

Assignment 2

by Ashley Edwards

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Aerodynamic Vehicle Testing and
Analysis (F3 Car)

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1. Abstract.

This paper will outline the procedures and methodology used to simulate changing aerodynamic setups on an F3 test car to identify what setup is the most effective. There will be test procedures outlined as well as additional maths channels that are used to calculate parameters that cannot be measured directly. The most effective setup will be outlined, and any improvements needed also stated.

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4. Introduction

This assignment will outline the effects that aerodynamic setup has on a race car with regards to its cornering characteristics and overall lap time. The setups will be compared to each other through the use of math channels and graphs, from here the setups will be evaluated on factors such as: Lap times, Maximum lateral acceleration, Aerodynamic drag and aerodynamic downforce.

During the report there will be secondary research to allow a better understanding of aerodynamic effects, as well as mathematical calculations displayed on the data analysis package to illustrate any trends that could be measured. The data was gathered using a motorsport simulator to allow for conditions to be controlled and repeated, as well as allowing the driver to give real-time feedback during the sessions. Existing literature will be used to support any points made with regards to changes in the race cars handling characteristics between setups. When the most effective setup has been identified, there will be recommendations made as to further improvements that could be done to remove any unwanted handling characteristics.

5. Literature Review

To be able to understand the data that has been gathered, secondary research must be undertaken to gain a better understanding of the effects that aerodynamic setups have on an F3 race car. One factor that causes a negative effect due to increased wing and splitter angle is aerodynamic drag, Hucho, W 1987 describes aerodynamic drag as a resistive force caused by moving a vehicle through air at speed, and is dependant on air density, Co-efficient of drag, vehicle velocity and frontal area. Aerodynamic drag is a side effect of creating downforce as increased wing angles allow more of the wing chord to be in contact with the air passing over it and this creates a resistive force.

One benefit of aerodynamic forces is to generate downforce, Segers, J 2008 states that a rise in aerodynamic downforce increases the cornering potential of the tyres, and potential of the cornering speeds. Aerodynamic downforce is a desirable effect due to its ability to increase lap times significantly, however, increases in downforce can lead to increased drag due to the wing or splitter angle being altered past the point where it is most efficient and increases the drag.

As stated above, increasing a race cars downforce has a direct correlation to an increased cornering speed. As shown in figure 1, the addition of aerodynamic apparatus can greatly increase the race cars ability to reach a higher lateral acceleration and therefore reduce lap times. When designing an aerodynamic package for a race car, the centre of pressure or COP must be in the right place for the car to be balanced. Rehnberg, S. et al 2013 states that a COP behind the CoG would cause the vehicle to understeer more as the speed increases, whereas a CoP in front of the CoG would cause the vehicle to become more unstable and more likely to oversteer as the speed increases which is undesirable.

The most common components to fit to a vehicle to increase its downforce are front splitters, and rear wings. McKay*, N. et al, 2002 states that aerodynamic devices work by creating a pressure difference that pushes the vehicle into the ground, and different chord lengths, camber and wing angle contribute to how efficient the device is at generating downforce.

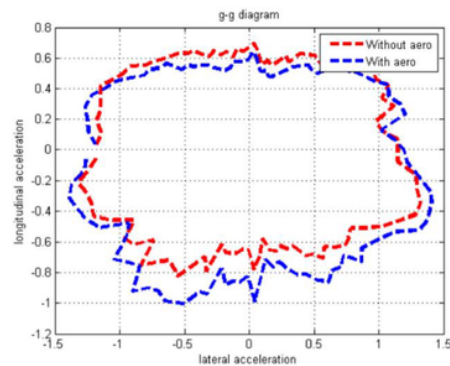


Figure 1 - G-G diagram taken from Rehnberg, S. et al, 2013

6. Methodology

The test was undertaken using a motorsport simulator to eliminate external factors such as weather conditions and car reliability from causing issues with the results. The group running the test had tasks assigned to each member to ensure the testing process was efficient and that the data could be gathered within the time allocation. The first test was a coast down test whereby the car was driven at a speed of 61m/s and then put in neutral and allowed to coast down to rest, from this test the rolling resistance, aero drag force and the Co-efficient of drag was calculated to be used in the active testing at the race track.

Once the coast down test was complete and the data analysed, the active test could begin on Silverstone national circuit. The setups that were tested were: F11 R12, F1 R1, F18 R18, F9 R9, F18 R1, F9 R1, F1 R18, F1 R9, F1 R6, F1 R12, F1 R10, F2 R12, F3 R12, F3 R12 HEIGHT F2 R4, F3 R12 HEIGHT F2.5 R4.5, F3 R12 HEIGHT F2.7 R4.7. However, the runs that will be analysed are: F18 R18, F9 R9 and F1 R6 due to insufficient data from the coast down test prior.

