

Assignment 2 - Aerodynamic Vehicle Testing and Analysis

by Jamie Prewett

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Race Engineering – Aerodynamic Vehicle
Testing and Analysis

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1. Introduction

The aerodynamic setup of a racing vehicle is a key element to maximising the vehicle's performance and stability. Professional motorsport teams spend hundreds of hours testing and analysing vehicle aerodynamics, adjusting elements such as frontal and rear downforce by millimetre increments to ensure the vehicle is reaching its optimal performance.

The objective for this assignment is to use the Base Performance Simulator to adjust the aerodynamic setup of a Formula 3 vehicle and analyse the performance and stability of each setup. With the peers in my group, I will conduct two simulation tests under a strict test plans, consisting of adjusting the front and rear downforce and ride height. The test results will be critically analysed through the use of calculations and math channels within Motec software. Foremost, I will choose the most favourable setup for the circuit and justify my opinion.

2. Literature Review

(2.1.)

Pembrey circuit is a racing circuit situated in Carmarthenshire, United Kingdom (Wikipedia, 2018). We chose this circuit for our second test session because of its length of 1.456 miles (RacingCircuits.info, 2019). It will enable us to produce a number of laps with each setup without going over the allocated time period we have in the simulator.

The circuit consists of 8 turns in total, each requiring a different rate of speed to successfully complete. This will allow us to analyse the data of the Formula 3 vehicle at different cornering speeds. The circuit also consists of two straights, allowing us to analyse the data of the Formula 3 vehicle while it travels at a high speed.



Image 1 – Pembrey Circuit Layout (RacingCircuits.info, 2019)

3. Methodology

(3.1.)

The first simulator session consisted of a series of Coastdown tests with the F3 model vehicle. Before we conducted the test, we created a test plan of different setups to use during the session. Refer to section 7.1 in my appendices for the test plan. This allowed us to utilise the full simulator session and collect sufficient data for the different setups. The Base Performance Simulator easily allowed us to finely tune the vehicle according to our test plan.

Each Coastdown test was carried out under a specific plan to ensure a fair test of the setups. The F3 vehicle accelerated from the start line and was held at 220 km/h in 5th gear, before being put into neutral to begin the Coastdown. The vehicle was allowed to slow down to a complete stop before we moved onto the next setup. While the tests were being conducted, I observed the vehicle for noticeable stability issues due to the unbalanced downforce and recorded my findings.

(3.2.)

For the second simulator session, we used Pembrey circuit to analyse our chosen setups in a track environment. Due to the allocated time allowed in the simulator, my group and I decided to only adjust the front and rear downforce for all but two setups of the F3 vehicle. Alike the first session, we created a test plan to utilise our time in the simulator. Refer to section 7.2 in my appendices for the test plan. Unlike the first session, we assigned each person within the group a job role to collect the data effectively.

We anticipated that we would be able to complete 5 laps with each setup but due to the allocated time set for us to record our data, some setups completed more laps than others. As the testing ensued, I asked the driver what he thought about each setup and to rate each one out of 10. Refer to my analysis section for the driver feedback.



Image 2 – Simulator Session 2 (Prewett, 2019)

4. Analysis

(4.1.)

To display the coastdown test results effectively, I have created a spreadsheet through the use of Microsoft Excel. The spreadsheet consists of important data copied from the Motec software, which were used to calculate equations to discover the aerodynamic lift and aerodynamic drag coefficients of each setup.

Each setup is labelled alphabetically, so I will refer to setups as "A, B, C" etc. throughout my analysis. Firstly, I input the 'static' data into the spreadsheet as the F3 vehicle was parked on the starting line. The ride height and tyre loads of the vehicle were constant at this time, as no forces were acting against the vehicle.

The constant velocity data in the spreadsheet was taken when the vehicle had reached its maximum velocity of around 220 km/h. The vehicle was held at around 6480 rpm in 5th gear for a few seconds, which made it easier for me to record the constant velocity data. As you can see within the spreadsheet, the vehicle reached different maximum velocities as each setup was applied. Although not a substantial amount, the maximum velocities of the setups ranged between 220 km/h to 218.2 km/h, a difference of 1.8 km/h. This is one example of unbalanced downforce, as the forces acting against the vehicle are restricting it from producing its maximum potential. I also converted the constant velocity results from km/h to m/s for my aerodynamic calculations.

The coastdown data section of the spreadsheet consists of four data points as the vehicle is slowing down. This is essential to my investigation as the setups that produce the best aerodynamic results take longer for the vehicle to slow down to a complete stop. To ensure a fair test between each setup, I have applied the following rule:

- **V1 & T1**

Record the lap time when the vehicle slows to 190 km/h.

