

THE ASSESSMENT OF DATA ANALYSIS AS A DRIVER DEVELOPMENT TOOL & STREAMLINING CAR SETUP WITH THE USE OF DESIGN OF EXPERIMENT

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APRIL 24, 2018

Declaration of Authenticity

This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.

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Abstract

An investigation into the benefits of engineering the driver through the use of data analysis before looking at the validity of using Design of Experiment software to streamline the car setup process. This has been achieved by using the University simulator to complete the tests and by looking into driver techniques and the data recorded to work with the driver on improving their own performance in the car, with the second part of the project being done through the use of specialist DOE software that will record the inputted information and produce information on the interactions of differing factors and also produce a solution to which it has calculated to be optimised. The results from that solution will then look to be validated on the simulator.

Acknowledgements

The author would like to thank the following for their help and support during this project.

Tim Tudor – Thank you for your time and guidance throughout the course of the project.

Joel Thomas – Thank you for dedicating a lot of time to my project in the simulator, approximately 100 hours have been spent in the simulator room working with me.

My Family and girlfriend – For the support through the project and for making sure I was on track at all time with my studies.

1 Contents

1	Introduction	1
2	Research.....	2
2.1	Data Logging.....	2
2.1.1	What data logging is.....	2
2.1.2	Different types of data loggers	3
2.1.3	The basics needed for data logging	4
2.2	Driver Techniques	5
2.2.1	Driver Vision	6
2.2.2	Throttle technique	6
2.2.3	Braking technique	7
2.2.4	Steering	7
2.3	Design of Experiment (DOE)	8
2.3.1	What is DOE	8
2.3.2	Different types of DOE	8
2.3.3	Box-Behnken	9
2.4	Vehicle Dynamics	9
3	Methodology.....	12
3.1	Simulator	12
3.2	Engineering the Driver	12
3.2.1	Choosing the circuit	13
3.2.2	Choosing the car	13
3.2.3	Test plans	14
3.2.4	Key Performance Indicators.....	16
3.3	Design of Experiment.....	17
4	Results & Analysis	21
4.1	Engineering the Driver	21
4.1.1	Overall lap times	21
4.1.2	Key Performance Indicators.....	24
4.2	Design of Experiments Results.....	33
4.2.1	DOE 1.....	33
4.2.2	DOE 2.....	38
4.2.3	DOE 3.....	43
4.2.4	Verification of results.....	46

5	Further Work.....	51
6	Conclusion.....	52
7	Bibliography	53
8	Appendix	54

Figure 2-1	Driver Vision (Scott Mansell 2016)	6
Figure 2-2	- Response surface diagram (Statgraphics 18).....	9
Figure 3-1	- University Simulator with Joel Thomas driving	12
Figure 3-2	Snetterton 300 circuit (Motec 2017)	13
Figure 3-3	- F3 car in the BPS simulator (Tim Tudor 2017).....	14
Figure 3-4	Excel screenshot of run information	14
Figure 3-5	- Intervention sheet template.....	15
Figure 3-6	- DOE test plan	19
Figure 4-1	- Predicted lap time improvement.....	21
Figure 4-2	- Graph to show all lap times including intervention flags	22
Figure 4-3	- graph to showing the fastest lap of each session.....	23
Figure 4-4	- Graph to show percentage of the lap spent at full throttle compared to lap time	24
Figure 4-5	- Throttle trace between session 19 and 8	25
Figure 4-6	- T1 trace from session 19 and 8.....	25
Figure 4-7	- Throttle trace for sessions 19 and 8 with highlighted sections.....	26
Figure 4-8	- Throttle trace for Session 1 comparison to session 19.....	27
Figure 4-9	- percentage of the lap spent not using either pedal	28
Figure 4-10	- Throttle & Brake trace for sessions 1 and 19	29
Figure 4-11	- Lateral G % for 100% Throttle for session 1	30
Figure 4-12	- Lateral G % for 100% Throttle for session 19	30
Figure 4-13	- GG plot for T session 19.....	31
Figure 4-14	- GG plot for T2 session 1.....	31
Figure 4-15	- full data overlay for session 1 and session 19	32
Figure 4-16	- DOE test 1 information table.....	34
Figure 4-17	- One factor influence for ARB distribution for DOE 1.....	34
Figure 4-18	- Single Factor Interaction for Front Camber for DOE 1	34
Figure 4-19	- Interaction diagram for AB in DOE 1	35
Figure 4-20	- Single Factor Interaction for Rear Camber for DOE 1.....	35
Figure 4-21	- Interaction diagram for AC in DOE 1	35
Figure 4-22	- Interaction diagram for BC in DOE 1.....	35
Figure 4-23	- Response surface at 0 for DOE 1	36
Figure 4-24	- Response surface at +1 for DOE 1	36
Figure 4-25	- Response surface at -1 for DOE 1	36
Figure 4-26	- Solutions for DOE 1.....	37
Figure 4-27	- Information table for DOE test 2	38
Figure 4-28	- One factor interaction for B in DOE 2.....	39
Figure 4-29	- One factor interaction for A in DOE 2.....	39
Figure 4-30	- One factor interaction for C in DOE 2.....	39
Figure 4-31	- Interaction for factors AB in DOE 2	39
Figure 4-32	- Interaction for factors BC in DOE 2.....	40

Figure 4-33 - Interaction for factors AC in DOE 2	40
Figure 4-34 - Cube for DOE 2	40
Figure 4-35 - Response surface at -1 for DOE 2	41
Figure 4-36 - Response surface at 0 for DOE 2	41
Figure 4-37 - Response surface for +1 in DOE 2.....	41
Figure 4-38 - Throttle trace comparison for DOE 2 in T1.....	42
Figure 4-39 - Solution for DOE 2	42
Figure 4-40 - Information table for DOE 3	43
Figure 4-41 – Interaction for factors AB in DOE 3.....	44
Figure 4-42 – One Factor interaction for C in DOE 3	44
Figure 4-43 – Interaction for factors AC in DOE 3.....	44
Figure 4-44 – Interaction factors for BC in DOE 3	44
Figure 4-45 - One Factor interaction for A in DOE 3	44
Figure 4-46 – One Factor interaction for B in DOE 3	44
Figure 4-47 - Response surface +1 DOE 3	45
Figure 4-48 - Response surface -1 DOE 3.....	45
Figure 4-49 - Response surface 0 DOE 3	45
Figure 4-50 - Solutions for DOE 3.....	46
Figure 4-51 - Percentage of the lap spent not on either pedal for DOE 2	47
Figure 4-52 - Amount of lap spent at full throttle for DOE 2	47
Figure 4-53 – Lateral G for 100% Throttle for DOE 2	48
Figure 4-54 – Throttle comparison for S19 to DOE 2.....	48
Figure 4-55 - Brands Hatch GP Data trace	50
Figure 8-1 - Intervention sheet 1	54
Figure 8-2 - Intervention sheet 2	55
Figure 8-3- Intervention sheet 3	56
Figure 8-4 - Intervention sheet 4	57
Figure 8-5 - Intervention sheet 5	58
Figure 8-6 - Intervention sheet 6	59
Figure 8-7 - Intervention sheet 7	60
Figure 8-8 - Intervention sheet 8	61
Figure 8-9 - Motec Maths channels	62
Figure 8-10 - Gantt chart 2017.....	62
Figure 8-11 - Gantt chart 2018.....	62

Table 1-1 Brands Hatch GP Clio Cup qualifying 2017.....	1
Table 2-1 - Target values for percentage of lateral acceleration where the driver should be at full throttle	8
Table 3-1 - Tables for the 3 DOE tests.....	18
Table 4-1 - Test results from DOE 1 optimised	37
Table 4-2 - DOE 2 solutions results	43
Table 4-3 - Results for solutions DOE 3.....	46
Table 4-4 - Brands Hatch GP Test 1 results.....	49
Table 4-5 - Brands Hatch GP Test 2 results.....	49
Table 4-6 - Brands Hatch GP Test 3 results.....	49

1 Introduction

The overview of this project is to look at two different areas that a race engineer would look at when looking to improve the performance of both the driver and the car.

The aim of this being to assess the use of data analysis as a driver development tool by looking to engineer the driver, using key performance indicators (KPI's) to assess the driver's performance throughout the project. The other aim is to determine the viability of using design of experiment to aid in car setup with the use of Design Expert software.

This will be done by firstly looking at improving the driver by the use of data analysis, this will be done using the base performance simulator within the university. The importance of engineering the driver can be seen when looking at the qualifying results for the final round of the Clio Cup UK at brands hatch GP, the difference between 1st to 20th is 3.22% and the difference within the top 10 is 0.25% showing that the gaps are close and in a series where all cars are equal with limited setup adjustment the driver who has worked with his engineer to get the most out of the cars current setup is the one who will be able to elevate themselves. The aims here are to not only to decrease the drivers lap times but also to increase the driver's consistency.

Table 1-1 Brands Hatch GP Clio Cup qualifying 2017

Pos	Driver	Time	MPH
1	BUSHELL	01:38.441	88.98
2	BURNS	01:38.443	88.98
3	ROWBOTTOM	01:38.497	88.93
4	ZELOS	01:38.524	88.91
5	COATES	01:38.597	88.84
6	McCARTHY	01:38.624	88.82
7	COLBURN	01:38.647	88.79
8	RIVETT	01:38.652	88.79
9	ORROCK	01:38.680	88.77
10	FULK	01:38.689	88.76
11	DORLIN	01:38.810	88.65
12	PATTISON	01:38.915	88.55
13	LIDSEY	01:39.031	88.45
14	THOMPSON	01:39.181	88.32
15	EDWARDS	01:39.254	88.25
16	READE	01:39.754	87.81
17	PALMER	01:40.044	87.55
18	OSBORNE	01:40.325	87.31
19	HARRISON	01:40.728	86.90
20	TAYLOR	01:41.614	86.20

The second part of the project will be done by using design of experiment which is a systematic method to determine the relationship between factors affecting a process and the output of that process. In other words, it is used to find cause-and-effect relationships. This information is needed to manage process inputs in order to optimize the output. The purpose for this part of the project is to look at streamlining car setup by using the above process to help identify interacting factors and reach the optimum setup quicker, the reason for wanting to reach this point quicker is that within motorsport track time is limited and costly and so every minute on track needs to be optimised in order to become more competitive. The test will also look to see if the setup can be applied generally to the car or whether it is circuit dependent.

2 Research

The areas of research here focus on data gathering and what is being looked for in the analysis of data including basic improvement techniques and then the design of experiment, its workings and applications.

2.1 Data Logging

This section will look at what data logging is, different types of loggers and the basics required for a data logging system.

2.1.1 What data logging is

Data logging is the capture of information from the vehicle via the use of a data acquisition system that will save the data onto either a hard drive or memory card that can then be downloaded after a session on track. The information is collected via different sensors on the vehicle which is then translated by the acquisition system and plotted onto graphs so that it can be reviewed.

The purpose for logging this data is that it allows the engineer to see what the car or driver is or isn't doing when on the circuit. This isn't a tool that can work alone however it is best used to compliment driver feedback and then using the two combined it is possible to look for areas of improvement. These systems can be used to not only look at driver/car performance but also be used to monitor the state of the vehicle by the use of sensors such as oil temperature/pressure, gearbox temperature etc. Allowing the engineer after the session to see if there is any abnormal running such as oil pressure or fuel pressure dipping in a long fast bend, a solution could then be created which would result in saving the engine if it was oil pressure dropping in a bend as if this happened consistently over the length of a race it could result in severe wear or even engine failure. This report is looking at use a data logger purely to improve performance though and so that side will not be investigated into any further.