To analyse the effect that the aerodynamic setups have on the race car, math channels are used to allow parameters to be analysed that cannot be measured directly. Firstly, constants must be added to be used as part of the math channels when required. The constants included: Air density = 1.223 Kg/m³, COG height = 0.23m, static front left wheel load = 1170n, static front right wheel load = 1159n, static rear left wheel load = 1580n, static rear right wheel load = 1584n, gravity = 9.81 m/s², Mass = 560kg and wheelbase = 2.73m.

The longitudinal weight transfer channel must be created by using the formula $(\text{Mass} \times (G \text{ force long} \times -1) \times \text{Cog/wheelbase})$, this channel will allow the changes in longitudinal weight transfer to be plotted and compared to the other setups. The race cars speed must also be converted to M/s from km/h by using the formula $\text{Speed m/s} = (\text{corr speed km/h} \times 1000/3600)$.

The front aero force channel was calculated by using the formula $(\text{Tire load FL} + \text{tire load FR}) - (\text{static wheel load FL} + \text{static wheel load FR}) + \text{longitudinal weight transfer}$, and the rear aero force by using the formula $(\text{tire load RL} + \text{tire load RR}) - (\text{static wheel load RL} + \text{static wheel load RR}) - \text{longitudinal weight transfer}$. Once these channels have been created, total aero force can now be calculated by adding both the front and rear aero force channels together, creating a total downforce channel.

The centre of pressure ratio can now be calculated to gain a better understanding of how much the centre of pressure changes in relation to the front axle. The centre of pressure was calculated using the formula $(\text{Front aero force/total aero force}) \times 100$, by using the front aero force in the equation any increase in the COP value would mean the COP is moving towards the rear axle and if the number decreases then the COP is moving towards the front axle.

The drag force channel can now be created to allow for a direct comparison of each setup. The channel was created by using the following equation: $0.5 \times \text{air density} \times C_d \times A \times v^2$. This channel can now be used to evaluate each setups efficiency, and directly compare to find the setup with the most downforce for the least amount of drag. The next channel that was created was the corner radius channel, this was created to be used in the Ackerman steering channel. The corner radius channel was created using the formula $V^2/\text{Lateral g force} \times \text{Gravity}$.

Using the corner radius channel, the Ackerman steering angle channel can now be created to calculate the required steering angle for the corners and can be used to identify understeer and oversteer, the channel was created using the formula $(\text{Wheelbase}/\text{corner radius}) \times -1$. This gives the Ackerman steering angle in radians. From here the Ackerman steering wheel percentage channel can be created to calculate the required steering input for the vehicle on each corner. The channel was created using the formula $(\text{Ackerman steering angle} \times \text{calibration factor})$, where the calibration factor was calculated from the skid pad test.

The understeer pct can now be calculated to identify if the car is understeering with different aerodynamic setups. The channel was created by using the formula $\text{abs}(\text{steering wheel pct}) - \text{abs}(\text{Ackerman steering wheel pct})$. The aero lift force was calculated using the formula $0.5 \times \text{air density} \times \text{Cl} \times V^2$ and was used to measure the downforce being generated. Finally, the aerodynamic efficiency can be created as a channel, by dividing the Cl value by the Cd value the efficiency of each setup can be plotted on Motec.

7. Results

Looking at appendix 1, it shows the relationship between aero drag force and velocity. As the race cars speed increases the drag force also increases for each setup, however noting the red trace being the F18 R18 setup the drag force is considerably higher than the black trace of F9 R9 and the green trace of F1 R6. The increased angles of both the front and rear wings cause more of the wing to be in contact with the air passing over it, and hence creates a larger resistive force due to it producing high downforce. The green trace of F1 R6 and the black trace of F9 R9 produce very similar amounts of drag and downforce despite the increased front splitter angle and rear wing angle.

Appendix 2 shows the relationship between total lift and speed for each of the setups, with the red trace being the F18 R18, the green being the F1 R6 and the black being the F9 R9. The red trace has a much higher lift force value throughout the graph than both others and increases exponentially as the speed increases. Whereas both the green and black setups have a lower lift force value throughout and have a smaller gradient, meaning the change of speed has less of an effect on the lift force being produced than the red trace. Appendix 2 also shows a 3 m/s difference in the top speed of the car between the red trace of F18 R18 and the green trace of F1 R6, this is due to the higher drag force that the red trace is experiencing as discussed above.