- **V2 & T2**

Record the lap time when the vehicle slows to 160 km/h.

- **V3 & T3**

Record the lap time when the vehicle slows to 40 km/h.

- **V4 & T4**

Record the lap time when the vehicle slows to 10 km/h.

Unfortunately, data for V4 & T4 were not available for some setups due to insufficient data logging. With these results inserted into spreadsheet, I was able to calculate the deceleration forces of the vehicle slowing down. These calculations, along with others to complete the spreadsheet, can be found under section 7.3 of my appendices.

(4.2.)

The use of additional math channels within Motec are crucial for me to investigate data that is not pre-set in the software. The math channels will allow me to monitor the vehicle's behaviour in more detail. To begin the process, I needed to establish all of the constant values that are relevant to my math channel calculations. To do this, I clicked on **Tools > Maths > Add Constant** within the software and input the following constants:

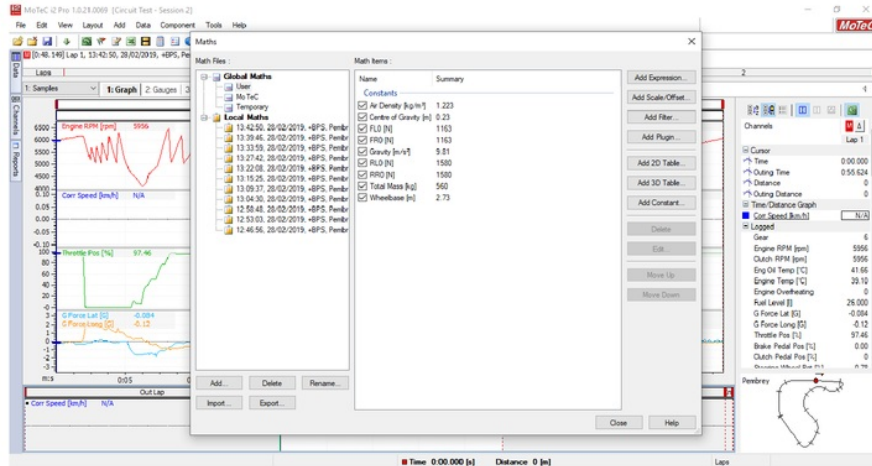


Image 3 – Constants inserted into Motec (Prewett, 2019)

These constants were used to create the math channels I required. As you can see, the 'FR0'/'FLO'/'RR0'/'RLO' values represent the static tyre loads of the vehicle with the full downforce and minimum ride height setup.

The additional math channels can be created by clicking **Tools > Maths > Add Expression**. Through this feature, I was able to input the equations using the constants I created and the pre-set math channels within the software. The following math channels were created to start my investigation:

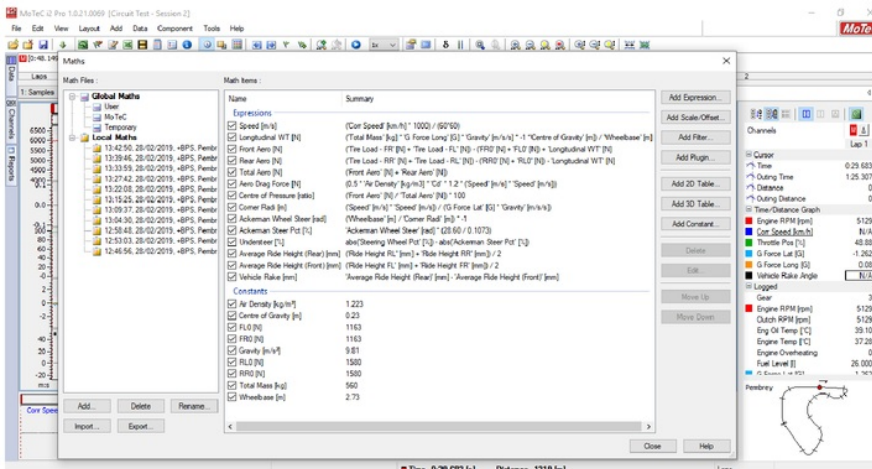


Image 4 – Expressions inserted into Motec (Prewett, 2019)

Throughout my analysis, I will be highlighting the importance of these expressions as I will be able to judge the characteristics of each aerodynamic setup from them. To calculate the 'Aero Drag Force', I required the use of coefficient of drag (Cd) values. I did this through the use of a setup sheet. I created a new setup sheet and inserted the aerodynamic specification, the date and time and the 'Cd' value of each setup. I retrieved the 'Cd' values of the relevant setups from the coastdown data, using the same 'Cd' values for the '18:18' setups as we were unable to perform a coastdown test of the '18:18 (Max/Min RH)' setups. The setup sheet can be seen below:

Image 5 – Modified Setup Sheet (Prewett, 2019)

Once I had saved the setup sheet with the necessary data, the 'Cd' values appeared onto the Motec software and I was able to implement it into my equation as a channel.

