

Aerodynamics

by Jack Beynon

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Aerodynamic Vehicle Testing and analysis (F3 Car)

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BSC MOTORSPORT ENGINEERING YEAR 3

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1.0 INTRODUCTION

In this report an analysis of an aero dynamic test session will be conducted. Firstly, a test on the skid pan which is given a 1.5-hour session, in this session the f3 car will be put through various tests In order to use the data to calculate various aero dynamic loads further on in the report. This will then be carried forward onto a test session around the pembrey race track circuit where 9 different aero set ups will be chosen to be tested. This data will then be loaded into motec with additional channels written in order to conduct a deeper search into how the vehicle is acting, graphs and print screens will be provided for evidence. Then two major lap times will be further analysed to work out why the time scale was what it was and how this can be improved. This will all be summarised in an end conclusion.

2.0 RESEARCH

Aerodynamics is one of main factors when looking into any motorsport or automotive design. The two main factors for an aerodynamicist has two major concerns, the creation of downforce to help push the vehicles tyres onto the track or road and improving the cornering forces and minimisation of drag, any product of air resistance which acts to slow the vehicle down (Forumlar1.com, 2019).

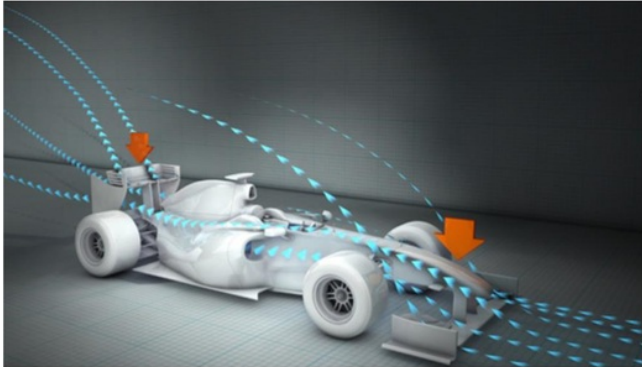


Figure.1 Forces acting on F1 vehicle

(Cook, 2016)

Race vehicle wings act in the same way as an Aeroplane wing but instead acting in reverse. Air flows at various speeds over the wing, by having to travel different distances over various contours this creates a difference in pressure or commonly known as Bernoulli's principle (Forumlar1.com, 2019). Once this pressure attempts to balance out, the wing moves in the direction of the low pressure, with race cars they use this to create negative lift or commonly known as downforce. From this vehicles and race cars are able to develop the capability of providing very good lateral G and in race cars this can be seen at around 3.5G.

3.0 METHODOLOGY – TEST SESSION ONE

Test one was conducted by using the simulator to run a skin pan test. This was done by choosing 9 different aerodynamic set ups and putting each of them through the exact same test by the exact same driver our results will be precise. This test will be allocated a 1.5-hour slot to run each set up.

AERO SET UP SHEET

<i>Set up number</i>	<i>FRONT</i>	<i>REAR</i>
1	Min	MIN
2	MIN	MID
3	MIN	MAX
4	MID	MIN
5	MID	MID
6	MID	MAX
7	MAX	MIN
8	MAX	MID
9	MAX	MAX

Figure.2 Aero test set up table.

Above in figure.2 shows the aero set up table as we can see there is 1- 9 tests in total which will be run down the skid pan and then the same around the Pembrey race track in test session 2. From these set ups the vehicle will go through one run per set up.

On the first set up the vehicle will need to stand stationary, so the static loads are able to be taken and following on in Motec we are able to find these values. Each test will be driven up to max speed at around 60M/s in gear 5 and from this the driver disengaged all drive and coasted down to 0 M/s. By running the test like this it enables two calculations to be carried out. One being the aerodynamic lift coefficient (Cl) and the other being the respective coefficient drag (Cd) .