Appendix 3 shows the lateral acceleration against speed that each car was able to achieve during their laps. Looking at appendix 3, the setup that could achieve the highest lateral acceleration in the high-speed corners was the red trace of F18 R18, however the green trace of F1 R6 shows higher cornering speeds but only 0.3g less through turn 2. The black trace of F9 R9 achieved the lowest cornering speed out of the three through turn 1 and cornered at 0.6g less than the red trace through turn 2. Through turn 5 the black trace achieves the highest lateral acceleration value and corners 5m/s higher than the red trace.

Appendix 4 shows the changes in aerodynamic downforce for each of the setups over their fastest lap. The red trace of F18 R18 shows a maximum front aero force of 11310n and a maximum rear aero force value of 10002n, this means that although both the front splitter and rear wing are set to their maximum angle the front splitter is generating more load into the tyres than the rear wing, this could be due to a phenomenon called ground effect. Milliken, W. et al, 1995 describes ground effect as when air passes underneath the vehicle it changes volume, this in turn increases the speed of the air passing under the car and causes a pressure difference and draws the car downwards to the road. Therefore, if the splitter was to be angled such that it could create an increased ground effect then the front splitter could generate more downforce than the rear wing despite the size difference.

Looking at appendix 5, the centre of pressure was 46% for both the black trace of F9 R9 and red trace of F18 R18, and 42% for the green trace of F1 R6. At the braking zone of turn 3 the black trace shows a change in the centre of pressure to 64%, whereas the green and red traces show a COP value of 58% and 56% respectively. Into the braking zone of turn 4 the red trace shows a large movement of the COP to 84%, with the black trace showing a COP of 77% and the green showing a COP value of 49%. This means that the green is the most stable in terms of the COP with a maximum COP value of 67%, and the red trace of F18 R18 being the least stable out of the three with a maximum value of 84%.

This is reflected in appendix 8, whereby the histogram shows the green trace having the highest % of the time at 42% and tends to move towards the front Axle of the race car, whereas the black and red traces show a COP that moves towards the rear axle of the vehicle and have lower values on the histogram. This means that the red and black setups have a less stable COP in comparison to the green setup.

Appendix 6 shows the understeer % for each setup, looking at appendix 6 the green trace has the most consistent understeer in terms of the high and low speed corners, with the values ranging from 20%-25%. Comparatively, the red trace has more understeer at lower speeds as shown in the graph but has a low understeer value of 13% through turn 1. Likewise, the black trace has an understeer value of 9% through turn 1, but has an understeer value of 30% through turn 4 where the vehicle is travelling at 34 M/s. This is reflected in appendix 7 where the graph shows the change in understeer when the COP moves, where the green trace doesn't move as much as the black or red, meaning that the green is the most stable out of the three setups.

8. Conclusion

From the testing and analysis undertaken, the most stable setup out of the three was the green trace of F1 R6 as well as setting the fastest lap of 49.730. Therefore, out of the three setups tested the F1 R6 is the best suited setup for this track. The red trace of F18 R18 was the second fastest with a lap time of 50.403, however had the least stable CoP value, had understeer value through the slower corners and produced the highest amount of drag out of the three. Finally, the black trace of F9 R9 had the slowest lap time of 50.842, and had the highest understeer value through the slower corners.

9. Evaluation

If the test was to be repeated, there are some points where there could be improvements made. One of which is to identify a more effective setup prior to the testing and spend more time to adjust around the original known good setup. Such as with the F1 R6 setup there could have been more time spent adjusting this setup rather than using F18 R18 for example as although F1 R6 was the most effective out of the three, there could have been a more effective setup than F1 R6 that wasn't tested. Likewise, different ride heights could have been tested to identify the affect that ground effect may have on the car and assisted gaining a better understanding of the aerodynamic behaviour of the race car.

One issue that could not be resolved is the test driver's consistency, human error is a realistic part of motor racing so although it is an accurate representation of how the driver and car react. Any human error with regards to cornering speeds, braking points etc could affect the results and not provide reliable data.

Finally, to aid in validating any conclusions made in this report, live testing should be undertaken to prove or disprove the conclusion. Live testing will allow for external variables to be a factor in the cars ability to generate fast lap times, giving a real world set of data.

10. References

Hucho, W. et al, (1987) *Aerodynamics of road vehicles*. 2nd ed, London: Butterworths.