(4.3.)

It is crucial for me to analyse the aerodynamic lift and drag the different aerodynamic setups that were applied to the vehicle. From this analysis, I will be able to rule out a favourable setup for the vehicle with justification from the Motec data.

For this section, I will be analysing three aerodynamic setups that were applied the vehicle at Pembrey Circuit. I have chosen the aerodynamic setups according to the driver feedback I received during the session, which are displayed below with a quotation from the driver:

- **18:18 (Minimum Ride Height) – Red Data Trace**

"9/10; understeer at high speed, very good capabilities at lower speeds".

- **1:1 – Black Data Trace**

"6/10; low grip, pressure is close to the centre, high lift".

- **18:9 – Green Data Trace**

"3/10; considerable oversteer, can feel rear downforce but vehicle is unstable".

I have used the 'Longitudinal WT', 'Understeer', 'Front Aero', 'Rear Aero' and 'Total Drag Force' channels to examine the setups in more detail. To provide a detailed analysis of these setups, I have chosen to examine the characteristics of the vehicle on the start/finish straight and two specific corners; turn 1, when the vehicle is entering the corner at a slow speed and turn 8, when the vehicle is entering the corner at a high speed.

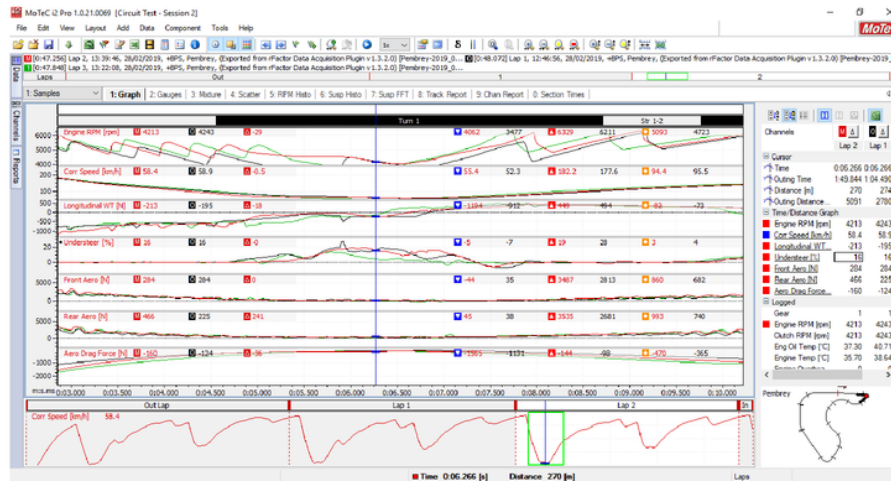


Image 6 – Turn 1 Data Traces (Prewett, 2019)

The first corner of the circuit was considered a true test of vehicle's capabilities. As the vehicle is entering the corner from such a high speed, it is more susceptible to understeer or oversteer if the aerodynamic setup is incorrectly applied.

As you can see, the 1:1 setup suffered from severe understeer while entering the corner and severe oversteer as the vehicle accelerated out of the corner. This is simply because the vehicle had minimal downforce. The unbalanced setup meant that the front wheels were being lifted by the aerodynamic forces underneath the vehicle while under braking, reducing its cornering capabilities. The minimal downforce at the rear allowed the rear wheels to lose grip while accelerating out of the corner. This was also the case for the 18:18 (minimum ride height). Although it had the most downforce, the vehicle had understeered into the corner from a high speed due to its aerodynamic imbalance. The driver feedback from both setups highlighted these issues.