3.0.1 METHODOLOGY - TEST SESSION TWO

As session two was running the set-up sheet around the Pembrey race track roles were set for each member of the team so the test was able to be run as efficient as possible and by making sure we were getting the exact data needed. This included someone monitoring the live data coming directly in, one making sure the aero set ups were exactly correct and others taking the data from the simulator and logging it in the appropriate folders.

SET UP NUMBER	AERO SET UP	DRIVER FEEDBACK	FEEDBACK SCORE
1	Min - Min	"Balanced, Low grip"	6/10
2	Min - Mid	"Safe, but slow and unresponsive"	5/10
3	Min - Max	"Sluggish cornering, understeers at high speed"	5/10
4	Mid - Min	"Lots of over steer"	4/10
5	Mid - Mid	"Balanced with more grip, but understeers at high speed"	7/10
6	Mid - Max	"Over steers, unstable"	3/10
7	Max - Min	"Hard to control, undriveable, lots of over steer"	1/10
8	Max - Mid	"COP feels low, Best compromise on drag"	7-10
9	Max - Max	"balances more grip but slight under/ over steel"	9/10

Figure.3 Set Up sheet with driver feedback.

Above in figure.3 shows the set up sheet with a driver feedback column. When the test was being run after each set up feedback from the driver was asked so a rough understanding was able to be noted so when analysing the Motec data we can cross reference back to what exactly the driver had implicated.

3.0.2 MOTEC METHODS

By conducting the session as it was. Two major data points were taken, one being the straight-line testing in the skid pan, and the other testing around Pembrey race track. From this data it can be inserted into the Motec analysis software, so a further investigation can be carried out. From this you would hope to see how the vehicle acts with both front and back wing angle being altered, this can affect the cars over all Centre of pressure or commonly known as COP, the balance can be affected in which the car could under steer or over steer.

As the Motec software has only stored channels to be able to conduct a deeper investigation 11 different math channels were entered. Below will state the various channels with the equations been derived. Before the channel are written Constant values need to be added in with basic known facts.

Constants -

Air density (Kg/M2) – 1.223

Cog (m) – 0.23

Front load Left 0 (N) – 1163

Front load Right 0 (N) – 1163

Rear Load left (N) – 1580

Rear load right (N) – 1580

Gravity (m/s2) – 9.81

Mass (Kg) – 560

Wheelbase (m) – 2.73

$$\text{Speed (m/s)} = \frac{\text{Distance}}{\text{Time}} = (\text{Cornering Speed} * 1000) / 60 * 60$$

$$\text{Long WT} = \Delta W = \frac{W A_y h}{t} = (\text{Mass} * \text{G force Long} * \text{Gravity} * \text{Cog}) / \text{Wheelbase}$$

$$\text{Front Aero} = (\text{Tire Load FL} + \text{Tire Load FR}) - (\text{Static Load FL} + \text{Static Load FR}) + \text{WT Long}$$

$$\text{Rear aero} = (\text{Tire Load RL} + \text{Tire Load RR}) - (\text{Static Load RL} + \text{Static Load RR}) - \text{WT Long}$$

$$\text{Aero Total} = \text{Aero Front} + \text{Aero Left}$$

$$\text{Centre of pressure} = (\text{Aero front} / \text{Aero Total} * 100)$$

$$\text{Aero Drag} = (0.5 * \text{Air density} * \text{Cd} * 1.2 * (\text{speed} * \text{speed}))$$

$$\text{Corner Radii (M)} = (\text{Speed} * \text{Speed} / \text{G force lateral} * \text{Gravity})$$

$$\text{Ackerman wheel steer (radians)} = (\text{Wheel base} / \text{Corner radii}) - 1$$

$$\text{Ackerman wheel steer (\%)} = (\text{Ackerman wheel steer}) * (28.60 / 0.1073)$$

$$\text{Under steer} = \text{Abs}(\text{Steering Wheel Pct} - \text{Abs Ackerman steer \%})$$

3.0.3 MOTEC – EXCEL

In order to calculate the co-efficient of drag value which is in the aero drag force calculation and excel spread sheet had to be formulated to do this. Below is a screen capture of the excel data log.

