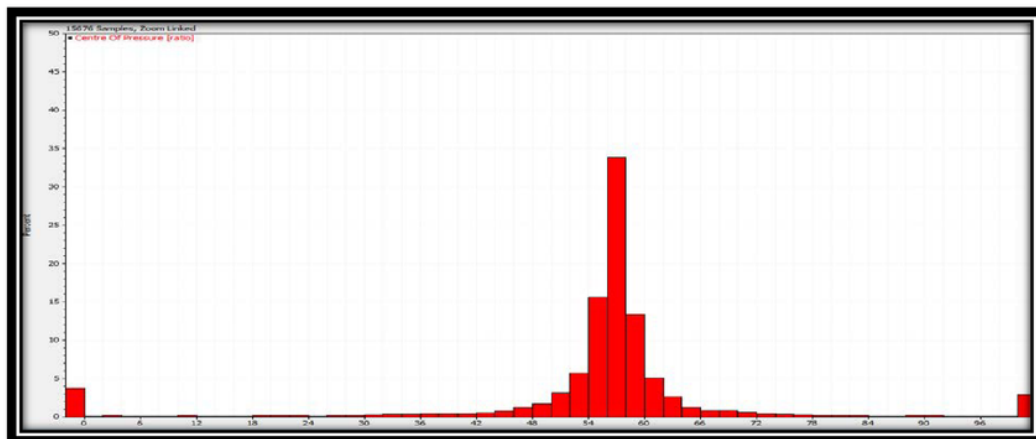


Figure (19)

This case shows that the front splitters angle is perpendicular and full setting 18 in front splitter which increases the airflow under the car this first point, the secondary is increasing the drag force which increases the pressure on the cars movement. There is sort of air weight pressure which will be generated on the front and under the car which lifts the rear of the car up, losing grip and stability, moderate brake performance and a lot of oversteer due to the loss of control of the rear of the car (Sergers, 2014).

5. F9R1

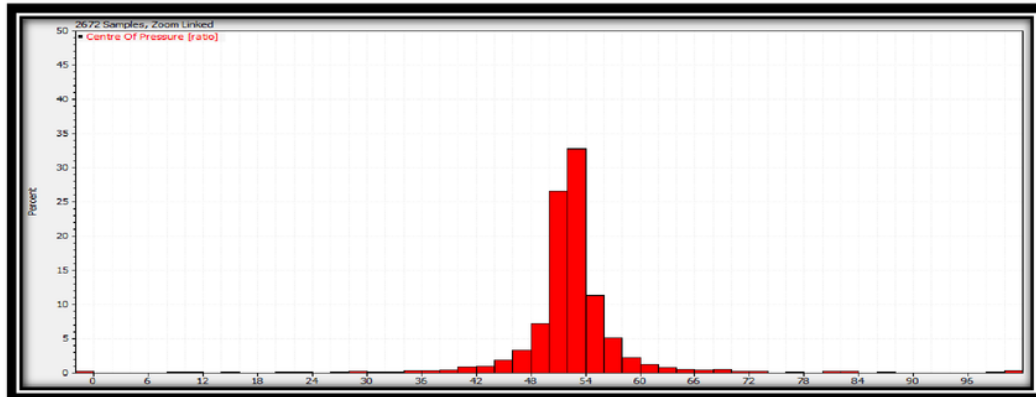


Figure (20)

COP here is in quite nice and is in the middle of the car due to front splitter angle which is setting 9. This allows a lot of air boundary layers to go under the car that lifts the car up but with low angle of rear wing which is one which does not give enough downforce to push the car down into the track, final occurring oversteer in the corners when the car accelerates because loss of control of the rear body of the car (Katz, 2006).

6. F1R18

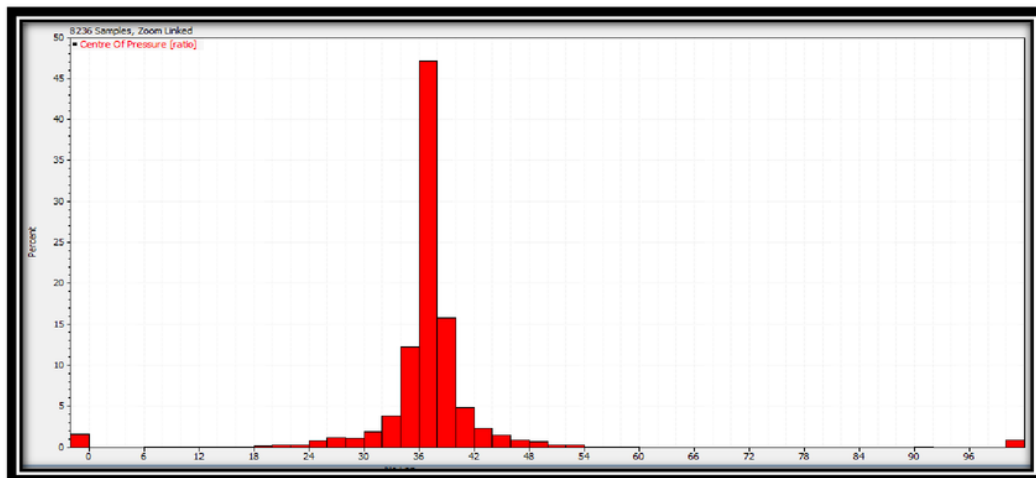


Figure (21)

COP is in rear of the car more than on the front as the graph shows, due to the increase in the downforce on the rear this generates a huge amount of air mass which affects the rear by making it feel heavy during movement which is due to loss of the control on the front and causes oversteering when the car accelerates around the tracks corners (Schuetz, 2016).