(McBeath, 2002) (Segers, 2008)

2.1.2 Different types of data loggers

When looking to extract data from a vehicle for a test there are two main options:

- Video data logger
- Multi-Channel data logger

An example of a video data logger is Race logic's Vbox system that utilises 2 cameras along with a GPS antenna so that its position and vehicle speed can be captured, it also has an internal accelerometer meaning it can capture lateral and longitudinal acceleration. The system is also capable of connecting to certain vehicles on board diagnostics (OBD) ports so that it can then read data from the ECU such as RPM, Brake pressure, steering input, throttle position. That is as long as the cars ECU can output that information. It does also have the option to have channels added to it however a separate module is needed for this.

The advantage to a video data logger is that it offers the driver and engineer the opportunity to visually see what has happened on track when reviewing a session meaning that oversteer/understeer can visually be seen and track positioning can be studied. The disadvantage to a system like this is that it is simplistic and so doesn't provide the option to run many channels meaning that if the engineer wanted to look at chassis behaviour by looking at damper displacement or looking at individual wheel speeds to look for signs of wheels locking under braking or spinning during acceleration.

An example of a multi-channel logger is a Motec system, the same as in the simulator. These systems can vary from small 4 channel loggers through to 127 channel loggers meaning that there is a large variety available from different manufacturers with their own software package for data review afterwards. A few well-known brands include: Motec, Pi, Cosworth and AIM. These loggers will all use GPS to log the cars position on circuit along with providing vehicle speed. The channels are able to log a multitude of things from the car depending on the users requirements, examples of channels that can be logged with the right sensors are: throttle position, brake pressure, steering angle, suspension position, tyre pressures, tyre temperatures, individual wheel speed and lateral/longitudinal acceleration. This is all done by different types of sensors be it displacement, speed, pressure, load or accelerometers. There is also the option with some systems to have a camera add on or the ability to import video from another source into the software that can then be sync'd allowing a video overlay. More expensive units will also allow the use to view data from the car on circuit in real time from the garage rather than having to wait to download the data from the car once it returns back to the pits. Allowing the engineer to relay information to the driver

on the fly such as brake or tyre temperature information allowing them to make adjustments to driving style accordingly this is known as telemetry due to the data being transmitted.

The advantage of the above system is that it can capture as much data as you want allowing a vast quantity of data to look through meaning that there are lots of potential opportunities to look for improvement in driver or car behaviour. The disadvantage to this is that with a huge amount of data to look through it means that it requires a large amount of time to look through and analyse meaning that between test sessions that information could be over looked unless the person studying the data is very knowledgeable or there are several people on hand to go through the data. (McBeath, 2002) (Segers, 2008)

2.1.3 The basics needed for data logging

As discussed in the previous section some loggers can have a huge variety of channels allowing a huge amount of data however this can be too much and so below is the minimum channels needed in order to have the beginnings of an effective logging system:

- Speed
Logging vehicle speed is considered the most crucial aspect to log. Ultimately it is what is trying to be improved, higher speeds equals distance covered quicker which results in shorter lap times. The easiest way to measure this would be by using the GPS being used to given the cars position on track, a more advanced way would be to use a wheel speed sensor on just one wheel or on each wheel. A speed trace is a very useful tool to compare against another driver as it will instantly highlight where time is being gained or lost by the difference in speed on a straight or through a bend. Another benefit from a speed trace is that the lateral acceleration can be calculated via the use of a math channel in the software.
- RPM
The analysis of this can quickly highlight areas for improvement, by looking at the RPM trace when braking if the driven wheels lock it is easily identifiable. The minimum RPM in the bend can be assessed to see if it is too low or too high which may hinder acceleration. In the acceleration phase wheel spin can quickly be identified by sudden spikes in the trace and how the driver moderates it can then be seen by the fluctuations.
- Accelerometers
To measure lateral and longitudinal G forces. These are useful for looking at deceleration and acceleration along with cornering loads. They have the ability to show how smooth the driver is

being as when plotted on a line graph they will rise or dip sharply. It should follow a relatively smooth path if an average was plotted however there will always be some small fluctuations due to 'noise' which could be bumps in the road/kerbs or the driver making adjustments due to locking a wheel or the car needed an adjustment to its line through a corner. The use can be expanded when combined together to make a GG plot which combines lateral and longitudinal forces onto a single graph, the use for this is to see if the driver is making the most out of the tyre in a particular corner. To make the most out of the tyre the driver should reach that peak under braking and then in an ideal scenario follow the path of the traction circle until it reaches the peak lateral loading.. It may be the case that due to the circuit or the characteristics of the car that the driver can't hold the car at the curve of that circuit when transitioning from braking to cornering however it should still be a transition any big dips will indicate that there is available traction the driver could utilise.

With the above three channels there would be enough to allow for improvements to be made as they can provide a lot of useful information as stated above however there is always the option for more and they can look to compliment the above. Other sensors to consider would be: throttle pedal position, steering wheel angle and brake pedal position or brake pressure. They allow the drivers inputs to be assessed as it may be the case that the driver is over working the inputs, such as aggressive steering or throttle input which is causing the car to be unbalanced and upsetting the handling rather than there actually being a handling issue.

The important fact to remember is that data loggers are part of a toolset to make a car or driver faster, driver feedback is just as important and so the engineer should look at the data and take the feedback from the driver to look at areas of improvement. A data logger is not a replacement for driver feedback (McBeath, 2002) (Segers, 2008) (Sergers, 2014)

2.2 Driver Techniques

This section will look at what it is that is trying to be improved and techniques that can be used to improve driving performance and that will be used to analyse the drivers performance.

2.2.1 Driver Vision

The most important aspect of racing is vision, the driver needs to be able to look correctly when navigating the circuit. 90% of the responses and actions in a race car are as a result of the feedback your brain gets from your eyes. (Bentley, 2011) The driver needs to be looking where they want to go not where they don't want to, the body will tend to direct the controls to where your vision is focused and so if the driver focuses on the grass then that is where they will likely end up. Figure 2-1 demonstrates where the driver should be looking when coming into a bend through the phases: 1. Braking Zone 2. Turn-in Point 3. Just before the Apex 4. Corner exit.

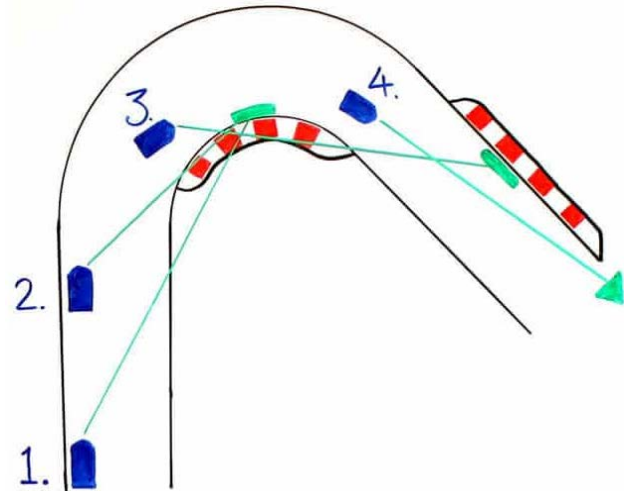


Figure 2-1 Driver Vision (Scott Mansell 2016)

The purpose for this is so that the driver is looking far enough ahead that the brain is able to plot a mental path of where they want go and then is already aware of when the brakes need to be applied, when to turn in, where the clipping point of the apex is and where the power can start to be reapplied. By doing this it means the inputs are proactive not reactive meaning that they are smoother and therefore faster. (Mansell , 2016) (Bentley, 2011)

The most important corner on the circuit starts with the one that leads on to the longest straight, by the driver having better vision this means that are able to either carry more speed and be on the power earlier meaning that they can maximise the speed down the straight. (Bentley, 2011)

2.2.2 Throttle technique

The way the driver uses the throttle as with all the inputs is important. The driver needs to make the most of the throttle in order to decrease lap times as in theory an increase in time spent at full throttle leads to an improved lap. That does not mean the driver should stamp on the throttle as soon as possible either as this can upset the balance of the car meaning the driver has to get back out of the throttle. The key to using the throttle is to be smooth, squeezing on to the throttle pedal in order to not upset the balance of the car, this also goes for when coming off the throttle a sharp and abrupt lift can unsettle the car before turning it in however the driver also needs to be positive when applying the throttle so whilst the throttle needs to be squeezed it needs to be done as quickly

as possible. The driver should be going onto the throttle and staying on it until the next braking zone, if they have to lift then they have gone on to the throttle too soon or too abruptly. (Segers, 2008) (Bentley, 2011)

The way that the throttle will be analysed in this report is both by the use of the throttle pedal trace within Motec that will plot the throttle against time or distance for each lap. The other way is by the use of a histogram which will display how much of the lap in percent is spent at different amounts of throttle. This can be used to see how much time the driver is on full throttle or off throttle. (Segers, 2008)

2.2.3 Braking technique

The way the driver applies the brakes is also important, again the same as the throttle the driver needs to be smooth with the application but also quickly reaching maximum braking effort as quickly as possible and then bleeding the brakes off smoothly as the driver reaches turn in. Doing this allows the chassis to settle before turning in rather than being pitched upwards by quickly lifting off the brakes and turning in.

Braking will be assessed the same as the throttle by the use of a trace and histogram. The trace being looked at is the percentage of brake pedal that is being applied, this allows the direct comparison between time off of the throttle and time spent on the brakes which will highlight a time spent 'freewheeling' where the driver is neither accelerating nor decelerating the car. (Segers, 2008)

2.2.4 Steering

The use of the steering wheel needs to be smooth and precise, a driver working the wheel either aggressively or in a sawing motion will result in upsetting the cars balance and also over working the front tyres reducing the lifespan. The best way for the driver to approach the corner is using the technique from 2.2.1 to plot a mental path for the corner in their mind and then smoothly steer that arc, it will not be possible every time to make the turn in one smooth radius as when driving on the limit of grip the car may need minor adjustments to keep the predetermined path however the less the driver is over working the wheel the better.

Steering will be looked at by using a steering wheel percentage rather than steering wheel angle however it is still a valid measurement and will still be able to see if the driver is over working the wheel and also be able to tell if the car is understeering by seeing if a high steering percent is held or if the driver is continually applying lock whilst going round the bend which will be an indicator that maybe too much speed has been carried into the bend. (Bentley, 2011)

In this project the steering will be combined with the throttle to look at the lateral loading on the car when full throttle is applied, this will be compared against the highest lateral load seen giving a percentage. The below table is used as a guide at to what percentage of the max lateral G the driver should be on full throttle. (Segers, 2008) (Fey, 1993)

Table 2-1 - Target values for percentage of lateral acceleration where the driver should be at full throttle

Power output (HP)	% lateral G at 100% throttle
< 150	95%
150-200	90%
250-400	85%
> 400	80%

2.3 Design of Experiment (DOE)

Below will explain what DOE is and how it is implemented including different methods and specifically the method that will be used for the tests in this report.

2.3.1 What is DOE

Design of experiment is a systematic method to determine the relationship between factors affecting a process and the output of that process. In other words, it is used to find cause-and-effect relationships. This information is needed to manage process inputs in order to optimize the output. DOEs main benefit is that it allows the user to make 2 or more changes per test to gather information rather than changing 1 thing at a time meaning the number of tests is reduced, the additional benefit is that it can identify any interaction between the different factors. It also allows the user to potentially test between a range of settings rather than testing each setting to find the information as the software is able to predict the results in-between. (Montgomery, 2009) (Byam, et al., 2003)

2.3.2 Different types of DOE

When looking at DOE there are a variety of options that the operator can use depending on their individual requirements. These vary from: one factor, two level multi-factor and multi-level split-plot designs with 2 – 12 factors to response surface designs.