Figure. 4 Aero Drag Excel sheet.

Starting from the left going down from 1-9 are the vehicles front and rear set up. Then the static load section can be seen, this was taken from the skin pan data from Motec when the vehicle was stationary. Next are the vehicles constants velocity loads, from this the next two columns, aero loads and balance and aero lift coefficients can be calculated. To calculate our co efficient value cost down data from motec need to be noted. In this section the car was accelerated up to max speed and then put in neutral and coasted down. The velocity 1 value was taken as the vehicle starts to slow down with velocity 2 coming just a second after, these both were logged, and their times taken also, the next parts was to take the velocity 3 & 4 value which is when the car is coming to a stop again both these velocities and times were taken. It is not necessary to coast down to 0m/s as if stopped at 20m/s the drag forces calculated would be the same. Below in figure.5 is an image showing how this is done.

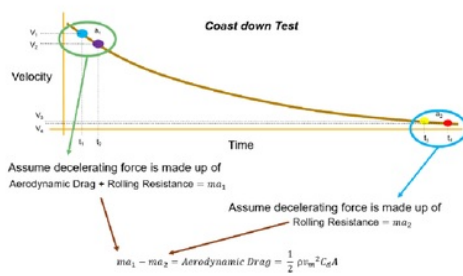


Figure.5 Coast down test (Tudor, 2019)

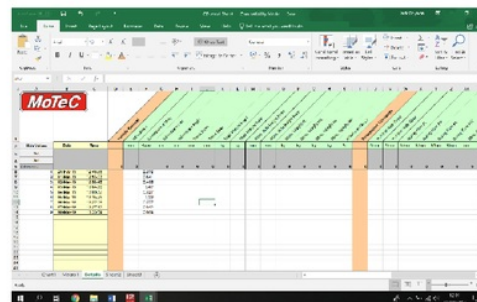


Figure.6 Motec Cd values

Once this data has been calculated the motec software can be loaded up and the excel sheet can be linked. By going on the Pembrey lap data each lap time can be read for each set up and another column can be added as Co efficient of drag, and our calculated values can be added in. This is clearly shown in Figure.6

4.0 SET UP X-Y GRAPHS

In this section of the report the Total Lift V Speed graphs will be shown, from looking into these charts a reference can be made back to section 3.0.1 which shows each set up and what the driver's feedback was, and hopefully from this an analysis can be made on how the car was acting.

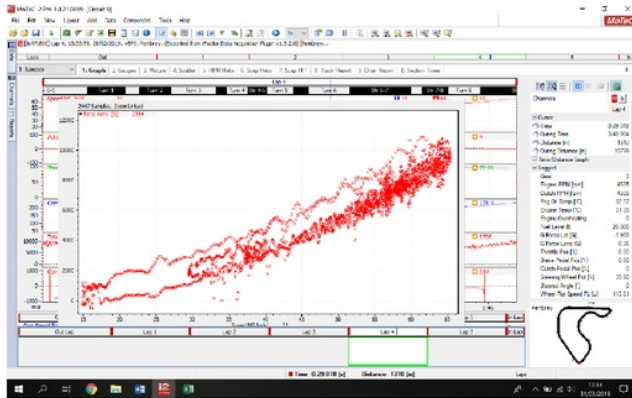


Figure.7 XY graph of set up 1 Min- Min

In figure.7 the data set from the vehicles set up 1, this had the front wing on 1 and the rear one on also. The first comment to make is that the curve which the lift is going up in a uniform curve in which we would call parasitic drag. Where the scatter plots are cluttered together is where the vehicles speed is increasing, and the force is increasing this set up has an average aero of around 8000N and when referring back to figure.3 the driver states that the vehicle is balanced but with the scatter point being low and below the curve it relates to how it has low grip also