7. F1R9

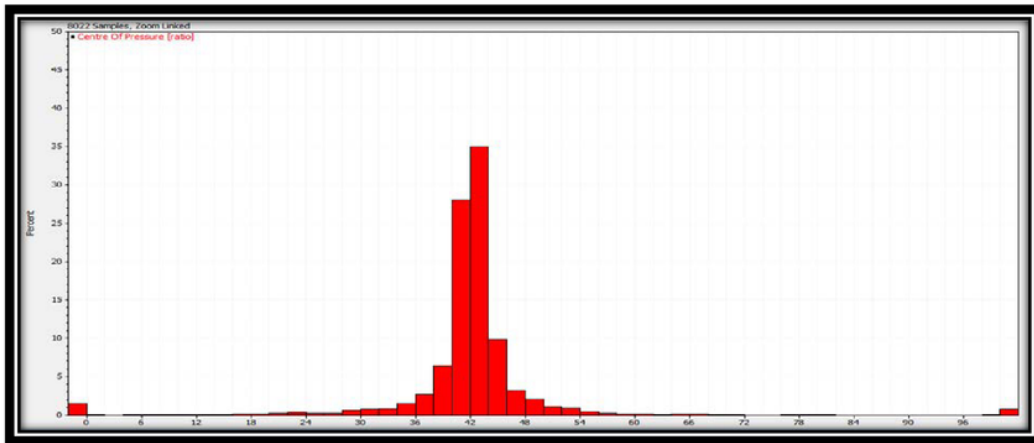


Figure (22)

COP is located near the centre of the car which gives nice balance between the front and rear aero forces, This encourage the driver to speed up the car, but there is some understeer due to the rear aero force is more than the front (Sergers, 2014).

8. F1R6

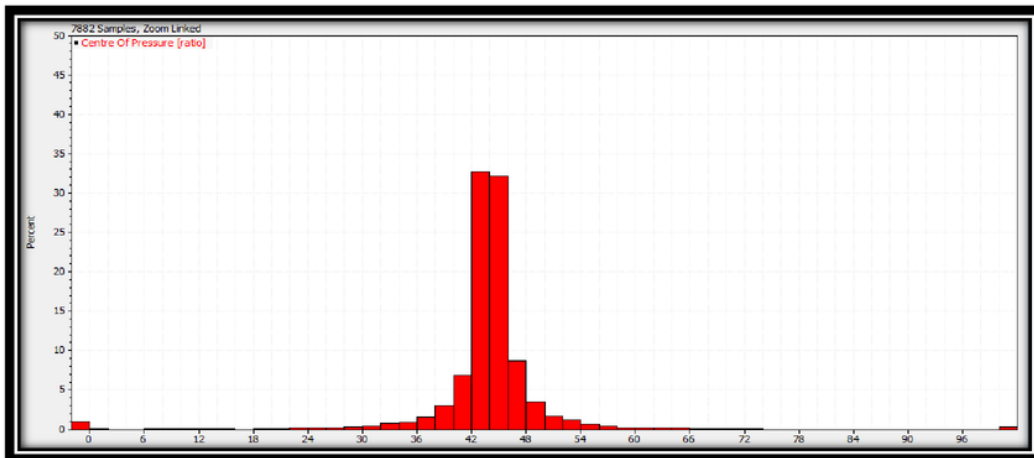


Figure (23)

COP is in optimize location which is very good to balancing the car performance, nice amount of grip which lead to high stability of the total body. The front splitter angle is feeding good amount of air under the car which is work actively with the rear wing angle 6 which is generates good down force to push down the car (McBeath, 2011).