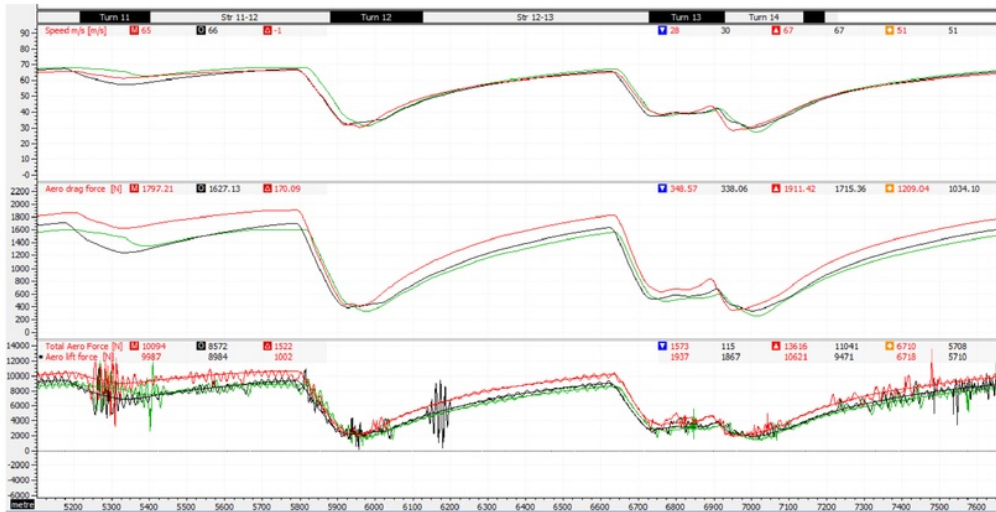
Segers, J. (2008) *Analysis techniques for race car data acquisition*. Warrendale: PA.

Rehnberg, S., Börjesson, L., Svensson, R., and Rice, J. (2013), *Race Car Aerodynamics - The Design Process of an Aerodynamic Package for the 2012 Chalmers Formula SAE Car*, SAE Technical Paper 2013-01-0797, <https://doi-org.ezproxy.uwtsd.ac.uk/10.4271/2013-01-0797>. Warrendale: PA.

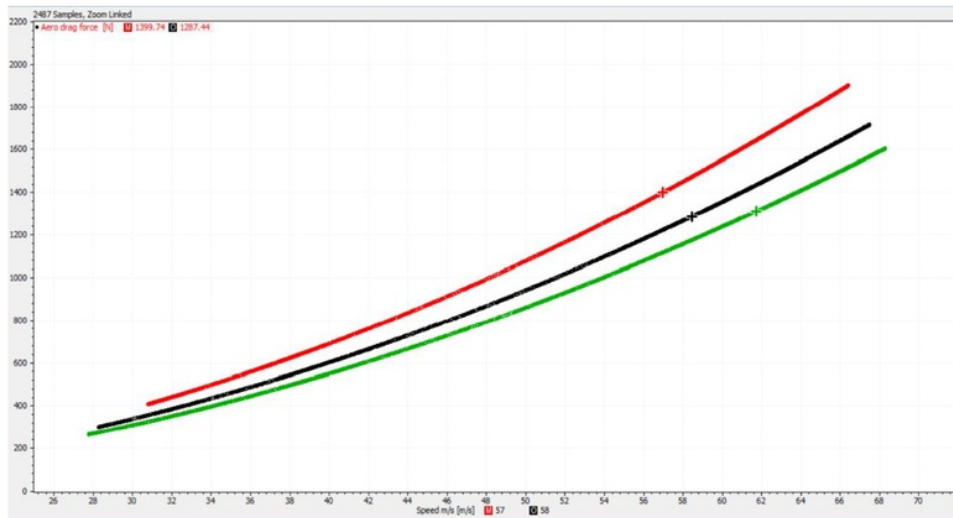
Milliken, W. Milliken, D (1995) *Race car vehicle dynamics*. Warrendale: PA.

Templeman, G. (2008) *The competition car data logging manual*. Dorchester: Veloce publishing.