The type of DOE correct for the user entirely depends on what they are looking for as an outcome, be it to see the interaction between different factors or whether the user is looking to optimise a process. In this project the aim is optimisation of the cars setup. To achieve this a response surface design will be looked at as it will give a result that is easier to interpret in the result of a surface model due to how it is displayed, as per the figure below:

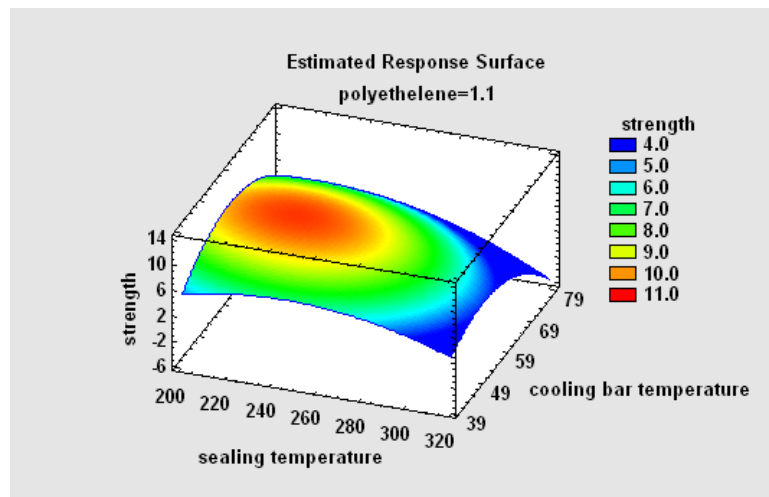


Figure 2-2 - Response surface diagram (Statgraphics 18)

Which shows how when 1 of the 3 factors shown is fixed how the response (strength in this case) is affected by the other two factors in the shape of a curve allowing the user to see not only the region where the optimum result will be but also an idea of the interaction between the two variable factors.

2.3.3 Box-Behnken

A design with three levels for each factor (-1, 0, +1). In order to reduce the amount of runs needed it does not run at the extreme of the combinations and so in order to create better predictions it repeats the central point several times. With this style of experiment it allows for errors within one or two of the runs however more than this will cause accuracy problems when create the response surface.

2.4 Vehicle Dynamics

This section will give a brief outline of different aspects of vehicle dynamics, as these will be altered when the setup of the car is changed during the DOE tests. The factors that will be adjusted during this project are:

- Camber

The camber of the wheel determines the amount that the wheel is leant over if it is looked at from above, if the top of the tyre leans in towards the centre of the vehicle it would be negative camber and if it was leaning away from the car it would be positive camber. Modern tyres will always want to be run with negative camber however older cross ply tyres could be run with a neutral or even positive camber. The benefit of running negative camber which would mean that when static and in a straight line that the outside of the tyre would not be in contact with the road is that when the car comes into a corner the tyre will start deflect and as the lateral loading increases the wheel will roll over and actually increase the amount of tyre that is contact with the road and allow the tyre to give a higher grip level. This is beneficial to a point, too much camber and the tyre will be too hot on the inside edge when running down the straight due to the increase weight on to a smaller contact surface and that it may also mean that the tyre doesn't deflect enough and so the desired amount of contact with the floor isn't reached. The other downside to running too much negative camber on the driven wheel is that as the contact patch with the tarmac is reduced when not under lateral load it means that the vehicle may struggle for traction when either accelerating or decelerating.

- Toe

The toe of a wheel is the angle from dead ahead that the wheel is pointing, toe in is where the front of the wheel is closer to the centreline of the vehicle compared to the rear and toe out is the opposite. If the wheel has toe out the it will be more responsive and quicker to turn in however can become unstable at higher speeds where as a wheel that has toe in will have more stability under acceleration or braking however can be lazier to turn in and can in both instances can reduce the top speed of the vehicle as the tyres will either be driving away from each other or driving towards each other, no toe will result in a tyre that is stable at speed however not as stable when accelerating as a tyre that toes in and not as willing to turn in or change direction as a tyre that has toe out.

- Aerodynamics

The aerodynamics of a vehicle compliment the mechanical grip, the benefit of this increases as the speed of the vehicle increases, with the highest benefit being in high speed corners when the car is setup to have high downforce. The drawback to increased downforce on the vehicle is that it will increase the drag and reduce the top speed of the vehicle. When the car has adjustable aerodynamics front to back it is possible to alter the vehicles centre of pressure by increasing or decreasing the downforce at either end of the vehicle, by doing this it is possible to change the balance of the car between understeer and oversteer.

- Ride Height

Ride height of the vehicle is important, the lower the better in theory as it will reduce the centre of gravity (CoG) of the vehicle which improves the handling however it is important to not only ensure that the vehicle is high enough that it doesn't bottom out constantly but also not so high that it has a negative impact on the CoG. The difference in height front to rear which is the rake of the vehicle is important as it will have an impact on the aerodynamics, as the angle of the underbody will act like a Venturi and accelerate the air under the car which gives the effect of sucking it into the tarmac and can complement the aerodynamics of the vehicle.

- Spring stiffness

Spring stiffness determines the wheel rate of the vehicle by multiplying the spring rate by the motion ratio of the suspension. The higher the value, the more weight transfer will happen across the corresponding axle whilst reducing the weight transfer on the opposing axle. The spring also contributes to the ride of the vehicle, a softer spring will soak up bumps, act more passively and allow more tyre compliance where as a stiffer spring will crash and skip across bumps and mean that the tyre is more likely to lose contact with the ground however it will be more responsive and help to increase weight transfer and in turn increase the load on the outside tyre which could increase its lateral grip.

- Anti-roll bar stiffness

Anti-roll bars can be of different designs however the use for them is the same, to add increased stiffness without altering the ride characteristics like you would if you increased the spring rate. The stiffness from the anti-roll bar is added to the wheel rate, resulting in the same effect in weight transfer due to the wheel rate increase.

(Smith, 1978) (Gillespie, 1992) (SAE , 2001) (Rowley, 2003)

3 Methodology

The project is split into two halves as stated in the introduction, with engineering the driver being looked at first followed by design of experiment to streamline car setup. In order to complete this the university simulator is being used along with a university student as the driver due to both its availability and also the cost of hiring a driver, car and circuit would be very expensive for the required testing time.

The first part of this section will look at engineering the driver and the processes used in order to complete this section of the project before looking at design of experiment for the second part.

3.1 Simulator

For all the testing to be carried out it will be completed in a Base Performance single seater style non-motion simulator. Base Performance Simulators (BPS) are a professional company who not only supply simulators to companies all over the world but also have simulators to hire at their facility enabling teams or drivers to gain circuit knowledge or trial different techniques without using valuable on circuit time.

The programme used for the software is based on the R factor game however BPS have created their own vehicles based on real world information including engineers from BPS going to circuits with teams to make sure the correlation between simulation and real world is accurate.



Figure 3-1 - University Simulator with Joel Thomas driving

3.2 Engineering the Driver

The driver chosen for the project is fellow student Joel Thomas, he has a driver's license but no on track circuit experience however, and he has played racing style video games and is interested in motorsport. This means that he is at a good level to start the project because whilst there will be a

lot to learn with technique he already understands the basics of brake, turn in, accelerate which gives a good foundation to build on.

3.2.1 Choosing the circuit

The first decisions to be made before any data could be analysed is to decide on both a car and circuit.

The circuit needed to have the following criteria:

- Not too long
- Good selection of corners (slow, medium and fast corners)
- An accurate model with good reference scenery such as trees/kerbs/marshal posts
- Ideally the driver already has some knowledge of the circuit layout

Several circuits were tested such as Silverstone, Oulton Park, Croft, Snetterton and Brands Hatch GP. From them it was decided that Snetterton was the one that fitted the criteria best and the one the driver was most comfortable on.

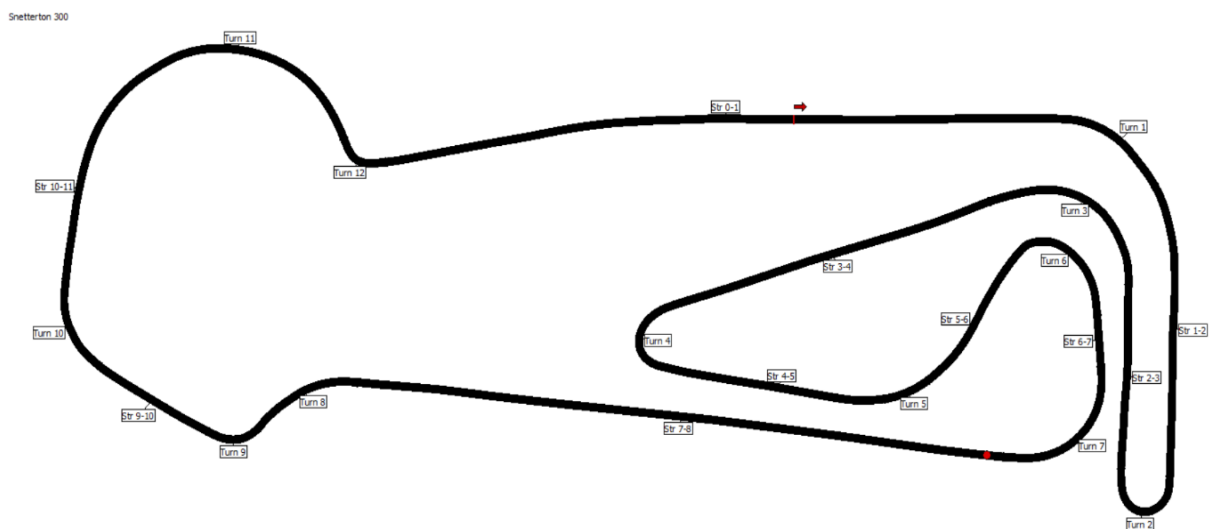


Figure 3-2 Snetterton 300 circuit (Motec 2017)

3.2.2 Choosing the car

The car chosen needed to have the following criteria:

- Accurate model of the real vehicle with proven correlation
- Challenging but not too fast for the driver
- Driver needs to be comfortable driving it to ensure consistency

The cars tested were an Aston Martin GT1, GP2 and F3 car. After several runs with each car the F3 car was decided on, it has been previously validated by Hitech GP round the Macau circuit where the difference between the simulator and the real car was 0.3s.

The GT1 car had heavy steering and so the driver didn't feel that he would be able to do long sessions with the car and remain consistent and with the GP2 it was felt that it was too quick for the driver at this level.



Figure 3-3 - F3 car in the BPS simulator (Tim Tudor 2017)

3.2.3 Test plans

The next step now that the driver, circuit and car had been chosen is to decide on how to conduct the tests, the decision made was to complete runs in groups of 10 laps. This was to give the driver the best opportunity to implement improvements discussed from the previous run due to the fact that it could take several laps to perfect what was discussed, this also provides a large amount of data to analyse as the driver may have had better sectors on a lap that was not his overall fastest.

For each run an excel spreadsheet was used that contained the drivers lap times, fastest lap time, average lap time, the number of laps that were deemed consist (within 105% of the best time) along with both driver and engineer comments on how the session went. A screenshot of one of the runs is shown in figure 3-3.