9. F1R12

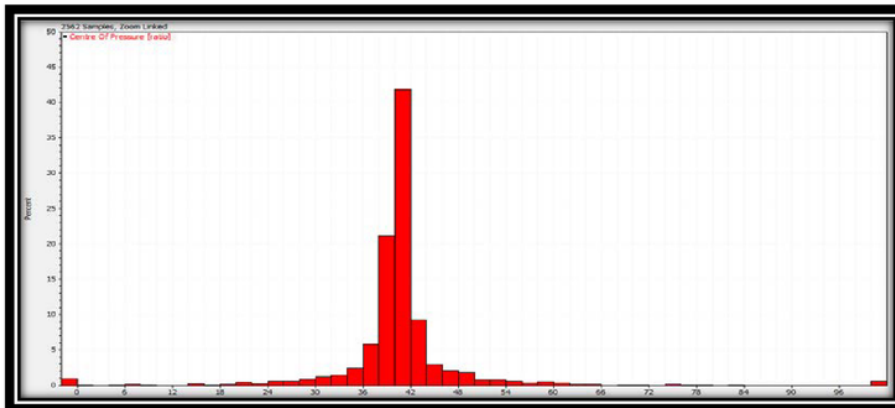


Figure (24)

COP is in near to the rear car because the rear wing angle is 12 which generates a lot of downforce on the rear than the front splitter which is allowed air pressure to go down and lift the car, But rear wing generates a lot of downforces that might cause understeer in some area of track corners but still keeps the car with nice stability (J.Bertin, 2002).

10 F1 R10

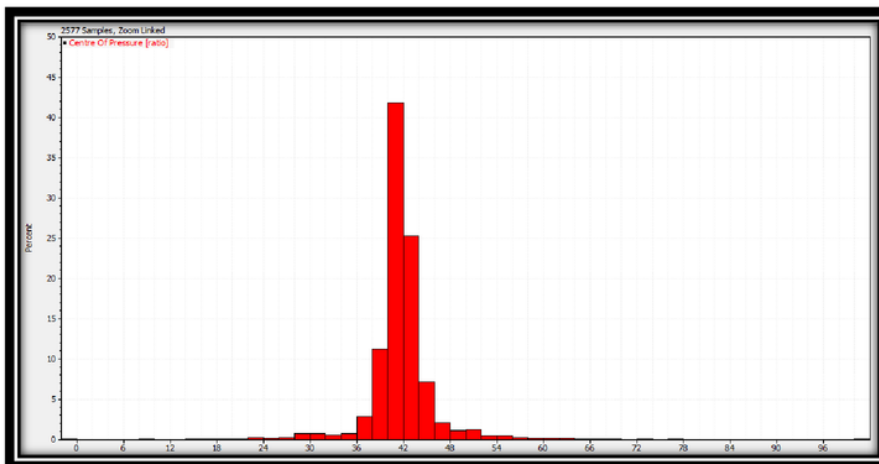


Figure (25)

The figure shows the front splitter angle is very low amount of air to go down the car comparing to the rear wing which is 10 angle, this case it keeps sort of balancing but because too much rear aero force, which occurring loss of grip and prevent speeds up the car with feels of heavy movement during the driving time (Katz, 2006).

11. F2R12

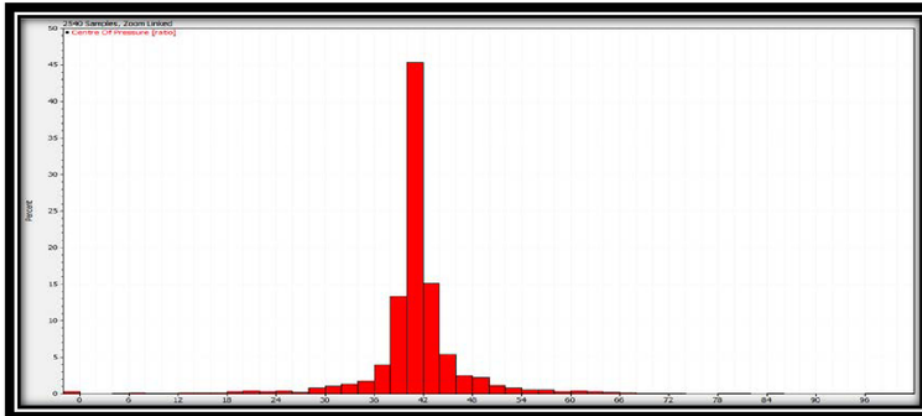


Figure (26)

Cop here is in good rear location due to the front splitter allows nice air pressure to lift the car up but the rear wing increases the downforce to specific limit which gives the feeling of very planted, low speed around the corner happened due to increasing aero rear force (Sergers, 2014).

12. F3 R12

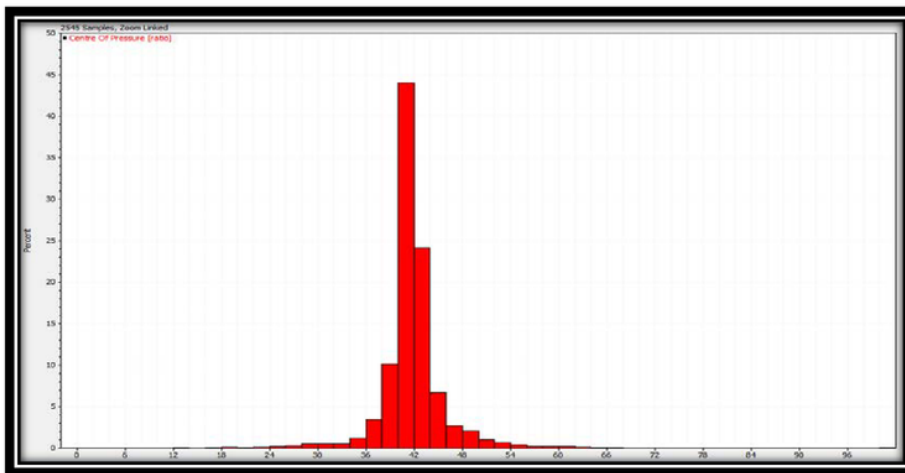


Figure (27)

A cop is located on the rear of the car surface which gives perfect performance due to very good front splitter angle and rear wing angle, but there is sort of understeer due to some increasing of air pressure under the car during speeds up in curves and hills (McBeath, 2011).