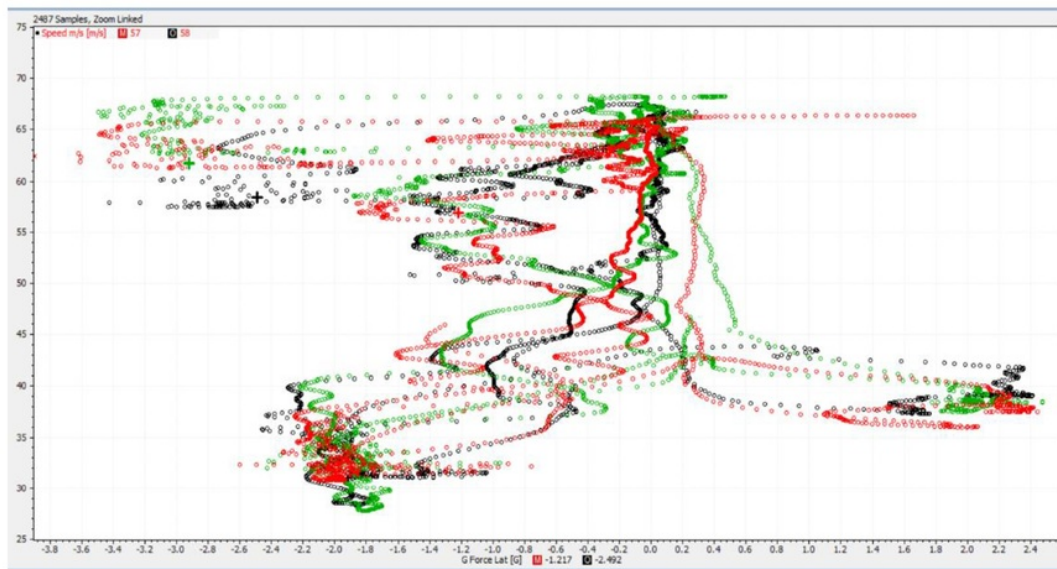
11. Appendices



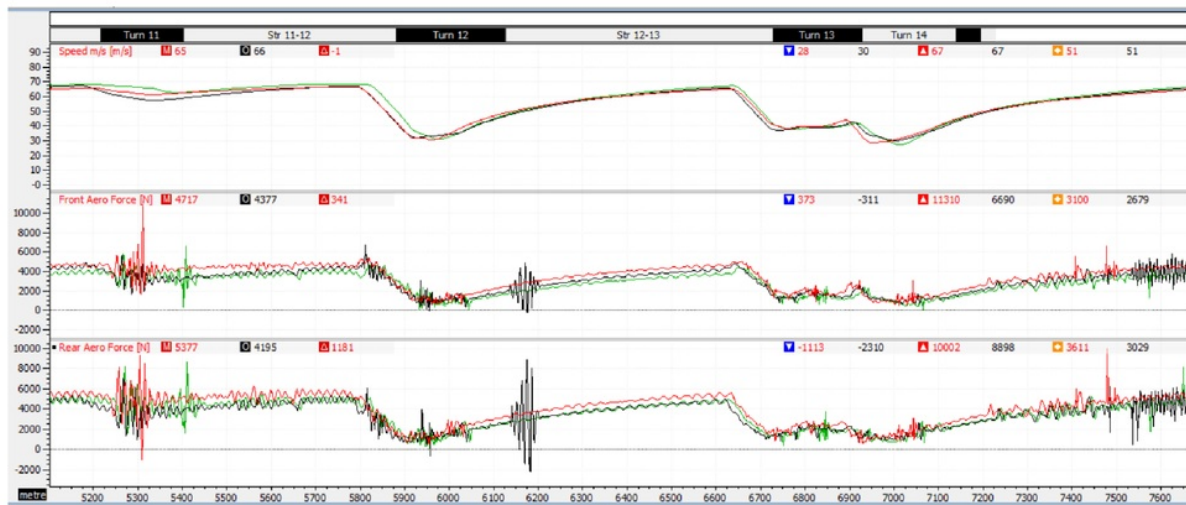
Appendix 1 - Aero drag force, total lift force against lap distance.



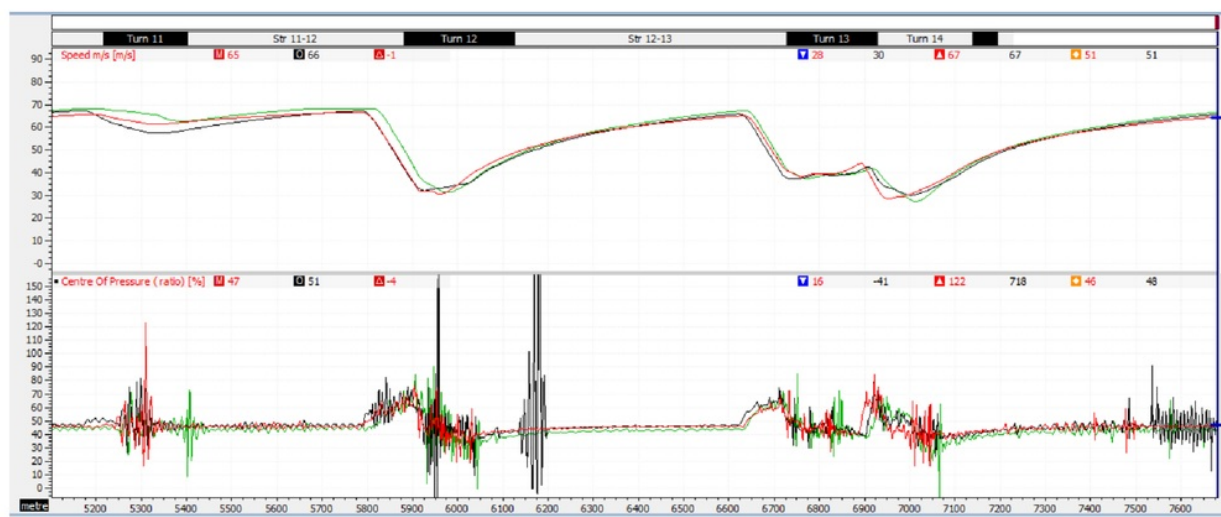
Appendix 2 - Total lift against speed (M/s)