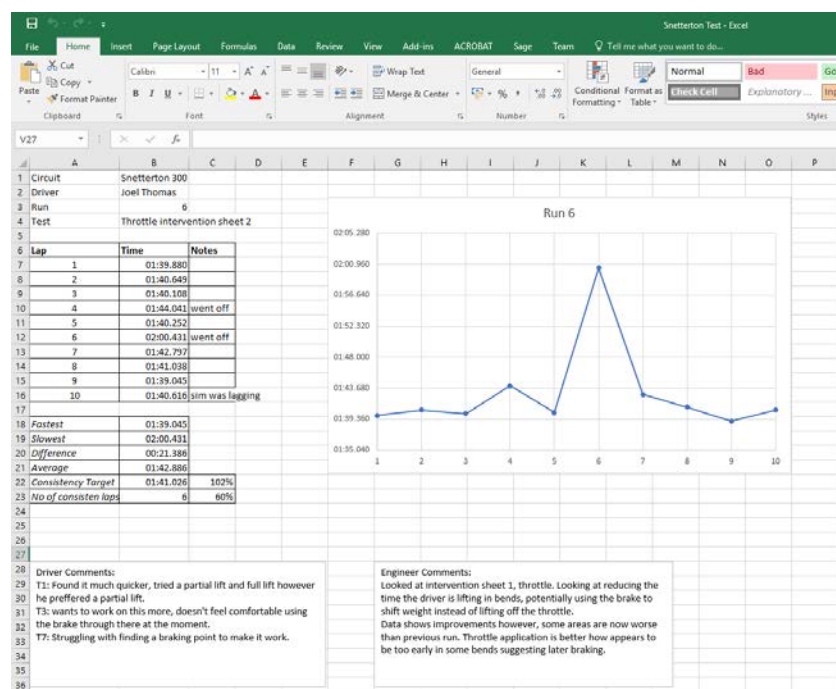


Figure 3-4 Excel screenshot of run information

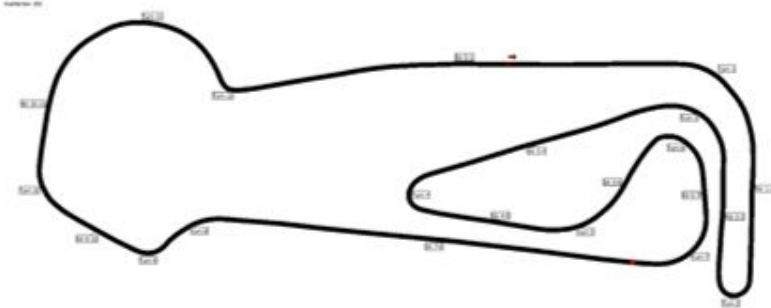
Before each session the driver was given 1 aspect to improve on so that the impact of that aspect could be measured. The aspects to be implemented were given to the driver in the way of an intervention sheet, this included the area being looked at including a data trace, circuit map for reference, the specific sections of the track it applied to highlighted and additional comments relating to what was being looked at including the potential gains, all the intervention sheets can be seen in the appendix and below is the template used to create these sheets for the sessions:

Driver: Joel Thomas
Circuit: Snetterton 300
Intervention:

INSERT DATA TRACE HERE

Points:

-



The circuit map shows the Snetterton 300 track layout. It is a single-lap circuit with several turns. The track starts on the left, goes into a large loop, then a smaller loop, and ends on the right. Various points on the track are labeled with numbers, likely indicating specific sections or corners of interest for the intervention.

Figure 3-5 - Intervention sheet template

The data from each session was input into a spreadsheet so that the KPI's could be assessed, from there it was possible to see how well the driver had implemented the intervention sheet.

3.2.4 Key Performance Indicators

A KPI is a key performance indicator, used to assess the performance of a project and targets that are key to its success. For this test there was 3 KPI's being looked at, these are:

1. Percentage of the lap spent at full throttle
2. Percentage of the lap spent not on either pedal
3. Percentage of max lateral G that 100% throttle was applied

3.2.4.1 KPI 1 – Percentage of the lap spent at full throttle

To look at the percentage of the lap spent at full the data from the lap is loaded into Motec and then a histogram is created for the throttle channel, the data from this can be exported straight into excel allowing it to be put into tables, the difference found and information plotted onto graphs to enabling the analysis to be conducted.

The importance for this KPI is that the theory is the more time spent at full throttle the quicker the lap time will be as the driver is utilising more of the engines potential more often throughout the lap as discussed in 2.2.2. The target we are looking for here is the highest possible number, it is not possible to define an actual target figure due to there being no definition of the overall amount of the lap that the driver should be at full throttle.

3.2.4.2 KPI 2 – Percentage of the lap spent not on either pedal

To gather the data for this KPI, the data from the 3.1.4.1 is combined with the exported data from Motec for the brake pedal percentage histogram. Both histograms will give a percentage for the lap that was spent with the sensor reading 0%. In theory, for maximum performance from the car the driver should either be accelerating or decelerating as this is impacting the car, the car should never be in a state of 'freewheeling' as this is time wasted by the driver as discussed in 2.2.3.

To find out the percentage of the lap spent with neither pedal being pressed the percentage of the lap off the brake is taken away from the percentage of the lap off the throttle. The target here is for this number to be as low as possible, with this an actual target number is definable as we know this needs to be as low as possible but it will never be 0% due to some corners requiring a lift before

turning in and so the driver will be off both the throttle and the brake at this point however this should only be for a small amount of time.

1% of the circuit distance is 47.8m, at 100mph the driver would cover that distance in 1.07 seconds. Based on that information an ideal target of less than 2% has been set.

3.2.4.3 KPI 3 – Percentage of max lateral G that 100% throttle was applied

This KPI is used to look at if the driver is making the most of the available grip from the car. As discussed in 2.2.4. The driver should be on full throttle shortly after the peak lateral G has been achieved, this mean that the driver is making the most out of the available grip. To calculate this information, the data needs to be looked at on Motec. For each corner the max lateral G is found, then the throttle trace is looked at to find the point the driver has reached 100% throttle and look for the lateral G loading at this point.

Using Excel the percentage can then be calculated by dividing the lateral G the driver was pulling when 100% throttle was applied by the max lateral G seen within that corner. This is then plotted onto a graph to look at this information over an entire lap.

That target for this KPI has been found during research, Table 2-1 is used as a guide for this information. Knowing that the car produces 244bhp, this gives a target of 85% meaning that the driver should be back to 100% throttle before the lateral G being seen drops below 85% of the peak.

3.3 Design of Experiment

The next section of the project looks at DOE, from Section 2.3. The basics of design of experiment and some background behind it are known. It is being used here to look at reducing the time spent to reach the ideal setup for the car.

The software being used for this is Design Expert, a computer based software that completes the tests for you when you provide the inputs (factors) and outputs (results). It will then be able to show you the links between factors and can optimise the desired results by using different combinations of factors.

Setup factors being looked at in this section are:

- Front Camber
- Rear Camber
- Front anti-roll bar (ARB) stiffness
- Rear ARB stiffness
- Front spring stiffness
- Rear spring stiffness
- Front wing
- Rear wing
- Front static ride height
- Rear static ride height
- Front toe

For this part of the project the decision has been made to use a response surface design of which the Box Behnken method was chosen due to its reduced amount of runs required whilst providing the surface response results. There is a maximum of 3 factors are allowed in each test. There are 11 factors above, resulting in 4 separate tests. Each factor is being tested at its minimum (-1), middle (0) and max (+1) setting which means there are 17 runs per test resulting in a total of 68 runs over the 4 tests, plus the runs using the optimised settings from the software. The time per run is approximately 10 minutes based on the drivers out lap and then 3 flying laps using an average lap time of 1:40 plus several minutes before the session to alter the cars setup within the software. Means that this would roughly take 11.5 hours to complete the entire test which is too long and so the decision was made to group some factors together to drop the number of tests down to 3 which would save 3 hours. To group the factors together the decision was made to pair together factors the could be used as a distribution, as an example the front and rear ARB distribution is where the minimum (-1) setting would be stiffest front ARB and disconnected rear ARB, Middle (0) would be the medium setting for both roll bars and Max (+1) would be disconnected front ARB and stiffest rear ARB. All distribution factors follow the same trend. This allowed the number of factors to be reduced to 7, which are as follows:

- Front Camber
- Rear Camber
- Anti-Roll bar distribution
- Spring stiffness distribution
- Aerodynamic distribution
- Static ride height distribution
- Toe front

The factors were put together into groups where it felt they had the most influence on each other, giving the following 3 test plans:

Table 3-1 - Tables for the 3 DOE tests

Test 1
Front Camber
Rear Camber
ARB Distribution

Test 2
Spring Distribution
Aero Distribution
Static Ride Height

Test 3
Toe Front
ARB Distribution
Spring Distribution

The next step is to decide on the outcomes that want to be assessed, for this choice it was decided to look at fastest lap time, average lap time and driver rating. These outcomes were decided as it is important to make sure the car is fast however it also needs to be consistently fast otherwise the driver could have 1 good lap and the rest poor resulting in them losing places during the race and the drivers rating was also important as wanted to see if lap time could be correlated with how the driver rated the setup. The units for the results are Seconds (S) for the lap times and the driver rating is unit-less, based on a scale of 1 – 10 where 1 is the driver is very unhappy with the setup to 10 where the driver is very happy with the setup.

All the above information is inputted into the Design Expert software, which creates the following test plan which includes the 5 centre runs with the 3 factors all at 0.

Std	Run	Factor 1 A:Spring Distribt...	Factor 2 B:Aero Distributi...	Factor 3 C:static Ride Hei...	Response 1 Fastest Lap Seconds	Response 2 Average Lap Seconds	Response 3 Driver Rating
14	1	0	0	0	97.66	97.84	8
3	2	-1	1	0	100.02	100.46	5
17	3	0	0	0	97.59	97.91	7
15	4	0	0	0	97.17	97.57	9
5	5	-1	0	-1	97.43	97.81	7
4	6	1	1	0	99.42	99.74	5
10	7	0	1	-1	99.11	99.46	5
11	8	0	-1	1	108.46	110.07	1
13	9	0	0	0	97.12	97.23	9
9	10	0	-1	-1	108.88	109.39	2
6	11	1	0	-1	97.64	98.12	7
1	12	-1	-1	0	105.89	106.55	3
2	13	1	-1	0	106.79	108.13	2
7	14	-1	0	1	98.37	98.45	7
8	15	1	0	1	96.96	97.53	9
16	16	0	0	0	97.2	97.7	8
12	17	0	1	1	99.76	100.61	5

Figure 3-6 - DOE test plan

In the above figure it shows it with the results already inputted into the table. From this results can be viewed which vary from different types of graphs looking at different aspects to what is being looked at here. The surface response models which generates a 3D model that maps out the results for the entire spectrum, infilling the spaces between -1, 0 and 1. This map is plotted with one of the factors being a constant. From there the software is able to show the influence of a factor on the others and also able to assess the possible options between -1 and 1 to look for an optimum result. It is capable to choose whether to minimise/maximise or aim for a result within certain limits. For this test the aim was to minimise the fastest and average lap time whilst maximise the driver rating.

The tests for the DOE runs will be run at 3 laps, instead of the 10 as per the runs in the driver development phase due to time constraints as there are many different settings to run. Also the driver is at a better level with his driving meaning that he is able to adapt to the setup changes quickly.

4 Results & Analysis

This section will be going through the results from the two different tests being looked at within this report. The first section will look at the results from engineering the driver including the KPI's and improvements made and the second the results from the DOE testing and the optimisation settings produced.