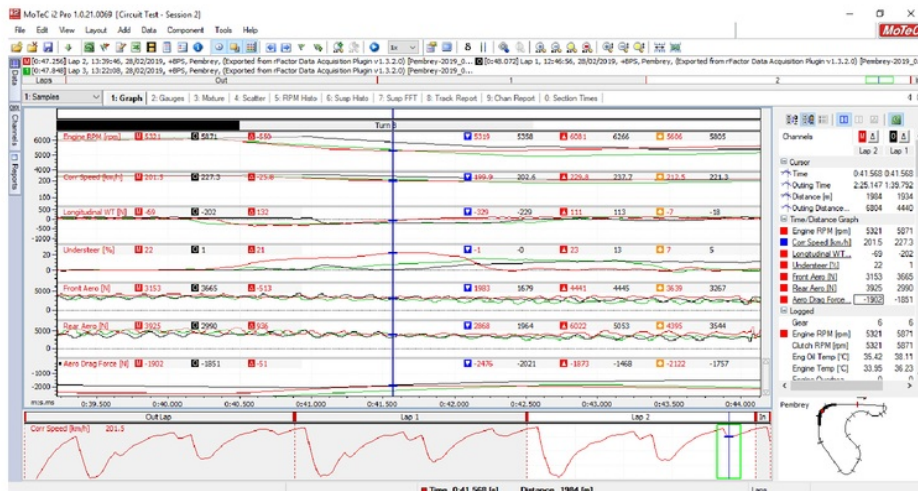


Image 7 – Turn 8 Data Traces (Prewett, 2019)

The 18:18 (minimum ride height) setup suffered from severe understeer while turning this particular corner. The vehicle enters the corner in excess of 200 km/h and due to the aerodynamic imbalance, the vehicle understeered as the driver turned into the corner. The vehicle required more rear downforce to be able to sufficiently turn the corner at that speed.

The 1:1 setup can be seen to produce a substantial amount of aerodynamic drag while entering the corner. The minimal downforce meant that the vehicle had more air resistance acting against it, thus producing more drag than the other setups. This also had a negative effect on the vehicle while exiting the corner, as it can be seen to produce an increasing amount of understeer as the aerodynamic drag increases with speed.

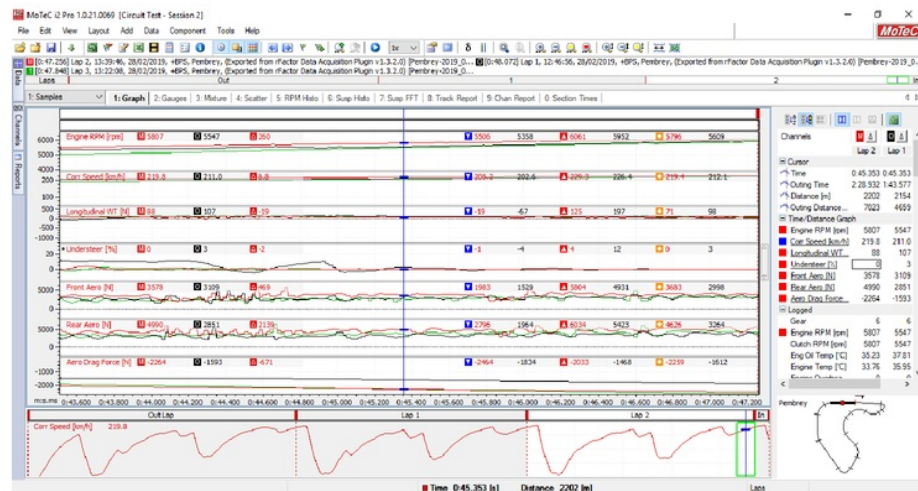


Image 8 – Start/Finish Straight Data Traces (Prewett, 2019)

As I previously stated, the 1:1 setup is producing more aerodynamic drag due to the minimal amount of downforce, which is clearly evident in this screenshot. The vehicle is producing a substantial amount of aerodynamic drag as it travels down the start/finish straight. More air resistance that is acting against the vehicle as the vehicle is travelling at a high speed.

To display the behaviour of each aerodynamic setup in a more sufficient manner, I can use the features within the Motec software to create a series of X-Y scatter plot diagrams of the vehicle while undertaking a lap of the track. To do this, I clicked on **Add > Scatter Plot** and inserted the necessary channels into the X-Y axis. The scatter plots can be seen below, with a short description of my findings:

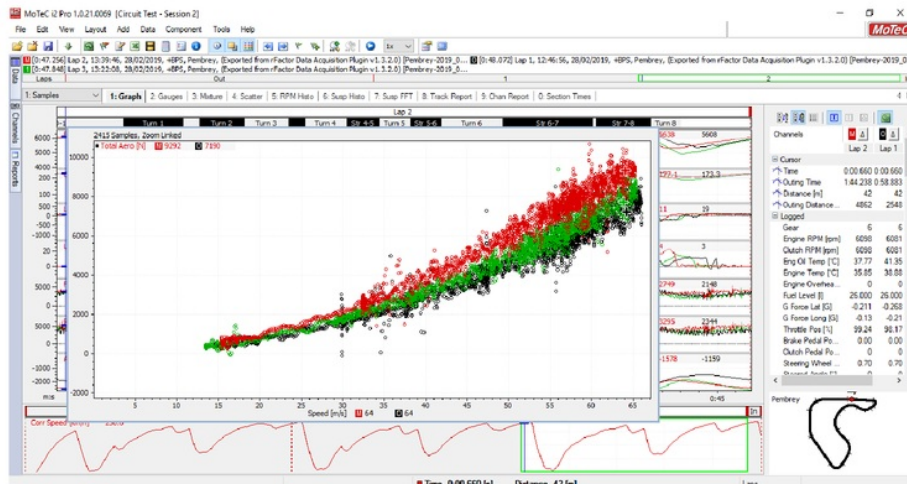


Image 9 – Total Aero/Speed Scatter Plot (Prewett, 2019)

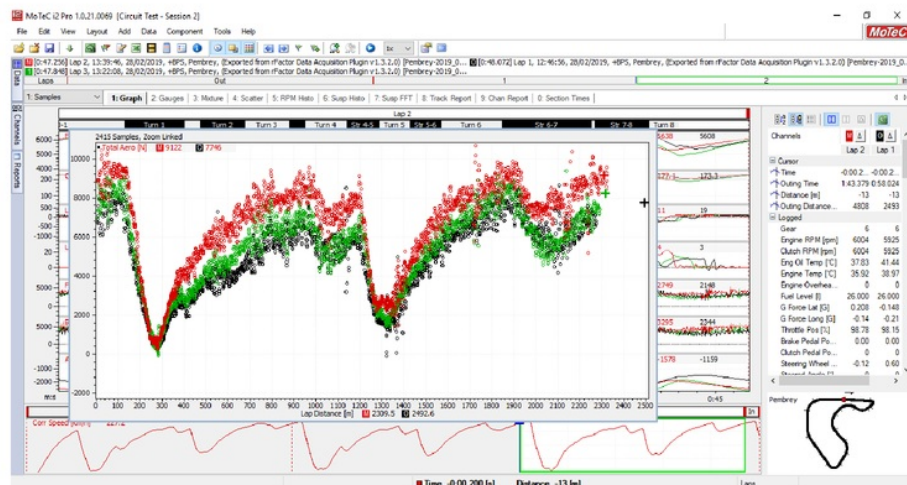


Image 10 – Total Aero/Lap Distance Scatter Plot (Prewett, 2019)

These scatter plots display the differentiation in aerodynamic lift between the three setups. As you can see, the 1:1 setup produced the most lift due to its lack of downforce. To minimise the lift, I would need provide a suitable aerodynamic balance by choosing the correct amount of downforce for the frontal and rear wings. The 'Total Aero/Speed' scatter plot is evidence that the aerodynamic lift of the vehicles increases as it increases in speed, which will explain why the driver had trouble controlling the vehicle at high speeds.

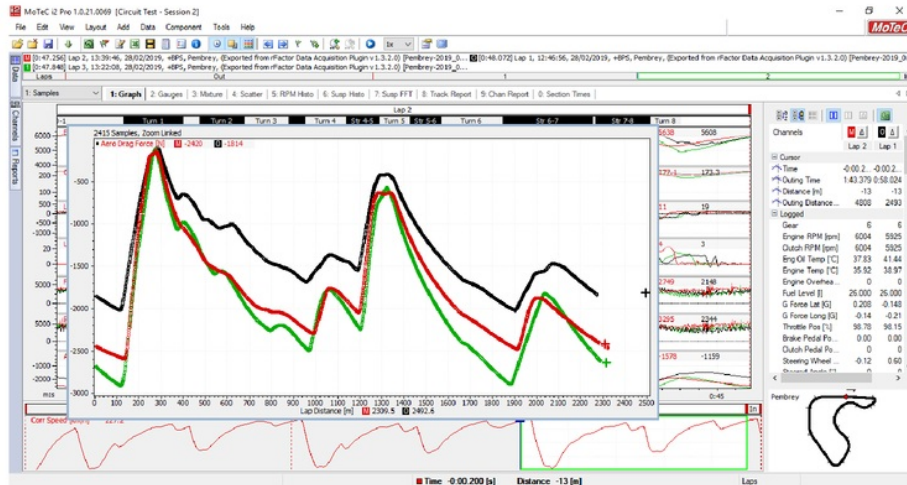


Image 11 – Aero Drag Force/Lap Distance Scatter Graph (Prewett, 2019)

This scatter plot displays how much aerodynamic drag the three setups produced during a lap of the circuit. As you can see, the 1:1 setup produces a substantial amount of aerodynamic drag due to its lack of downforce. The driver reported that the vehicle provided a poor level of grip, which is evident through the scatter plots. Particularly through turns 4 and 5 of the circuit, the driver would find it difficult to fully commit into the corners.