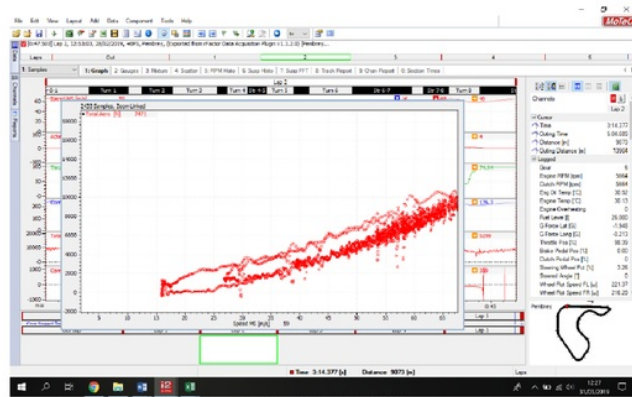


Figure.8 XY Graph of set up 2 Min-Mid

Figure.8 shows the graph of set up 2 which had the front wing set a 1 and the rear wing set at 9. As we can see this graph is much different than the first set up, as this set up has a much lower total lift than the first with a lot lower average of scatter plots at around 2000-3000, as noted by the driver this set up was safe but unresponsive.

4.0.1 SET UP XY GRAPH

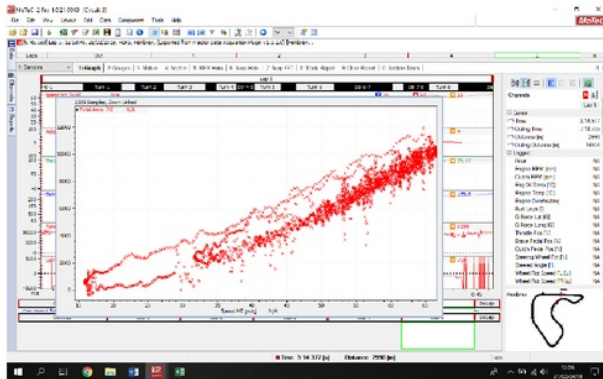


Figure.9 shows set up 3 which was the front wing at 1 and the rear wing at 18. This graph shows that as the speed gets higher most of the scatter points are lower down, as fed back from the driver he said that as the vehicles speed increased the car would understeer and this is because the car is seeing less aero force.

Figure.9 Graph of set up 3 Min-Max

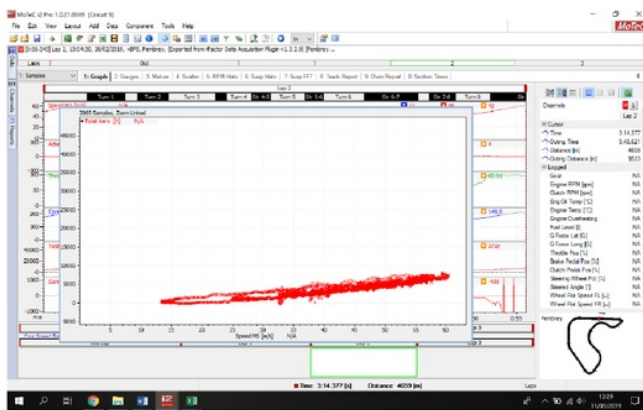


Figure.10 Graph set up 4 Mid-Min

Above in figure.10 shows set up 4, this consisted as a front wing on 9 and rear wing of 0. This set up shows a completely different form as opposed to the previous. This has a contact total aero force across all speeds it doesn't affect it that much. The from this it can be suggested that the vehicle would act un balanced and understeer a lot around the course. And if we refer back to the set-up page with the feedback on our driver commented that this would be a 4/10 set up with the car understeering constantly.