4.1 Engineering the Driver

4.1.1 Overall lap times

In total the driver completed 180 laps of Snetterton for this element of the project split between 19 sessions. Before starting any testing for the project predictions were made that the drivers performance would improve as per the below graph, however this was based on the driver completing 10 sessions as before starting it was unsure how many sessions would be needed to reach the desired performance. The graph is showing the percentage decrease in time compared to the original fastest lap time from the first session.

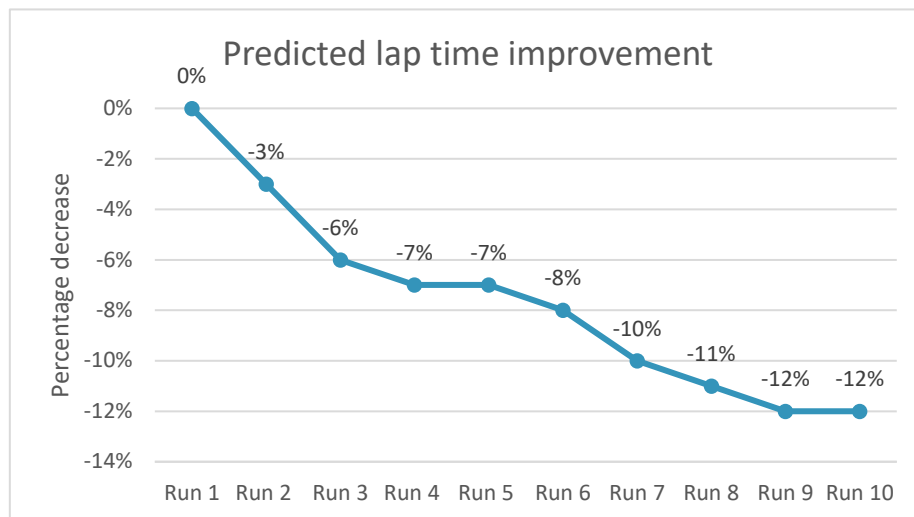


Figure 4-1 - Predicted lap time improvement

The prediction shows a sharp decrease in driver time as he finds large segments of time throughout the lap before reaching some stagnation in lap time as new techniques are tried and maybe focus is lost in other parts of the circuit before the driver can apply all the feedback to continuously improve to the point where time to find is minimal and it is felt that the most has been extracted from the car.

Below is the results for all the laps completed in one graph which includes flags as to where the interventions were introduced to the driver allowing quick reference as to the intervention number and the result after implementing the feedback:

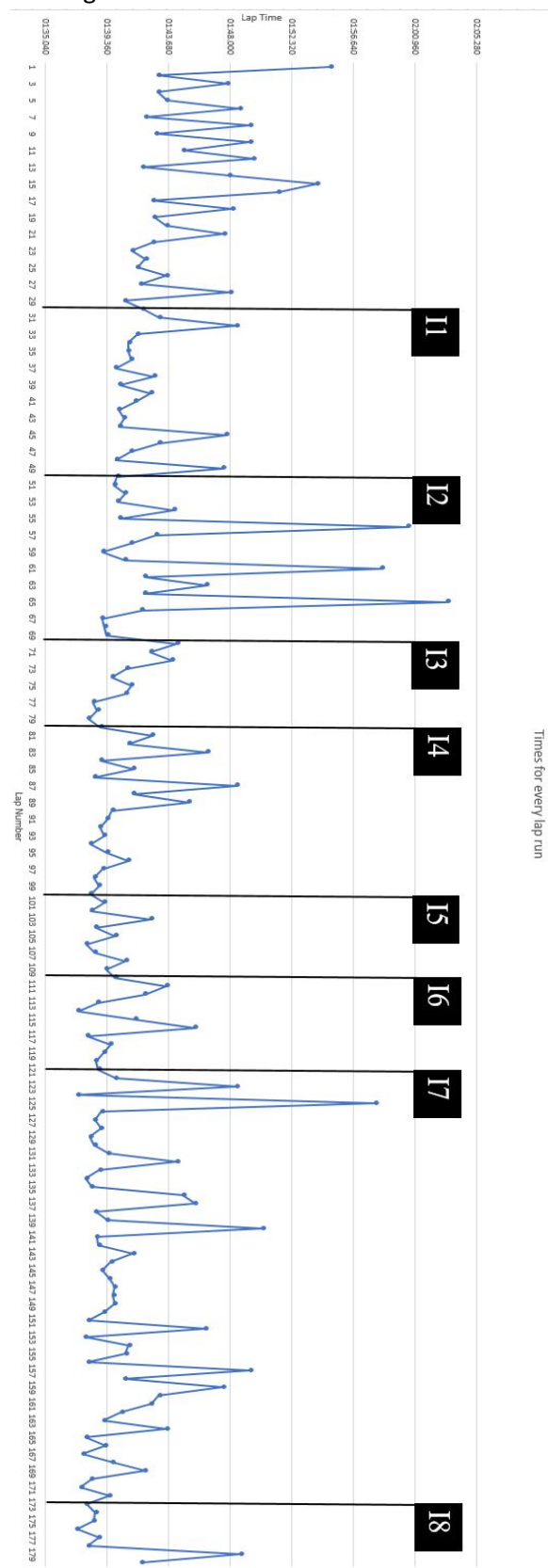


Figure 4-2 - Graph to show all lap times including intervention flags

Figure 4-2 shows that the overall trend is a decrease in lap time that there is spikes within groups of laps where the driver may be struggling with particular aspects or new techniques however the fluctuations in lap times does decrease until lap 120 where it starts to increase. This prompted a gap between Intervention 7 and 8, reason being that the driver had a break of 4 weeks over the Christmas period which meant it took time to dial back into his prior performance. Which is why when looking at the graph below showing the fastest lap times there is a peak in lap times rather than a consistent decrease.

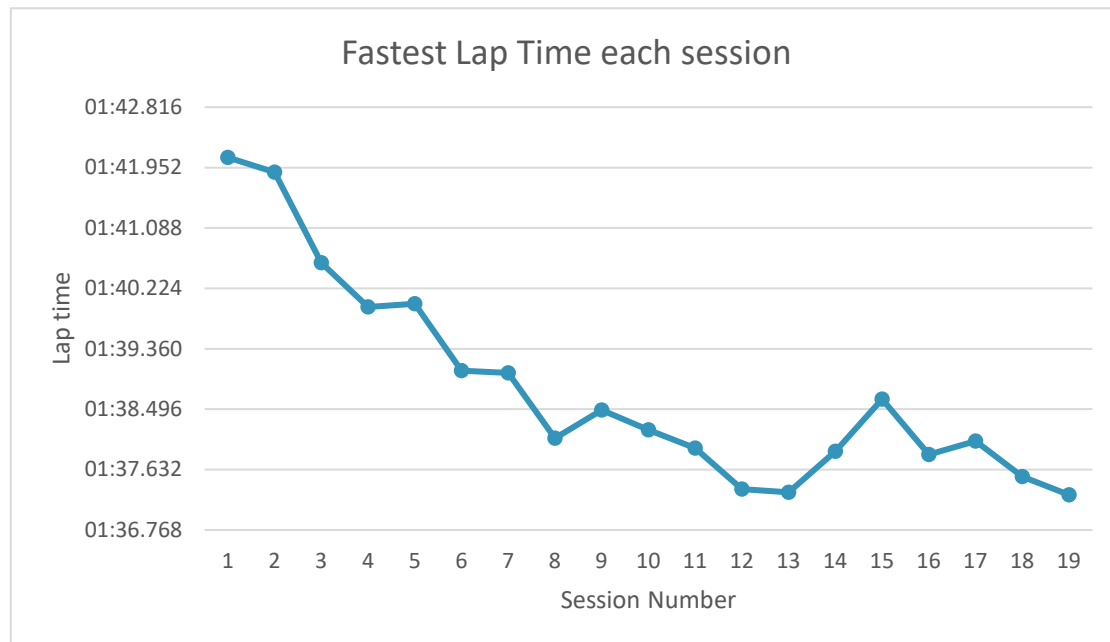


Figure 4-3 - graph to showing the fastest lap of each session

The above figure shows that there is an overall downward trend except for runs 14 and 15 where the times go back up however as mentioned above this is due to the break over the Christmas period and in session 19 the driver does record his overall fastest time. This graphs shows that the predictions made before the testing were close in there trends however the figures quoted were not with the driver recording an overall improvement of 4.21% in lap time.

The driver stated he felt like he could give no more and that it was fast as he could get and looking at the data the time to be gained was approximately 2 tenths. The probably of achieving a perfect lap is small and so it was decided at this point to not chase the final few tenths.

4.1.2 Key Performance Indicators

The previous section shows the results from the testing and this section will look at the KPI's that were used in order to reach that end lap time, from 3.2.4 it is known that there are 3 KPI's being looked at.

4.1.2.1 Percentage of the lap spent at full throttle

The first results shown for the amount of lap spent at full throttle, below is the graph comparing the fastest lap time in each session to the amount of time spent on full throttle during that lap:

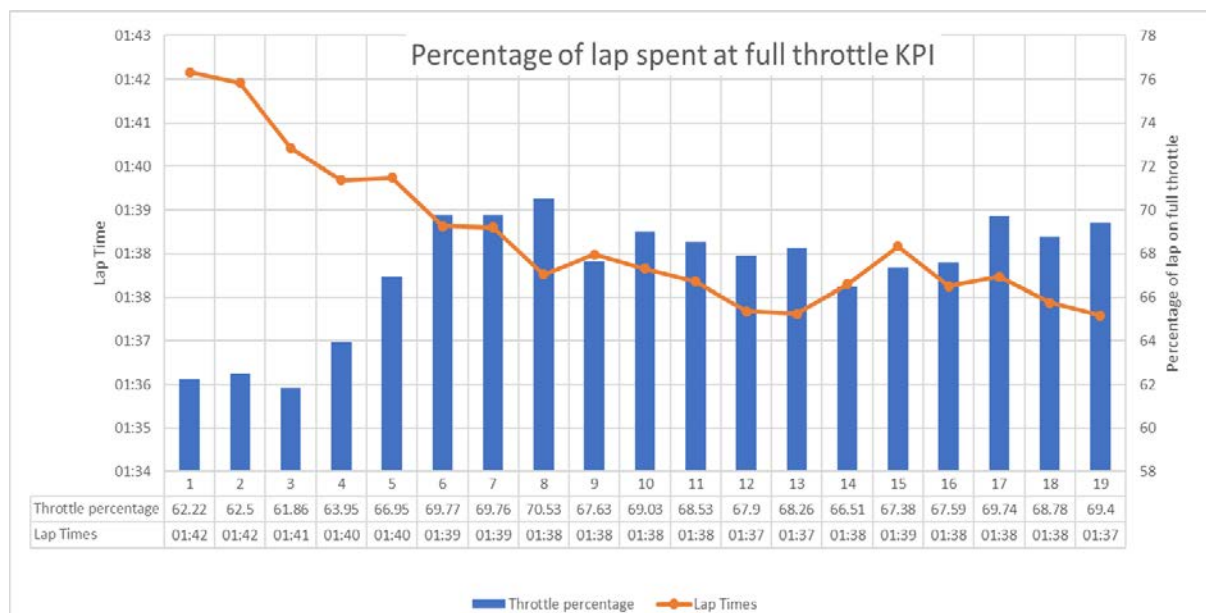


Figure 4-4 - Graph to show percentage of the lap spent at full throttle compared to lap time

The above figure shows the trend of that as the lap time goes up the amount of time at full throttle goes up which correlated with what was researched in section 2.2.2. There are some anomalies in that though where we see that the fastest overall time in session 19 has a throttle percentage of 69.4% however the session that contained the lap with the highest percentage spent on full throttle is session 8 where the driver spent an additional 1.13% on the throttle however was 0.808 seconds slower.