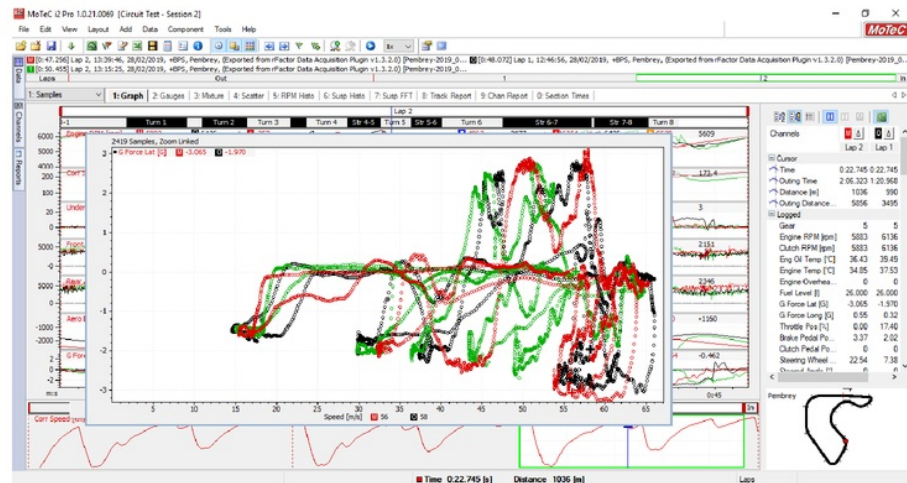


Image 12 – Lateral Acceleration/Speed Scatter Plot (Prewett, 2019)

This scatter plot displays the lateral acceleration experienced by the vehicle in relation to its speed. According to the plot, the 18:18 (minimum ride height) setup experienced the highest lateral acceleration spikes during a lap of the track. As the centre of gravity is lower due to the minimum ride height adjustment, the vehicle is able to withstand a higher amount of G-forces through the corners.

(4.4.)

The 'Ackerman Wheel Steer' calculation is important for the analysis of steering geometry. The calculation allows me to measure the steer angle of front wheels in relation to the steering wheel input. Especially in a motorsport application, the vehicle should have direct and precise steering while turning a corner. The differentiation between the steering wheel percentage and the Ackerman steering percentage will determine how precise the steering is and how much steering input is lost through the steering rack and linkages.

To provide a detailed explanation, I will be using the steering analysis test that had been created for this assignment. I added the '**Centre of Pressure**', '**Ackerman Steer Pct**', '**Steering Wheel Pct**' and '**Corner Radii**' channels into Motec to display the relevant data traces. These channels required manual scaling to display the results effectively, so I set each channel to a scale of a minimum of -100 and a maximum of 100.

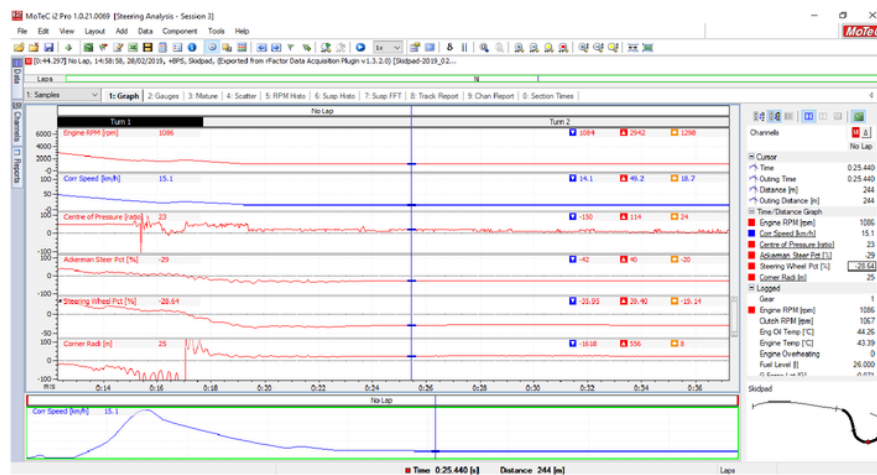


Image 13 – Steering Analysis Data Traces (Prewett, 2019)

The screenshot above displays the steering characteristics of the vehicle as the driver is turning the steering wheel. As you can see, there is a percentage difference of 0.36% between the 'Ackerman Steer Pct' and 'Steering Wheel Pct' channels as the vehicle is turning the corner. This shows that a very minimal amount of steering input was lost through the steering rack and linkages, enabling the vehicle to perform well around corners due to its direct steering.