13. F2 R4 (FH2-RH4CM)

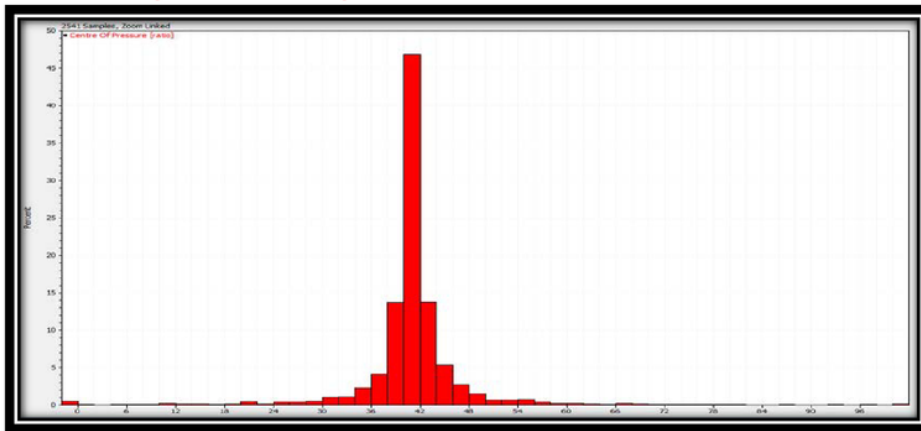


Figure (28)

COP is in a good location near to the back which gives extra grip in over all of the car balancing, but low generating downforce on the rear car it might causing lift the rear car up and losses rotation force of the rear wheels (McBeath, 2011).

14. F2.5 R4.5

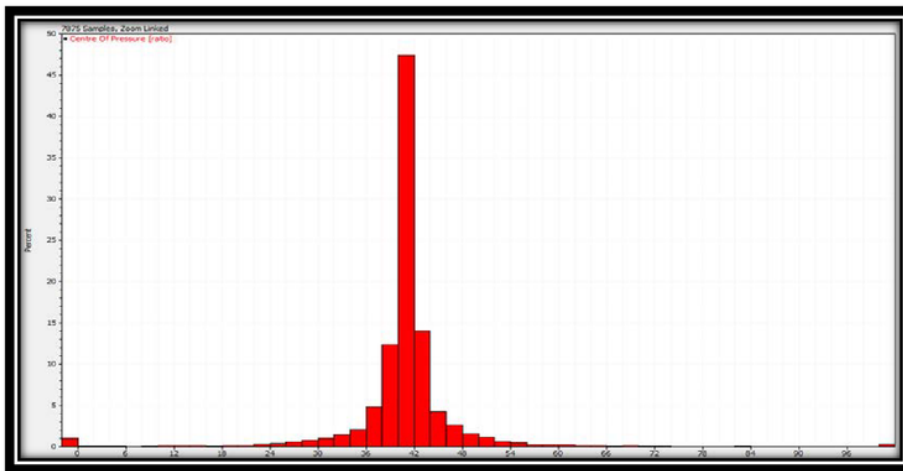


Figure (29)

COP is near to rear wing which gives reasonable balancing between front and rear but there is less downforce on the rear which guides the car more understeer on the front and desired to speeds up around corners (Sergers, 2014).

13. Comparison between the setup laps.

Overall lift (Downforce)

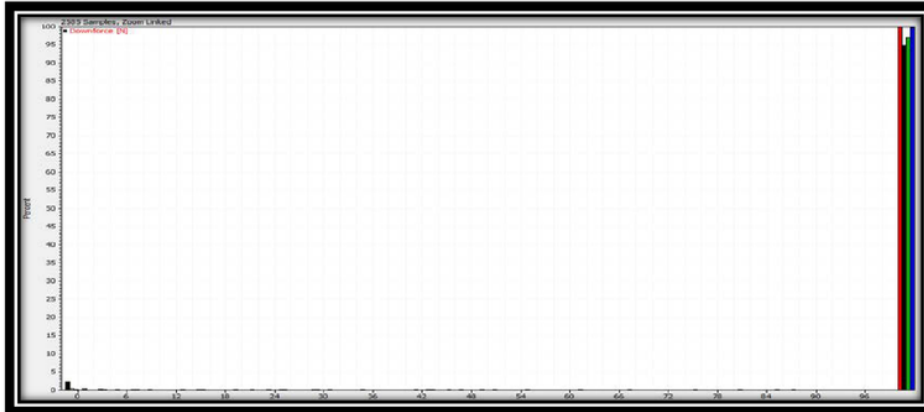


Figure (30)