This could be because one of two reasons: the driver had a slower minimum speed within a corner that meant he could get to full throttle sooner due to have a lower lateral acceleration however the faster way through the corner was to have a higher minimum speed which means that overall the driver may have an average throttle position higher than the other session even though less time was spent at full throttle or that the driver had gone into a corner with full throttle however this resulted

in the driver understeering and scrubbing off speed slowing the car down more than if they had lifted slightly or used the brakes.

When comparing the throttle trace between the two sessions below the actual reason for the difference can be seen:

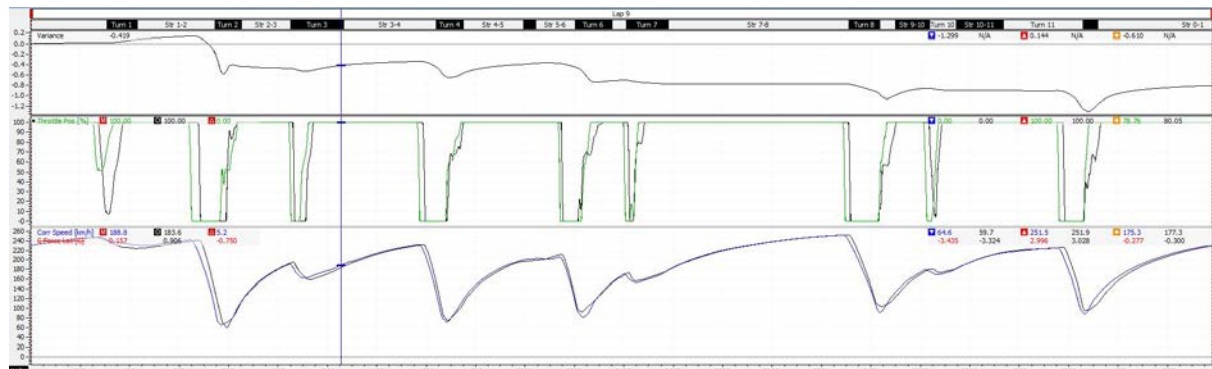




Figure 4-7 - Throttle trace for sessions 19 and 8 with highlighted sections

Figure 4-7 highlights sections where this continues to be a trend throughout the lap. Showing where the driver has actually been braking later but coming off the brakes at the same time resulting in a higher minimum speed through the corner however the driver has then been unable to get the car back to full throttle as quickly, the reasoning for this could be that the additional minimum speed carried has drifted the car closer to the edge of the circuit and so the driver has had to wait slightly longer before he can return to full throttle.

This is confirmed when discussing the lap with the driver which goes back to the point discussed in 2.1.3 that a data logger is not replacement for driver feedback and that the two need to be combined in order to understand how to go faster.

What the above confirms is that in the majority of cases the more time spent at full throttle in a lap the faster the lap time will be, the anomaly seen here is as a result of the above and when looking at the data Motec states that the driver spent less time off the throttle during the lap in session 9 and as a result the overall throttle pedal average was 80.05% compared to session 9's average of 78.87%.

To show the development of the driver when it comes to the use of the throttle pedal the fastest lap from the drivers first session is compared to that of the overall fastest lap the areas where the driver has improved on the throttle can be seen below.

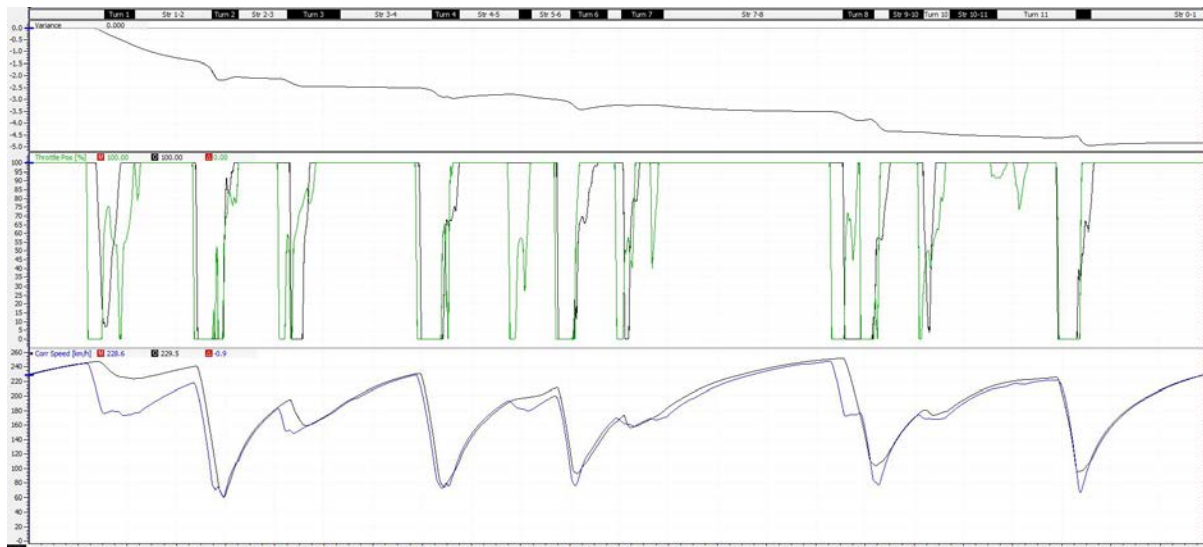


Figure 4-8 - Throttle trace for Session 1 comparison to session 19

Between session 1 and session 19 the driver had spent an additional 7.18% of the lap at full throttle which contributed to a lap time decrease of 4.825 seconds.

The way this has been achieved is through the use of the intervention sheets, looking at figures 8-2, 8-3, 8-6 and 8-8 the emphasis was working on the application of the throttle as the driver was trying to get back to full throttle as quickly as possible however the compromise was that the aggressive steps were causing the car to become imbalanced. The discussion with the driver at these points was to work on squeezing the throttle pedal to reach that 100% as what was looked at in 2.2.2 Throttle technique and from there the drivers throttle inputs improved however as seen in Figure 4-6 some of the throttle inputs are not ideal however it is not always possible for the driver to apply the throttle in a smooth curve due as discussed when looking at the comparison between session 8 and 19 above.

4.1.2.2 Percentage of the lap not spent on either pedal

The second KPI is looking at the amount of time as a percentage where the driver is not using any pedal, show in the below graph:

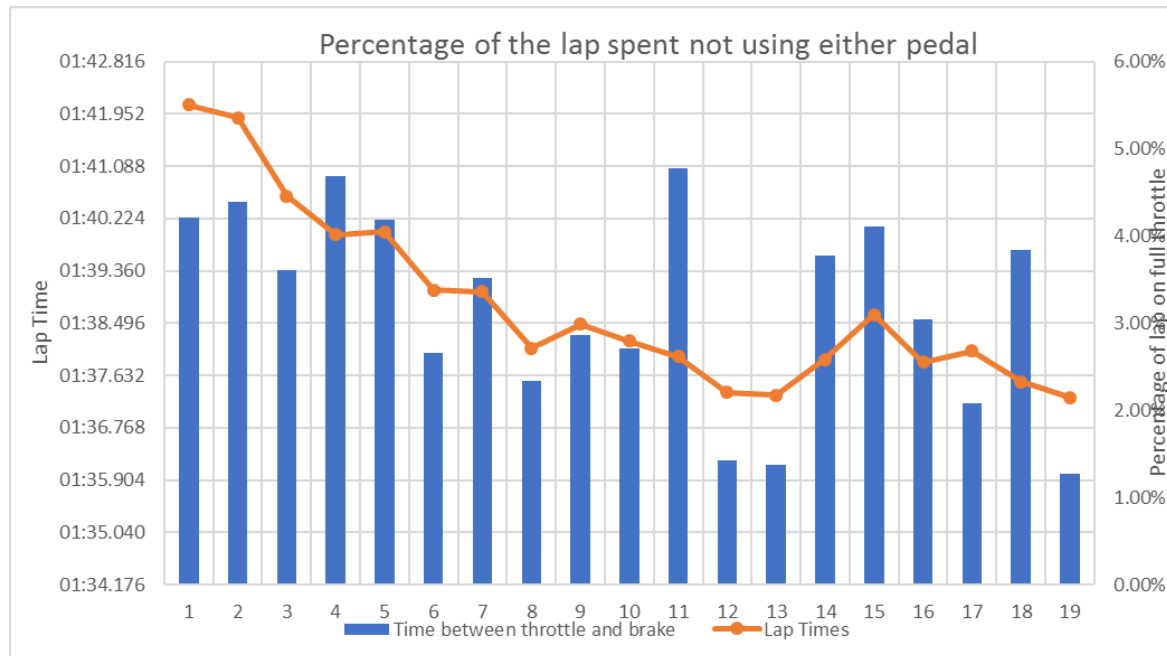


Figure 4-9 - percentage of the lap spent not using either pedal

Figure 4-9 follows the trends that as the percentage decreases with the lap time, with the only anomaly being in session 11 however the reason for this is that where the driver would normally have a lift in turns 1 and 10, it is normally a lift but the driver would still maintain some throttle to keep the car stable, however in this session the driver came completely out of the throttle at those two turns however has been able to carry higher minimum speeds during the run compared to previous runs. As a result in the next run he is then able to reduce the lap time and the time spent not using either pedal by taking the best of both and combining them.

It is possible to see how far the driver has come from the first session through to session 19 in the below figure, the driver has come from a difference of 4.21% down to 1.27% which is a difference of 2.94% which equates to a distance of 140.5m that the driver is now either accelerating or decelerating compared to before. The key areas that have been impacted are in T2, T3 and T6 which is where the driver has decreased the time from releasing the brake pedal to pressing the throttle. Session 1 is the coloured trace and session 19 is the black trace.

Figure 4-10 confirms what was researched in the driver technique section that the less time the driver spends 'freewheeling' the faster the lap time will be.