4.0.3 SET UP XY GRAPHS

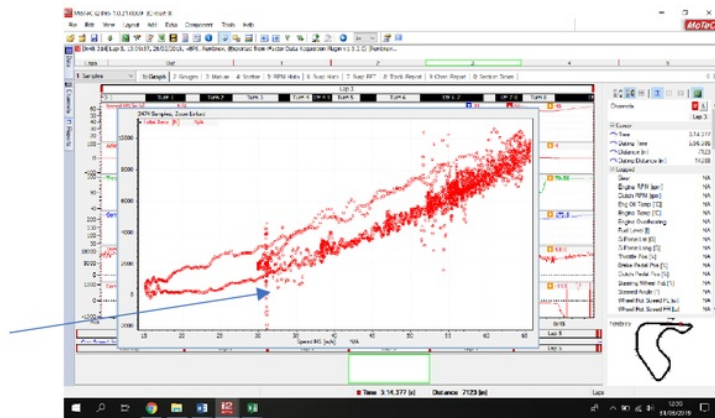


Figure.11 Graph of Set up 5 Mid-Mid

Set up 5 was one of the highest rated set ups from the driver's feedback when the test was run. as can be seen from the graph above the flow of scatter points are very uniform and have a maximum total aero of 10583N. Outside the area there are some plots which show different, the blue arrow shows these points. Most of these plots are when entering major corners which would suggest that the vehicle is understeering, but it has an overall good balance. This relates back to exactly what to our driver said.

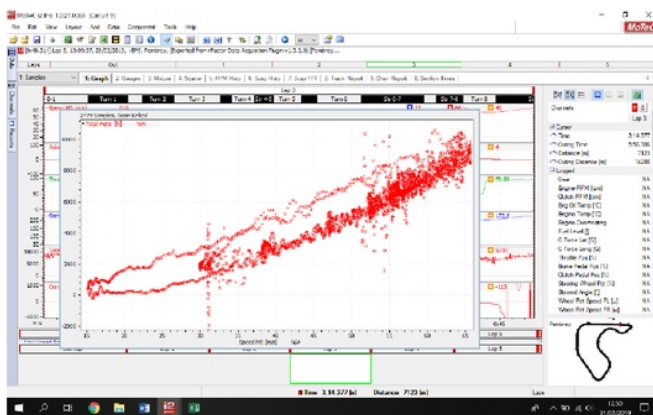


Figure.12 Graph of Set up 6 Mid-max

Above in figure.12 shows the XY graph for set up 6, this set up had the front wing on 9 and rear wing on 18. When looking into the graph there is a lot of scatter plots all over and they are not as clumped together as the other, this tells us that the vehicle is very unbalanced and that it is likely to oversteer a large amount. And when referring to our driver feedback section that is exactly what he said.

4.0.4 SET UP XY GRAPHS

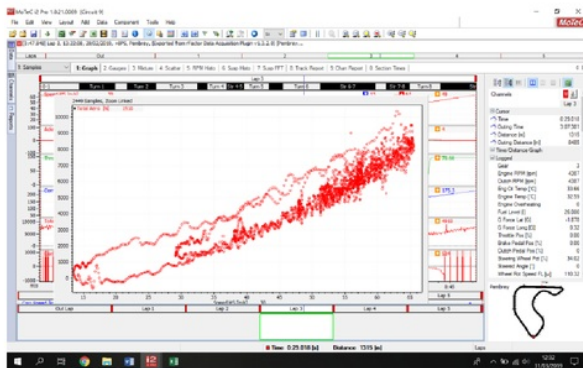


Figure.13 Graph of Set up 7 Max – Min

Figure.13 shows the set up 7 this had a front wing of 18 and rear wing of 1. This set up would never be used on any cars as with the front wing at 18 and rear on one it would be basically undrivable. This would be seen as huge amounts of over steer as the car is just completely un drivable and when referring back to the chart our driver stated the same and struggled to even get one lap around the pembrey circuit like this.