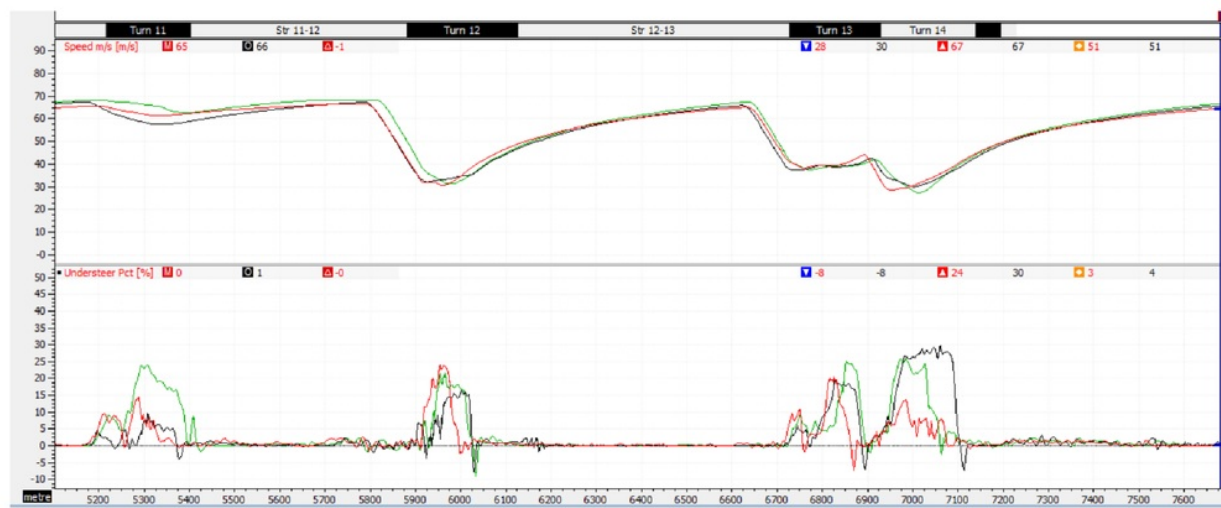
Appendix 3 - Lateral Acceleration against Speed (M/s)



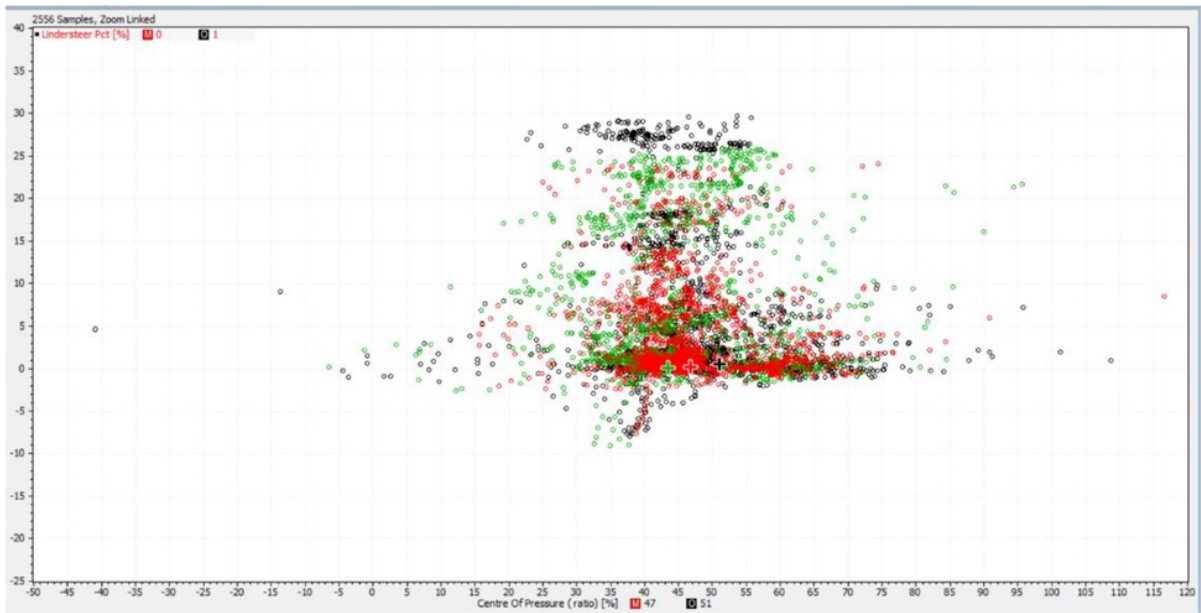
Appendix 4 - Front and rear aero force against lap distance