According to Jorge Serrers, the Down force is air pressure that pushed the car down, Formula 3 racing cars is able to produce more than three times of its weight as downforce, if the air pressure under the car is low that increasing the downforce on the top of the car, the rear wing enhancing the down force or negative lift to push the car down, there is type of disparity between F18R18 and F9R9 because the front and rear same wing angle value for each lap. Theoretically the downforce is able to pin down, For example, Here even if the driver decide to driving upside down which it can be happened on some track bends because the F3 can generate down force to increase weight to increase grip and total stability, the highest downforce is F2R12 which is 100%, gives extra force to push the car forward, the rear wing decrease the rear turbulences which was sucks the rear aero and slow the car speed (Formula One World Championship Limited, 2019).

Down force B

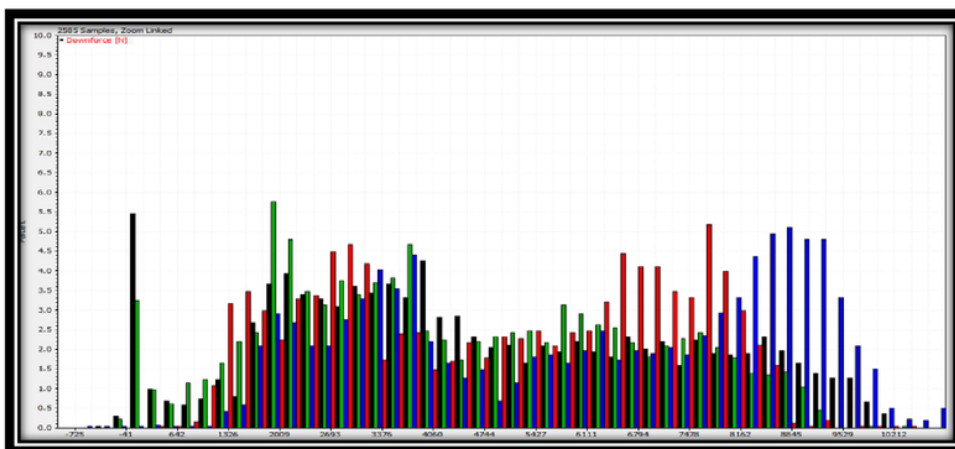


Figure (31)

Overall lift or downforce for F2R12 is typical rear wings angle and front splitter angle to use it for dry race, Because the front aero force is reasonable for lift up the car with small amount of air under the car meets the high aero rear force is being created through the rear wing, which it gives the quiet nice weight to push the car forward (McBeath, 2011).

WT (Balance)

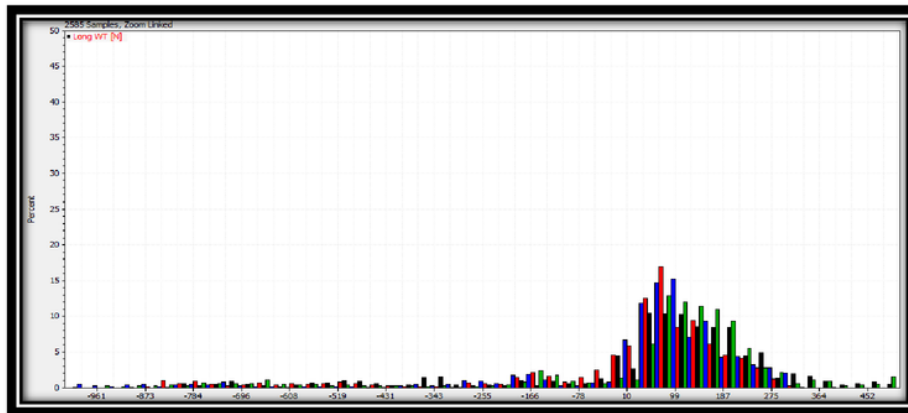


Figure (32)

Weight Transfer(WT) relies on the longitudinal force which pushes the car back or forward due to the front or rear aero force, so positive WT means the rear aero force in this laps is work good and helps the car to go forwards increase the brake performance and increase the grip, if the WT is negative it means the high aero force in the front which pushes the car down and lose the grip and stability. As the figure shows the F1R1 is the positive highest value of longitudinal force (seat.com, 2019)