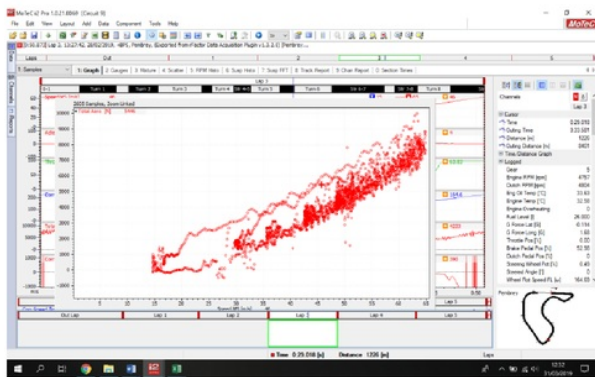


Figure.14 Graph of set up 8 Max-Mid

Set up 8 which had a wing set up of 18 front and 9 rear. When looking into the graph the curve can be seen to increase smooth with no big scatter points going off as in comparison to the previous set up 6. This set up is balanced and seems to be one of the best as the lap time is second best. The driver implicated that this was the best compromise on drag and the COP (centre of pressure) on the vehicle seems low.

4.0.5 SET UP XY GRAPHS

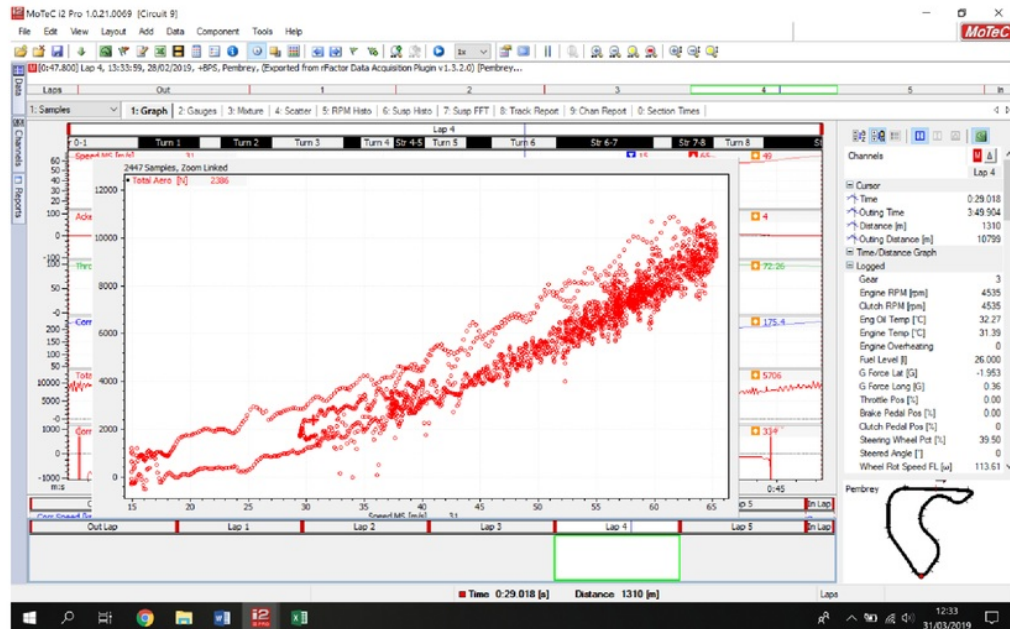


Figure.15 Graphs of Set Up 9 Max-Max

In figure.15 shows the graph of Max-Max, in the graph we can see that most of the scatter point are cluttered together which suggest that this vehicle isn't under or over steering as much as the other set ups, but some points do suggest at some points the car was undergoing some light over and understeering. This is mentioned by the driver when the feedback was given during the testing. This set up gave the fastest lap time at 47.800, the driver mentioned that this was a comfortable set up but there is room for improvement.