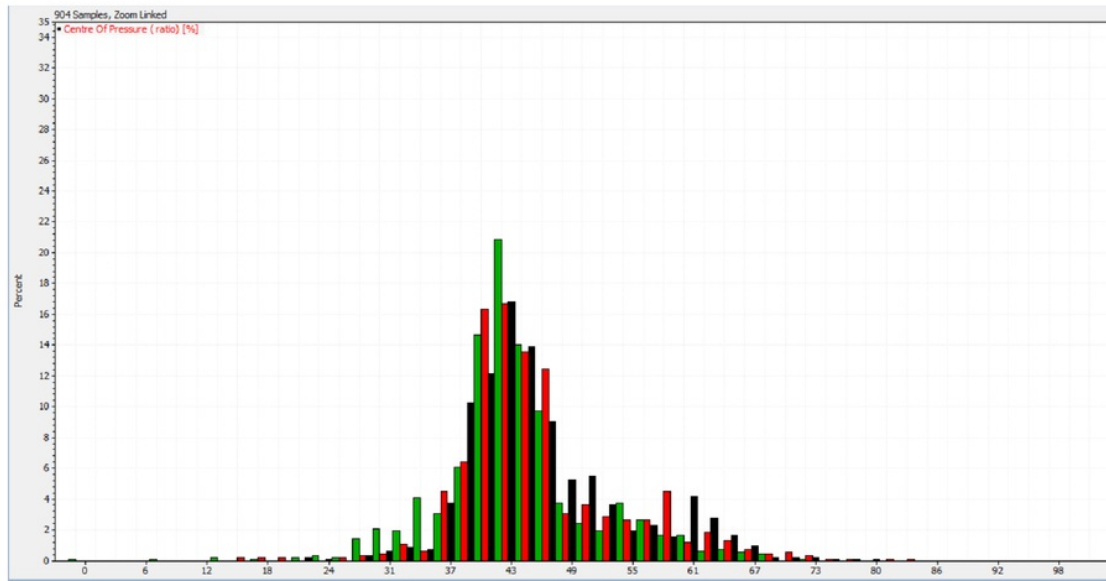
Appendix 5- Centre of pressure against lap distance