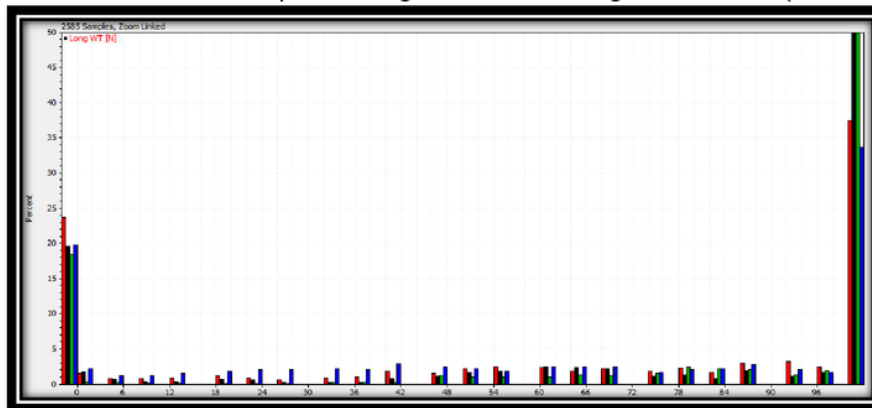


Figure (33)

Reasonable Positive WT in the car it gives may advantages such as, feel the car in corning speed and brakes good which decreases spending time on the track,F2R12 is perfect WT transfer balancing comparing to other laps (McBeath, 2011).

COP

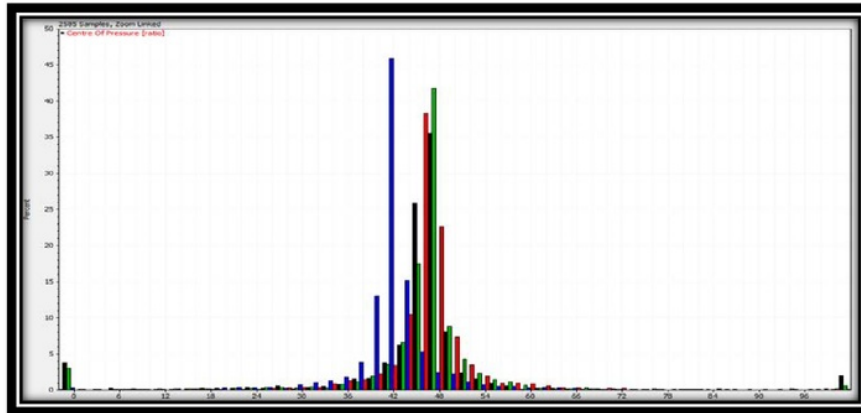


Figure (34)

COP is a term used to interpret that point of application of the ground reacting force vector, thus the total ground force vector shows the sum of forces dealing between the physical object and its supporting surface. Note the centre of pressure is moving always not staying reliant on the aero front and rear aero forces (J.Bertin, 2002). The figure shows the COP is better performance with F2R12 which is blue line, COP is functioning on the rear more than the front because the most of the laps rear wings angle between 9, 18 and 12 which is maximize the downforce and COP on the rear, Blue line shows COP has stayed on the 42% of car body between 45 to 55% which means the aero on the front is reason to increase the downforce, which is more beneficial to keep high performance (Sergers, 2014).

Total Math channels

Name	Summary	
Expressions		
☒ speed [m/s]	(Car Speed) [m/s]*1000/(60*60)	Add Expression...
☒ Long WT [N]	(MASS) [kg]*G Force Long [G]*G [m/s^2]*1/CxG [m^2]/Wheelbase [m]	Add Scale/Offset...
☒ Front Aero [N]	(Tire Load - FL [N])-(Tire Load - FR [N])-(FLO [N])-(FRD [N])-(Long WT [N])	Add Filter...
☒ Rear Aero [N]	(Tire Load - RL [N])-(Tire Load - RR [N])-(RLO [N])-(RRD [N])-(Long WT [N])	Add Plugin...
☒ Total Aero [N]	(Front Aero [N])+(Rear Aero [N])	Add 2D Table...
☒ Centre Of Pressure [ratio]	(Front Aero [N])/(Total Aero [N]*100)	Add 3D Table...
☒ Aero Drag Force [N]	(0.5*Air Density [kg/m^3]*CD*(speed [m/s])^2)	Add Constant...
☒ Corner Radius [m]	(speed [m/s]^2)/(G Force Lat [G]*9.81)	Delete
☒ Ackerman wheel steer angle [rad]	(Wheelbase [m])/(Corner Radius [m])	Edit...
☒ Ackerman steer % [%]	(Ackerman wheel steer angle [rad])*20.62/-0.1073/-1	Move Up
☒ Under steer % [%]	abs(Sheering Wheel Pot [N])-(abs(Ackerman steer % [ratio]))	Move Down
☒ Aero Drag [N]	0.5*Air Density [kg/m^3]*Cd*(speed [m/s])^2	
☒ Downforce [N]	(Front Aero [N])+(Rear Aero [N])	
☒ Aero efficiency [%]	(CL [N])/(Cd)	
☒ Roll Angle [deg]	atan((Ride Height FL [mm])+(Ride Height FR [mm])/2)-(Ride Height RL [mm])+(Ride Height RR [mm])/2)/(Wheelbase [m])	
☒ CL [N]	((Downforce [N])/(0.5*Aero [N])*(Air Density [kg/m^3]*speed [m/s]^2)	
☒ Roll angle [deg]	(Cayn Roll Angle [rad])*(180/(3.14))	
☒ New Long WT	((New Mass [kg])*G Force Long [G]*G [m/s^2]*1/CxG [m^2]/Wheelbase [m])	
☒ New Front Aero [N]	(Tire Load - FL [N])-(Tire Load - FR [N])-(FLO [N])-(FRD [N])-(New Long WT)	
☒ New Rear Aero [N]	(Tire Load - RL [N])-(Tire Load - RR [N])-(RLO [N])-(RRD [N])-(New Long WT)	
☒ New Down Force Lift [N]	(New Front Aero [N])+(New Rear Aero [N])	
Constants		
☒ Air Density [kg/m^3]	1.223	
☒ Area [m^2]	1.2	
☒ CxG [m]	0.23	
☒ FLO [N]	1163	
☒ FRD [N]	1163	
☒ G [m/s^2]	9.81	
☒ MASS [kg]	560	
☒ New Mass [kg]	476	
☒ RLO [N]	1580	
☒ RRD [N]	1583	
☒ Wheelbase [m]	2.73	