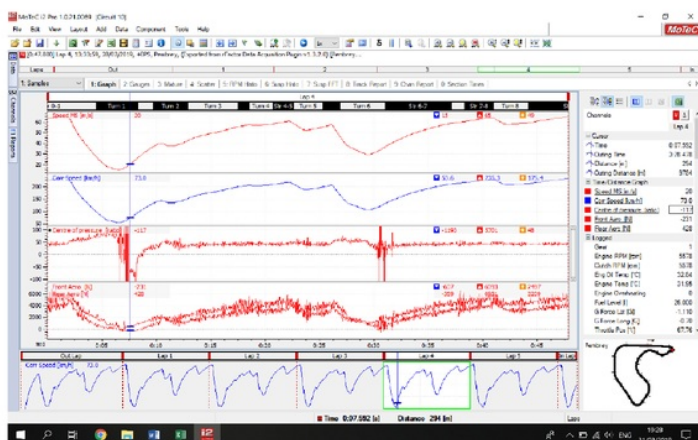


Figure.16 Screenshot of motec data set up 9

figure.16 shows a print screen of the motec data showing set up 9 around pembrey race rack. the rear and total aero are fairly balanced together with the centre of pressure being -117 when entering corner one.

5.0 LAP ANALYSIS SET UP 4

In this section of the report two lap times will be compared, this will consist of set up 4 which was the slowest around pembrey and then set up 9 which was the quickest. Below set up 4 will be analysed first.

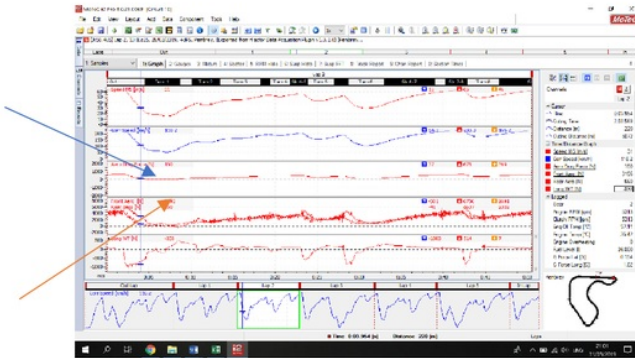


Figure.17 Motec data from set up 4

As mentioned previously this vehicle was set up with a wing angle on 9 at the front and a rear wing set to one. As most would know, no one would ever run this set up as the car acts as you can imagine. From having a greater angle at the front wing the rear wing doesn't give any downforce to the rear tyres which means no tracking and the steering of the vehicle is harder, the blue= arrow above shows the aero drag force of this set up shows to be around 150N which is very low. Also when looking into the data the orange arrow is representing the aero drag force of front and also the rear, this can be seen as 3196 on the front and 660 rear. As the car is feeling unbalanced the driver is unable to get on the throttle as well as he wants to when exiting corner one, this is what let this set up down.



Figure.18 Motec data from set up 4

As seen in figure.18 the driver is unable to get on the throttle as he must correct for the unbalance of the vehicle this is shown in figure.19 below.

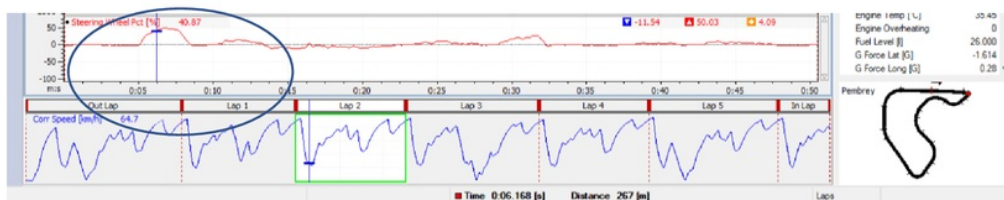


Figure.19 Motec data from set up 4

5.0.1 LAP ANALYSIS SET UP 9

In the previous page set up 4 had been analysed, now set up 9 will be investigated to see how it was the fastest lap and why.