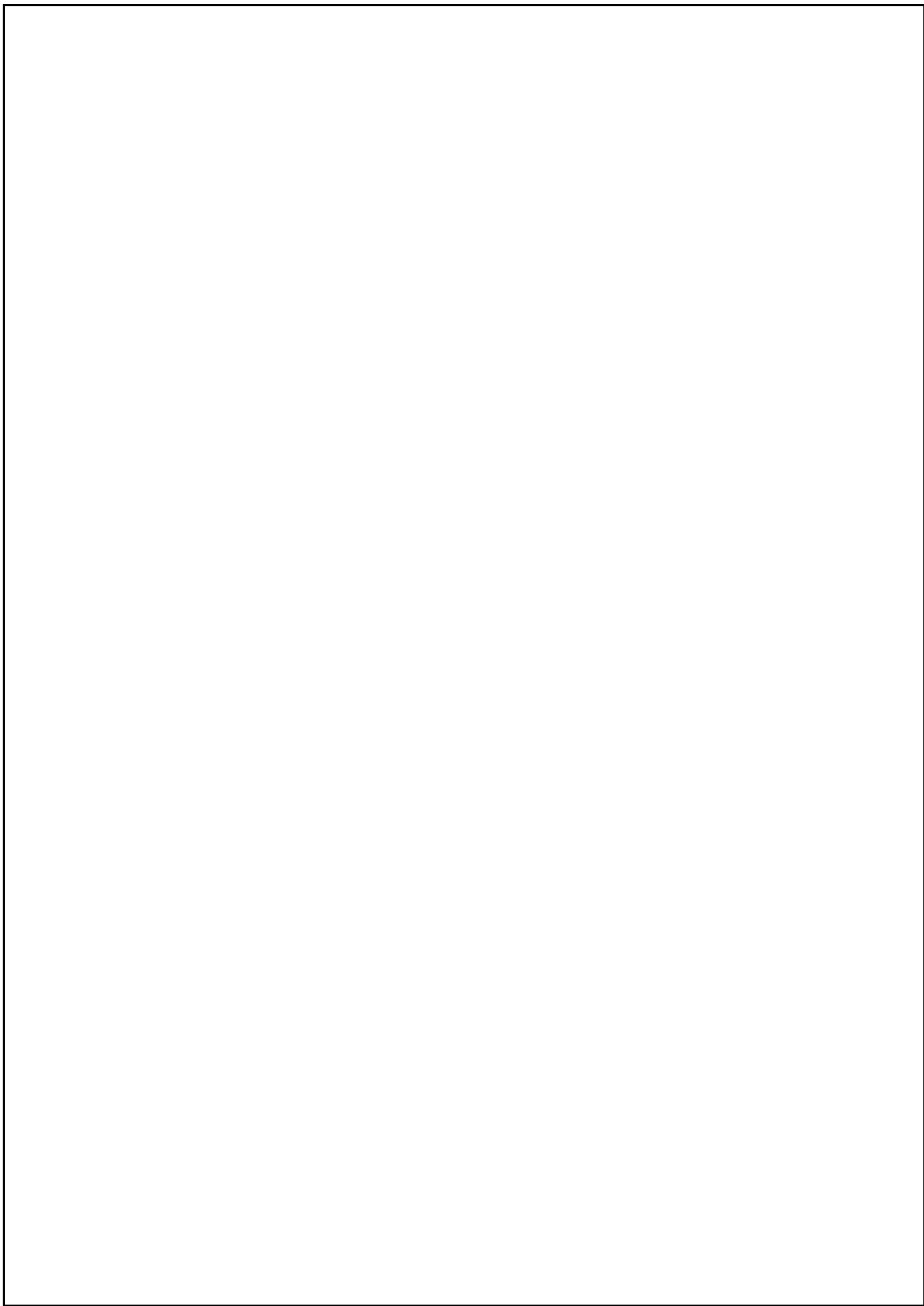
Appendix 6- Understeer against lap distance

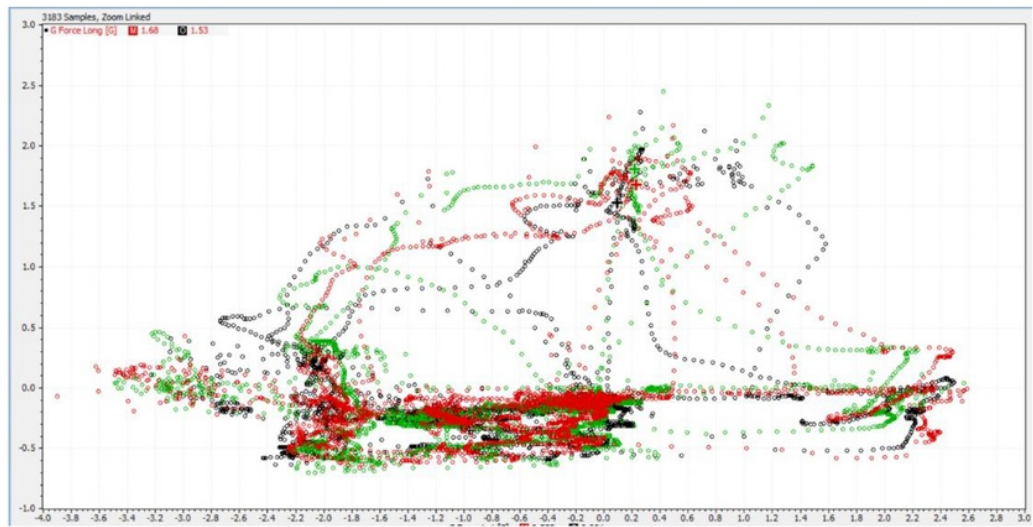


Appendix 7 - Understeer against centre of pressure



Appendix 8 - COP stability histogram





Appendix 9- G-G diagram