Figure (35)

New math channels for COP,WT, G Long Force, New front Aero, New Down force, Roll angle, Rake angle, CL, New constant mass which is 85% of total mass 560. With the original math channels it has been created before.

Car Balance (Drag Force)

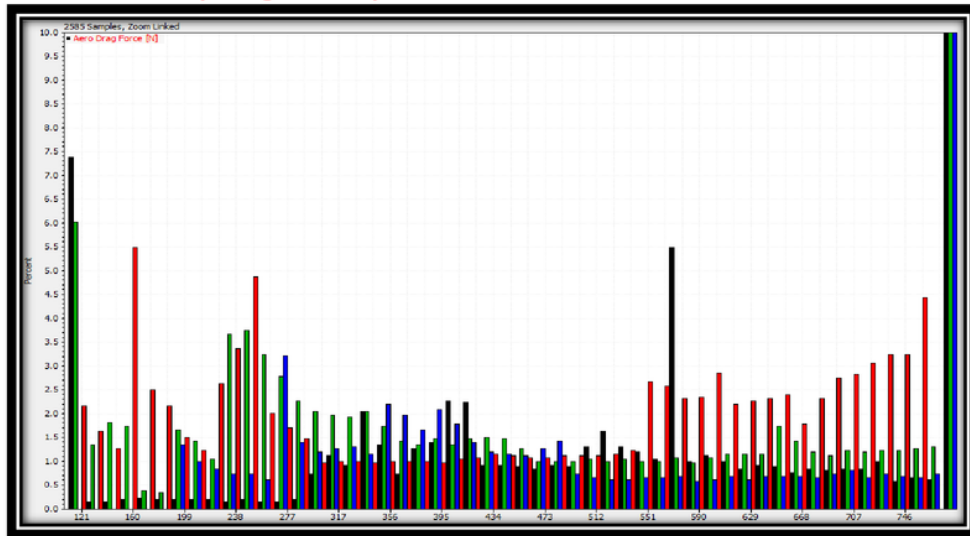


Figure (36)

Drag force is the force that resists the car moving forwards, So Drag force is decreased in some cases when the car slows down in corners and curves, F1R1 Drag force and downforce in the front and rear are close to each other, which means increase the weight in the front and in the rears that affect the speed and low distance, when the air going down the car with high amount that lift the rear car up which lose grip and stability, low brake feeling if it needs to manage the car (Formula One World Championship Limited, 2019).

Understeer

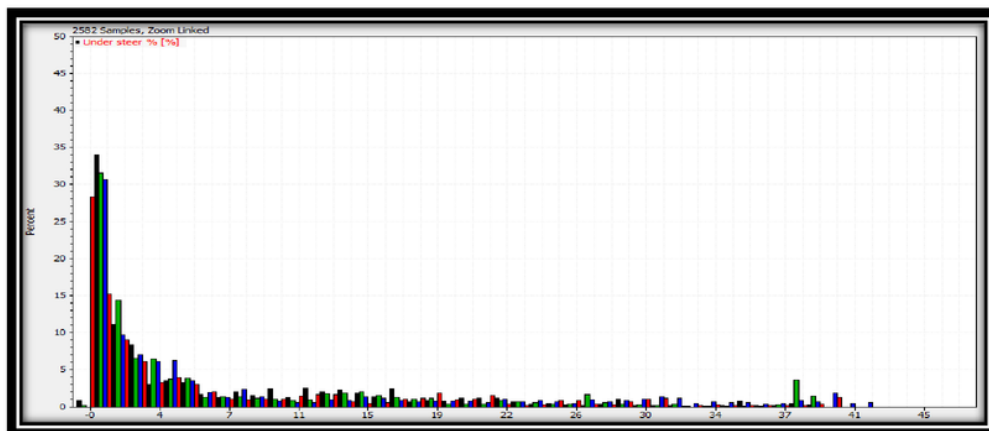


Figure (37)

Understeer is early turning on corners and quick steering correction to turn the car, which is the decision it has been taken to turn and increases the wheel grip, Here the four laps shows understeering which the recommendation to the drivers is don't turn early and give extra attention at the corners to ensure keeps the car on the track.