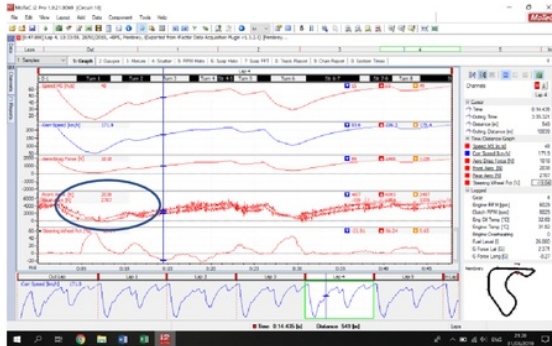


Figure.20 Motec data from set up 9

For set up 9 the wing angle of the for the front of the vehicle was 18 and the rear also 18, this would mean that we would see a large aero force and by looking at figure.20 that the aero drag force is much great with the data logging it at 1018N when coming out of corner one. The above circle is showing the front and rear aero force with the front being 2038N on the front and 2707 on the rear of the vehicle. As comparison back to set up 4 this is a massive difference.

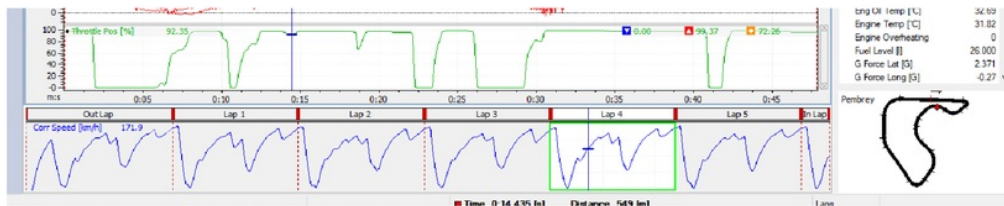


Figure.21 shows the throttle position of set up 9

As seen in figure.21 the driver is much more fluid on the throttle his consistency is much better than the previous set up which is improving his lap time greatly when exiting the corners in order for him to gain a better time. When the driver drove with this set up he mentioned it as the best but he could still encounter some over steer and under steer at high revs, this can be seen below when looking into the understeer channel

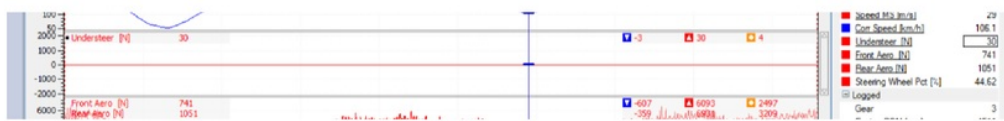


Figure.22 Motec data showing understeer

Above in figure.22 the driver is under going some under steer on turn 6 when exiting the corner.

6.0 ANALYSIS CONCLUSION

Throughout this report an investigation has been carried out in order to look into detail of how a vehicle acts with different aero set up, this was done by conducting a test in the skin pan to be able to use various equations to work out different aero forces on the vehicle. Then taken to pembrey the car was put through various laps of each set up to be able to get the data needed. This data was analysed in motec by using various channels to work out why the vehicle was acting in this way and why. Throughout the report various wing angles alters how the car behaved dramatically, some being good and some being bad. By using set up 9 which had a wing angle of 18 front and 18 rear the car handled well, with minimal under steer as compared to other set ups and was able to set a good time. However if the ride height of the vehicle was able to be altered as well as the ride height a optimum set up might be able to made and if the vehicle was tested around a dry circuit a better lap time would hopefully be able to be set.

BIBLIOGRAPHY

Cook, R., 2016. *Aerodynamics*. [Online]

Available at: <http://www.rogercook.co.uk/2016/03/f1-aerodynamics-in-schools.html>

Forumlar1.com, 2019. *Aerodynamics*. [Online]

Available at: <https://www.formula1.com/en/championship/inside-f1/understanding-f1-racing/Aerodynamics.html>

Tudor, T., 2019. *Aero Drag forces*, Swansea: s.n.