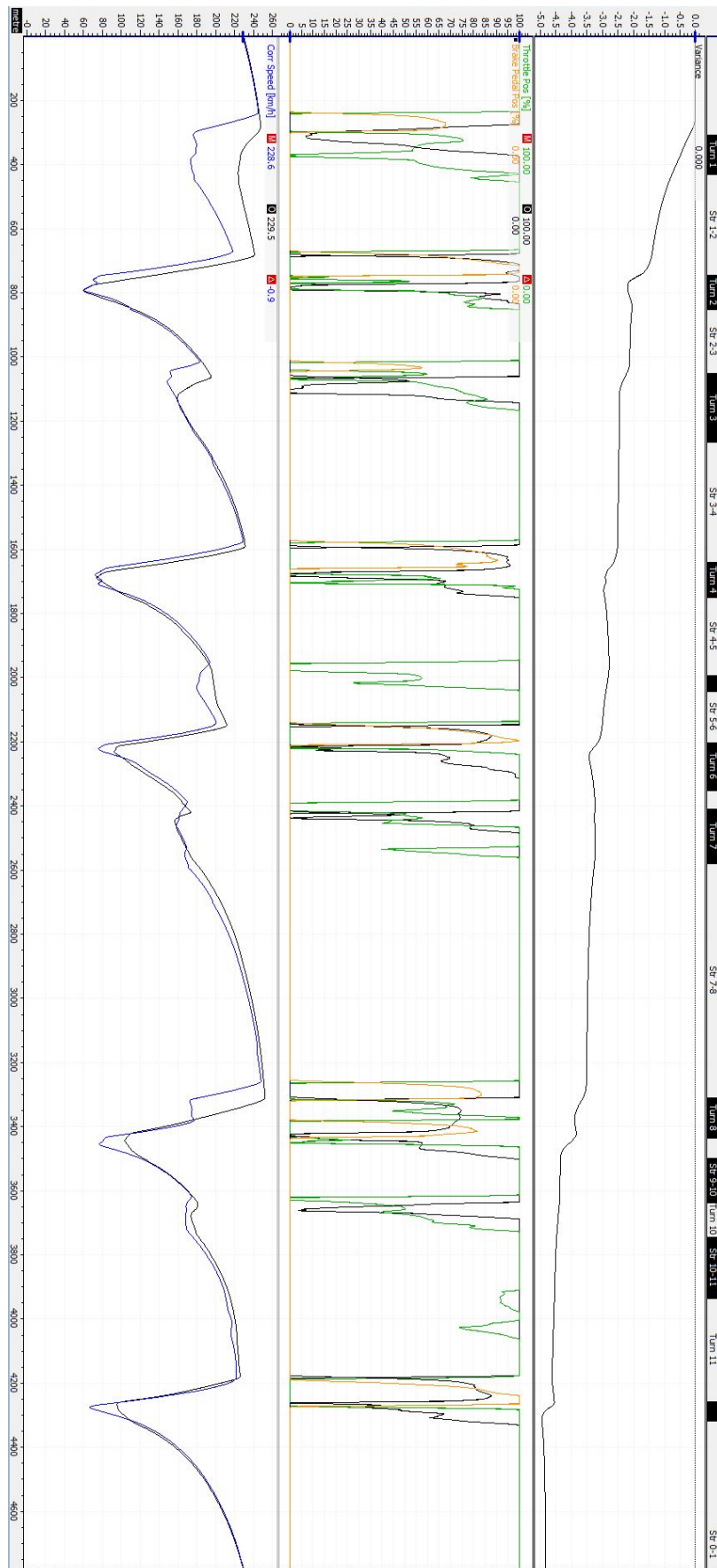


Figure 4-10 - Throttle & Brake trace for sessions 1 and 19

4.1.2.3 Percentage of max lateral G that 100% throttle was applied

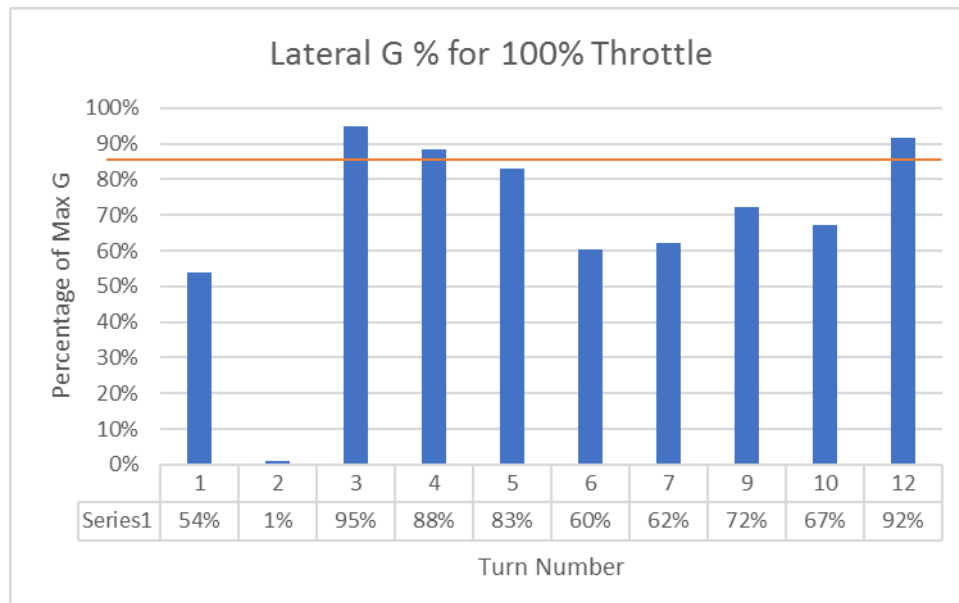


Figure 4-11 - Lateral G % for 100% Throttle for session 1

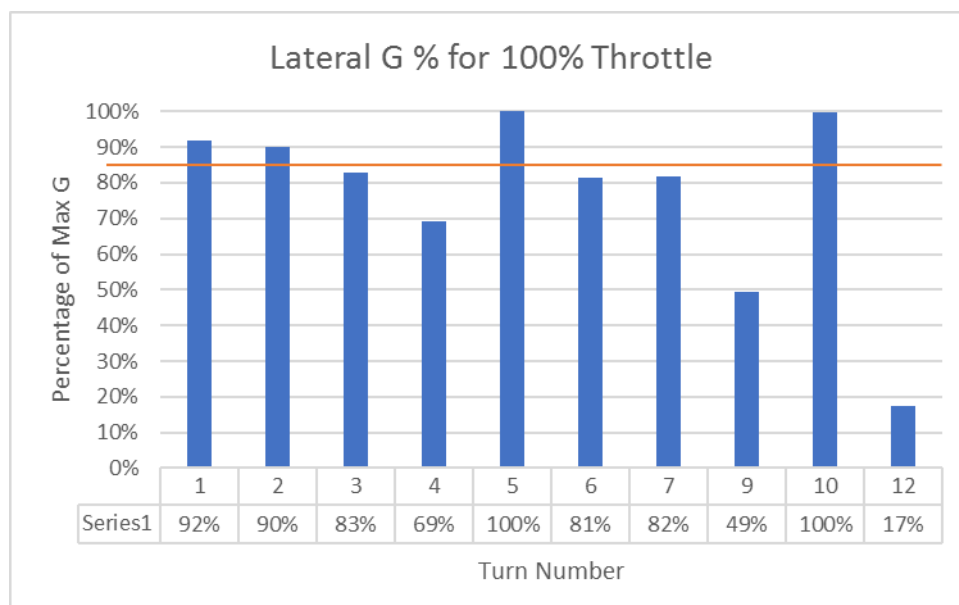


Figure 4-12 - Lateral G % for 100% Throttle for session 19

Figure 4-11 & Figure 4-12 show the results for the fastest lap in each season at what percentage of the max lateral G in a corner that the driver is back onto 100% throttle. From Table 3-1 it is known that the target for this vehicle is 85% which is the orange line on both graphs. For session 19 there are 4 out of 10 corners with a further 3 that are within 4% of the target compared to session 1 where there is 3 out of 10 corners where the target was hit and 1 corner that was within 2% of that target. This shows the progression made when going through the data feedback with the driver. The reason for the target not being met in some of the corners is the same as discussed in 4.1.2.1 where the

driver has carried a higher minimum speed and as a result been pushed more towards the edge of the circuit mean there has been a delay in getting on the throttle and by the time he has the lateral loading has decreased. The techniques used here to improve are those discussed in 2.2 Driver Techniques by the driver being smoother on the steering and throttle he is more likely to be able to get to full throttle whilst the tyre is still loading as the non-aggressive inputs allow for more use of the traction circle as seen below, an eclipse has been drawn to represent the traction circle for the tyre it is this shape due to the scaling of the graph:

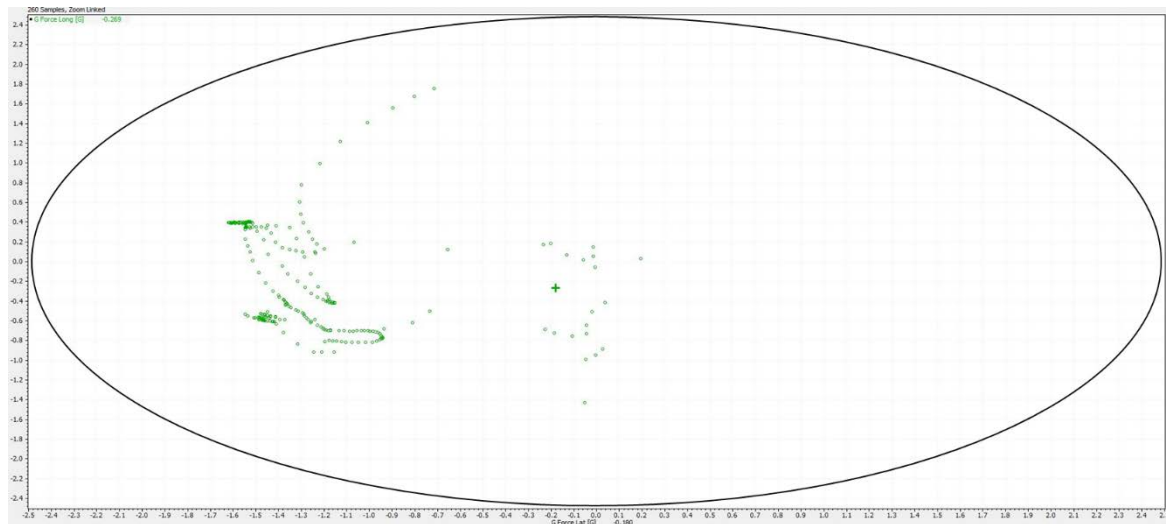


Figure 4-14 - GG plot for T2 session 1

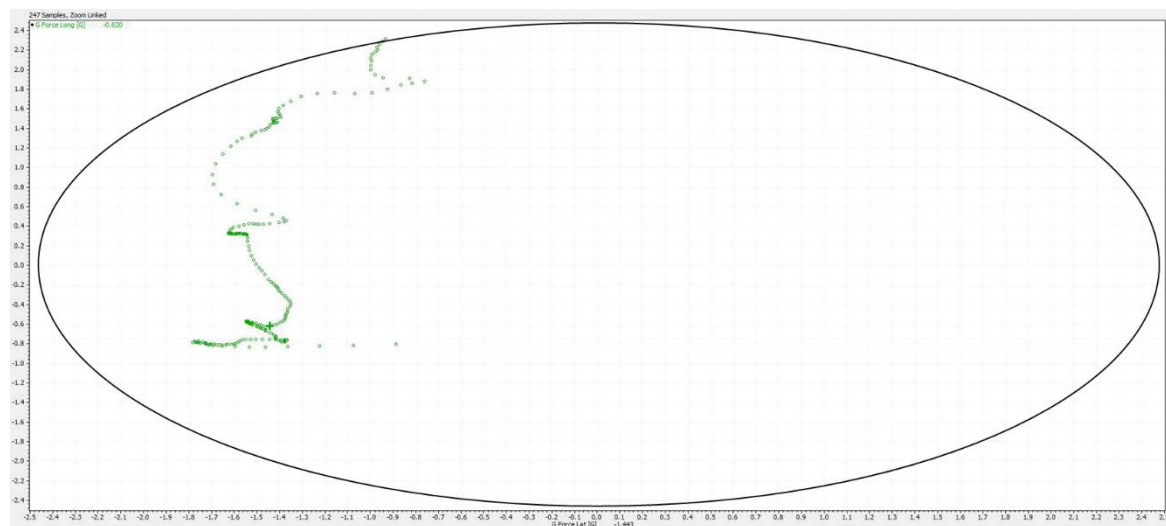


Figure 4-13 - GG plot for T session 19

Whilst both plots are not ideal it does show that the driver is making more use of the lateral grip of the tyre whilst braking in session 19 and then has a messy application of throttle as seen in the throttle trace in Figure 4-8 however is still back to full throttle quicker than in session 1, where the GG plot shows that the driver was on and off the throttle with a lot of lateral movement in the car which is why there isn't a clear path that can be followed in the data.