The previous figure shows four chosen laps to compares, for example, FIR1 show a nice amount of grip but there is exist an amount of oversteer around the corners, brake performance is nice which gives slightly more stable.

F18R18 which is the black line the highest positive value of understeer which means more stable the road surface, aero front and rear acceptable amount.

F9R9 is a green line, understeer in the front is high which guide the car to oversteering sometimes due to less stability on the front, all this affect the brake performance and burning fuel and waste the time.

F2R12 blue line which is very low understeer value in the front which guide the car for loads of grip and enhancing the stability of the car through cornering speed. This lap is recommended to use it in dry track (.buildyourownracecar.com, 2019).

Total Math channels

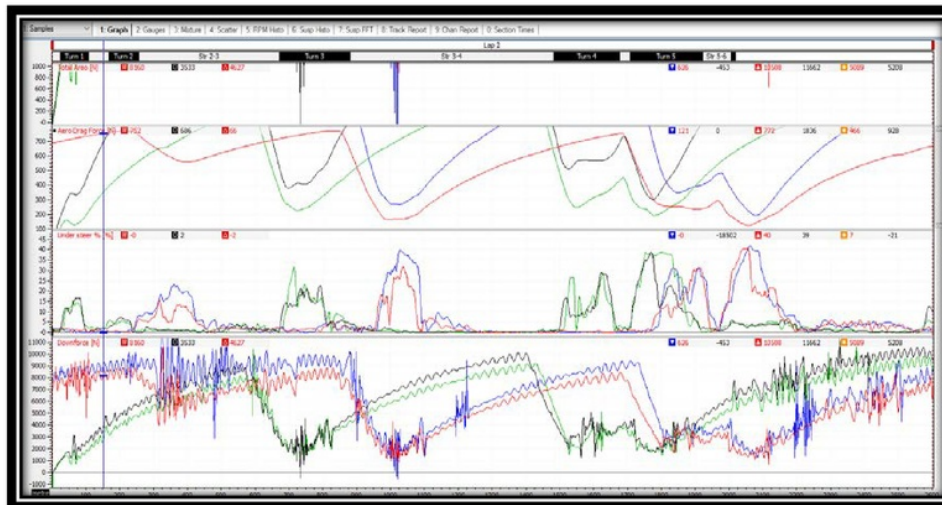


Figure (38)

This figure shows different math channels such as total Aero which is consists of aero front and rear, also aero drag force and downforce acting on the four chosen laps (J.Bertin, 2002).

Fastest Three Laps



Figure (39)

Figure shows the total Silverton circuit Laps, This laps is been done in different time but in the same place, To find finest lap chose less time spent in all circuit, the chosen three lap which they are in the next figure.

Aero Front	Aero Rear	F L Time
11	12	51.621
1	1	50:492
18	18	50:401
9	9	50:846
18	1	53:823
9	1	52:174
1	18	50:981
1	9	50:070
1	6	49:733
1	12	50:041
1	10	50:332
2	12	49:613
3	12	49:710
H 2	4	49:638
H 2.5	4.5	49:526
H 2.7	4.7	49:520

Table (4)

three bottom laps positive values to fastest time which the first one is 49:520 Sec, 2nd 49:526Sec, Third 49:638 Sec. all this from Silverstone circuit.

14. Discussion

Automotive aerodynamics is emphasis and study of the aerodynamics of racing cars, main purposes are to minimize drag force, wind noise, burning a lot of fuel produce emissions, stops undesired lift forces and other aerodynamic characteristics that cause instability during the racing car at high speed, air, and viscous must be considered in this case of study.

The downforce comes partly from the reaction of the airflow with the upper surface of a wing, but it is the interaction between the air to the lower surface of a wing that causes the majority of the downforce. (McBeath, 2011).

15 Conclusion

A cars aerodynamics is comprised of four important forces, these include Thrust Force, Drag Force, Lift Force and Down Force. The strategy of aerodynamics is the practice of using the ambient air as a beneficial part of the environment in the design of the body shape of the car during the design process. The total aerodynamic forces which appear in the way the air is moving over the car and how it is impacting the cars performance.

For example on older cars, the shape is a lot less optimised shape which increases the drag force acting upon the car when it is accelerating, this impacts the fuel consumption and the time in which it takes to cover a certain distance.

Modern cars utilise a teardrop like shape in order to reduce frontal drag area for example the design of an aeroplane which has been used on the front of cars also for this reason.

There are some tools to increase the weight on the rear and front of the car without adding physical mass, such as rear wings, splitters, diffusers and dams. These all increase the stability and grip of the car by correctly distributing the air in the front and rear areas of the vehicle (Sergers, 2014).

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