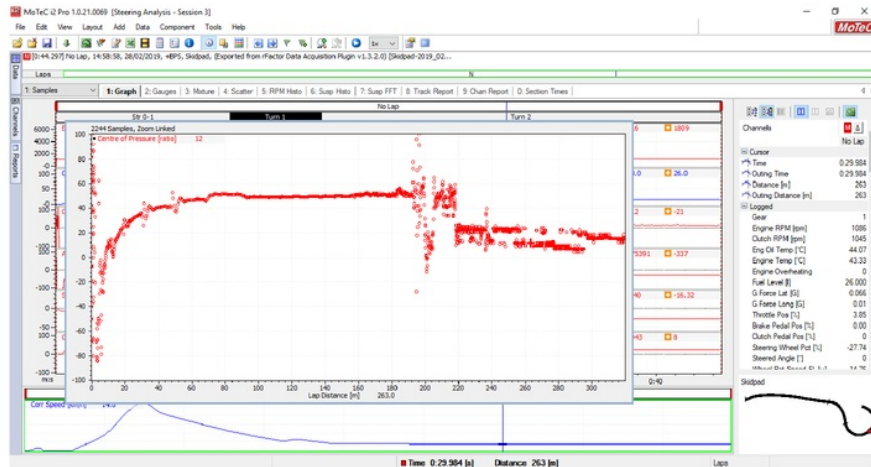


Image 14 – Centre of Pressure/Lap Distance Scatter Plot (Prewett, 2019)

According to this scatter plot, the centre of pressure remains constant as the vehicle is travelling in a straight line. When the vehicle turns the corner, its centre of pressure drops.

(4.5.)

Typically, the aerodynamic setup that produced the fastest lap time of the circuit session would be considered as the most favourable for the vehicle. The fastest lap of the session had been recorded at **00:46.598**, achieved by the 18:18 setup. To justify this choice, I will compare the front and rear aerodynamic loads of the 18:18 setup with the second and third fastest setups of the session through the use of scatter plots. The 18:18 (minimum downforce) setup produced a lap time of **00:47.256** and the 9:9 setup produced a lap time of **00:47.500**, a difference of just 0.902 seconds between them.



Image 15 – Front Aero/Lap Distance Scatter Plot (Prewett, 2019)

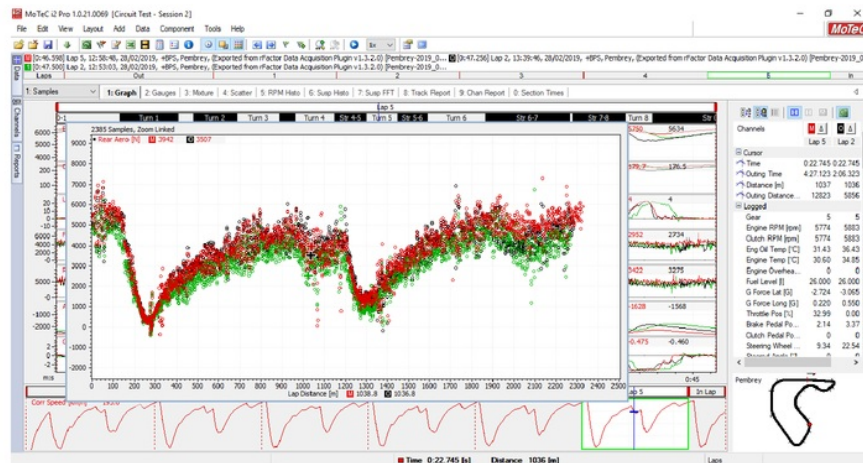


Image 16 – Rear Aero/Lap Distance Scatter Plot (Prewett, 2019)

As you can see from the scatter plots, the 18:18 setup experiences the most aerodynamic forces in comparison to the other setups. Throughout the duration of the lap, the 18:18 (minimum ride height) setup maintains the same amount of aerodynamic force at the front of the vehicle, but a noticeable drop in force can be seen at the rear when it reaches a high speed. This may be the reason why the 18:18 (minimum ride height) setup produced a fastest lap that was 0.658 seconds slower than the 18:18 setup.

The unmodified ride height of the 18:18 setup allows the vehicle to gain more aerodynamic loads at high speeds, generating minimal aerodynamic lift as the forces are able to hold it down. Not only is the vehicle able to achieve a higher top speed, but it is easier to control around the circuit, especially at high speed.

From this analysis, I can conclude that the 18:18 aerodynamic setup is most favourable for the F3 vehicle.

5. Conclusion

Throughout this investigation, I have displayed my knowledge on vehicle aerodynamics and how different aerodynamic setups can affect a vehicle's steering and aerodynamic capabilities. Through the use of Motec, I have been able to successfully analyse the recorded data from the two simulator sessions and provide a detailed explanation about each setup I have discussed in this report. I have highlighted the importance of having a correctly balanced aerodynamic setup as the vehicle will be able to reach its optimum performance and decrease its lap times, which is absolutely vital in a motorsport scenario. I have also chosen a setup that is most favourable for the Formula 3 vehicle to use competitively, using the data I have analysed.

I feel that I could have provided more analysis on the different setups we have tested. The limited word count meant that I had to restrict the amount of data I can analyse for this report.

6. References

Prewett, J., 2019. Illustrations & Screenshots. s.l.:s.n.

RacingCircuits.info, 2019. Pembrey - RacingCircuits.info. [Online]
Available at: <http://www.racingcircuits.info/europe/united-kingdom/pembrey.html#.XKGhFphKjIU>
[Accessed 4 March 2019].

Wikipedia, 2018. Pembrey Circuit - Wikipedia. [Online]
Available at: https://en.wikipedia.org/wiki/Pembrey_Circuit
[Accessed 4 March 2019].

7. Appendices

(7.1.)

Session one test plan:

Minimum downforce = 1

Medium downforce = 9

Maximum downforce = 18

Minimum ride height (front) = 2 cm

Minimum ride height (rear) = 4 cm

Maximum ride height (front) = 3 cm

Maximum ride height (rear) = 5 cm

- Front wing = 1
Rear wing = 1
- Front wing = 9
Rear wing = 9
- Front wing = 18
Rear wing = 18
- Front wing = 18
Rear wing = 1
- Front wing = 1
Rear wing = 18
- Front wing = 9
Rear wing = 18
- Front wing = 18
Rear wing = 9
- Front wing = 1
Rear wing = 9
- Front wing = 9
Rear wing = 1
- Front wing = 18
Rear wing = 18
Ride height (front) = 2 cm
Ride height (rear) = 4 cm
- Front wing = 18
Rear wing = 18
Ride height (front) = 3 cm
Ride height (rear) = 5 cm

(7.2.)

Session two test plan:

Minimum downforce = 1

Medium downforce = 9

Maximum downforce = 18

Minimum ride height (front) = 2 cm

Minimum ride height (rear) = 4 cm

Maximum ride height (front) = 3 cm

Maximum ride height (rear) = 5 cm

- Front wing = 1
Rear wing = 1
- Front wing = 9
Rear wing = 9
- Front wing = 18
Rear wing = 18
- Front wing = 18
Rear wing = 1
- Front wing = 1
Rear wing = 18
- Front wing = 9
Rear wing = 18
- Front wing = 18
Rear wing = 9
- Front wing = 1
Rear wing = 9
- Front wing = 9
Rear wing = 1
- Front wing = 18
Rear wing = 18
Ride height (front) = 2 cm
Ride height (rear) = 4 cm
- Front wing = 18
Rear wing = 18
Ride height (front) = 3 cm
Ride height (rear) = 5 cm

(7.3.)

Calculations to acquire the coastdown test data are as follows:

- A1

$$= (V2 - V1) \div (T2 - T1)$$

- A2

$$= (V4 - V3) \div (T4 - T3)$$

- Rolling Resistance

$$= \text{Total Mass} \times A2$$

- Aero Drag

$$= (\text{Total Mass} \times A1) - \text{Rolling Resistance}$$

- Cd

$$= ((\text{Total Mass} \times A1) - \text{Rolling Resistance}) \div (0.5 \times \text{Air Density} \times (((V1 + V2) \div 2)^2) \div \text{Frontal Area})$$

The coastdown spreadsheet can be found at:

https://uowtsd-my.sharepoint.com/:f/g/personal/jprewett_149702_student_uwtsd_ac_uk/EoSITTZPlhxNu5CfHQzPIA0Bbw2InrulyWXz8eepOkUHmA?e=HUQcBv