4.1.2.4 Overall Analysis

Below are the data traces for session 1 and 19 showing:

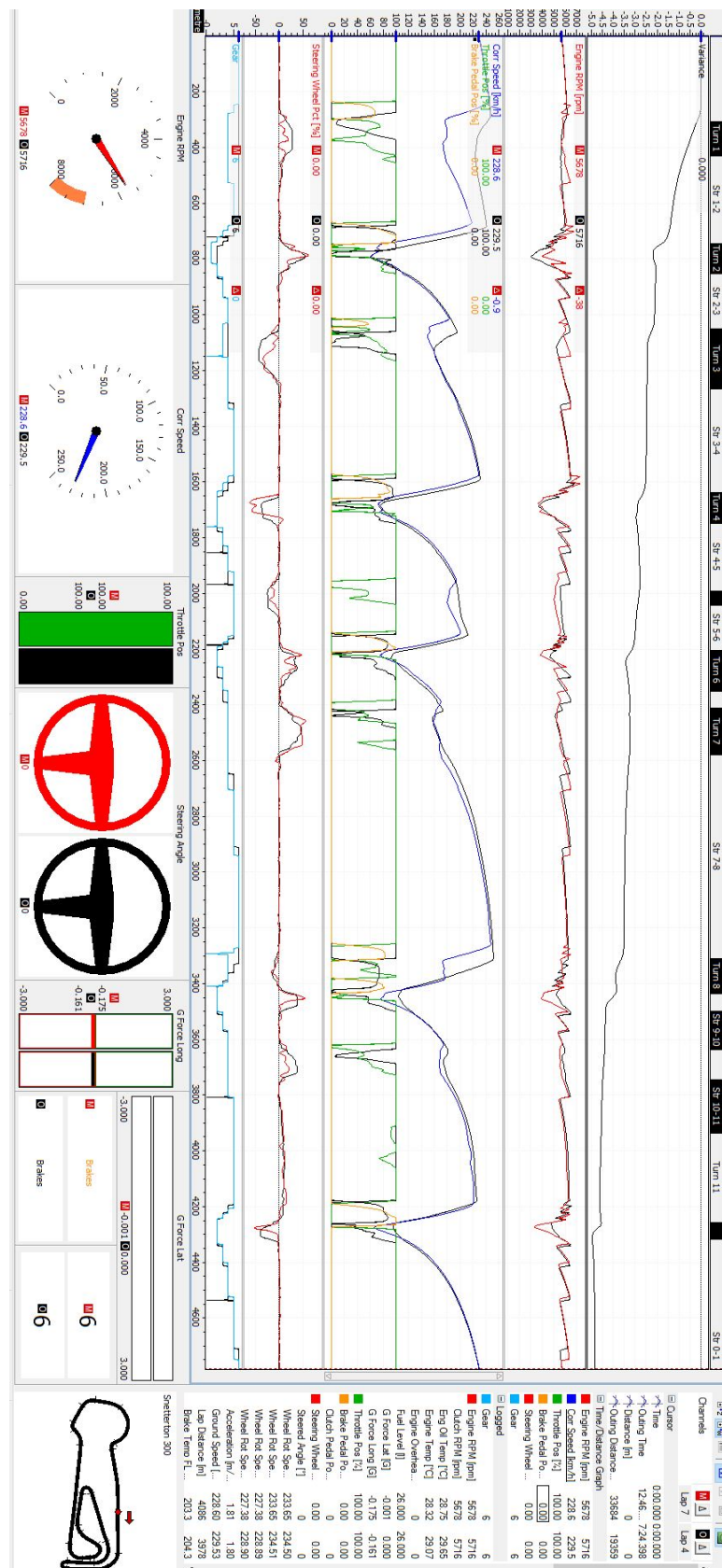


Figure 4-15 - full data overlay for session 1 and session 19

The trace shows: Time difference between laps, RPM, Speed, Throttle, Brake, Steering wheel percentage, Gear selected, Steered angle, G force for longitudinal and lateral along with a circuit map. The coloured travel is for session 1 and black for session 19.

The trace immediately highlights big improvements the driver has made in speed over a lap with being able to brake later and carry more speed through the bends whilst being smoother on all of the inputs, particularly the steering where the driver has gone from lots of sawing to more smooth and precise inputs which is what has helped the driver to maximise the results for the KPIs.

This correlates with the earlier discussion in the report that no lap can be perfect and that there will always be small errors that will be costing the driver time and in this instance Motec has given the fastest ideal time of 1:37.111 which is 0.160 seconds faster than the driver had achieved showing that the drivers lap was very close to being ideal.

4.2 Design of Experiments Results

This section will look at the results from the three DOE tests before looking to validate the information by testing the results at Brands Hatch GP circuit to see if the setup can be carried over to a different circuit.

The prediction for the results of this test are that it will look to produce a car that has high speed understeer and low speed oversteer. The reason for this is that when looking to navigate slower bends on a circuit the driver will be able to apply the power sooner if the back of the car has some controllable rotation so that the driver is able to return the steering wheel back to the straight ahead position sooner and squeeze the throttle however, the other side to this is that in a high speed corner this is not desirable as the rotation could easily lead to a spin and so it is much easier for the driver to deal with some front end understeer as it will provide them with the confidence that the car is unlikely to spin.

4.2.1 DOE 1

The results of the first test are in the below screenshot from the design expert software:

	Std	Run	Factor 1 A:ARB Distribution	Factor 2 B:Front Camber	Factor 3 C:Rear Camber	Response 1 Fastest Lap Seconds	Response 2 Average Lap	Response 3 Driver Rating
	15	1	0	-3	-1	97.49	97.71	9
	6	2	1	-3	-2	97.81	98.1	6
	4	3	1	-2.1	-1	97.21	97.56	8
	7	4	-1	-3	-0.1	97.88	97.96	6
	9	5	0	-4	-2	97.6	97.83	8
	10	6	0	-2.1	-2	98.78	98.94	6
	17	7	0	-3	-1	97.42	97.7	7
	13	8	0	-3	-1	97.61	97.83	8
	16	9	0	-3	-1	97.85	97.95	9
	3	10	-1	-2.1	-1	98.64	98.66	6
	8	11	1	-3	-0.1	98.32	98.62	7
	11	12	0	-4	-0.1	97.37	97.55	9
	5	13	-1	-3	-2	98.67	98.99	4
	2	14	1	-4	-1	98.93	99.61	2
	14	15	0	-3	-1	96.8	97.6	9
	12	16	0	-2.1	-0.1	97.84	98.26	8
	1	17	-1	-4	-1	98.2	98.28	7

Figure 4-16 - DOE test 1 information table

Figure 4-16 shows that there was just over 2 seconds between the quickest and slowest laps in the fastest laps column however within the driver response column the results vary from 2 through to 9 showing a big difference in the drivers feeling even though the difference in time was minor. The below figures will show the influence that the single factor will have on a lap time:

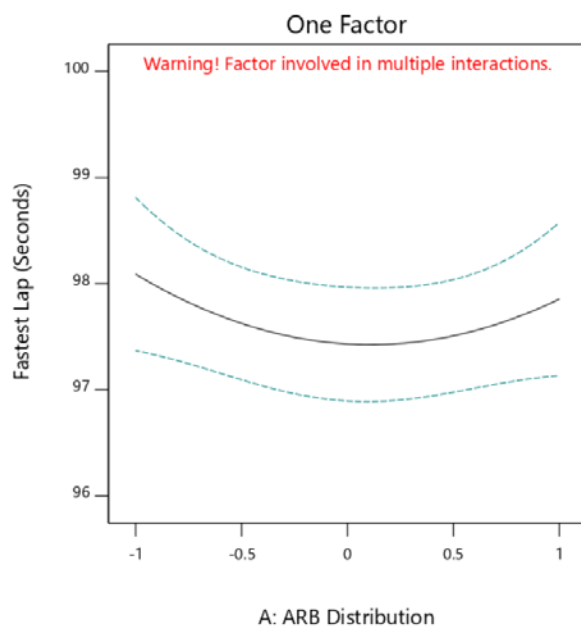


Figure 4-17 - One factor influence for ARB distribution for DOE 1

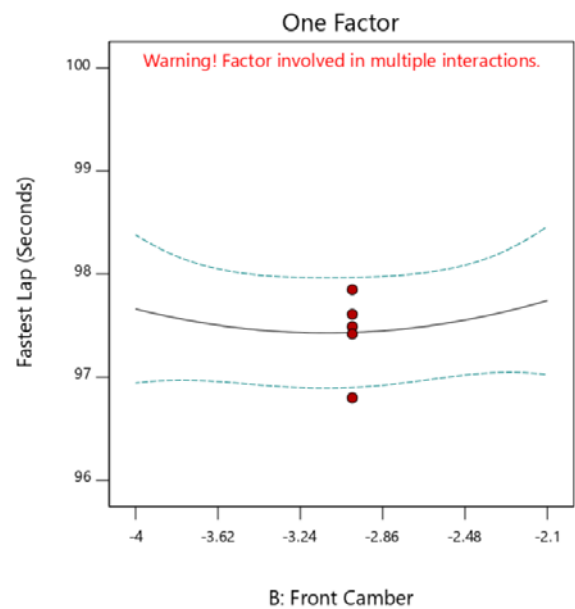


Figure 4-18 - Single Factor Interaction for Front Camber for DOE 1

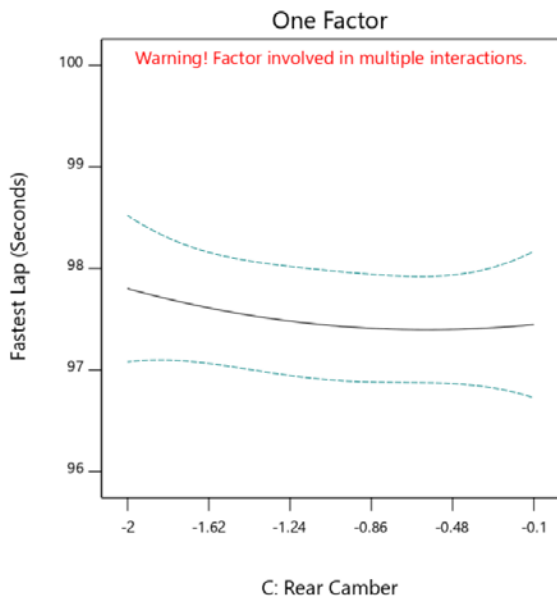


Figure 4-19 - Single Factor Interaction for Rear Camber for DOE 1

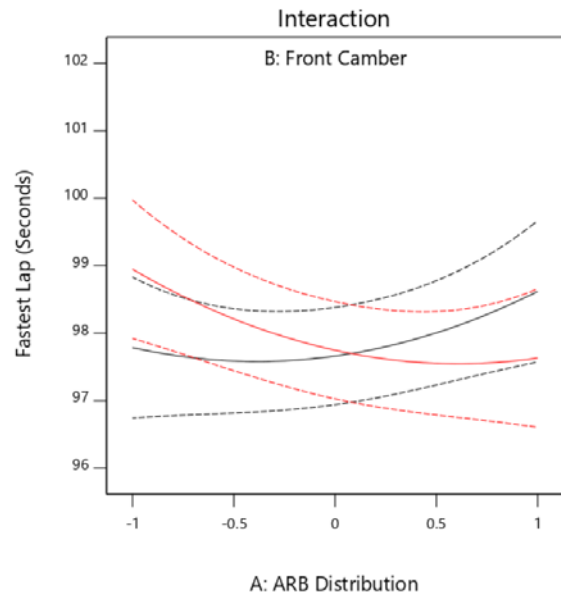


Figure 4-20 – Interaction for factors AB in DOE1

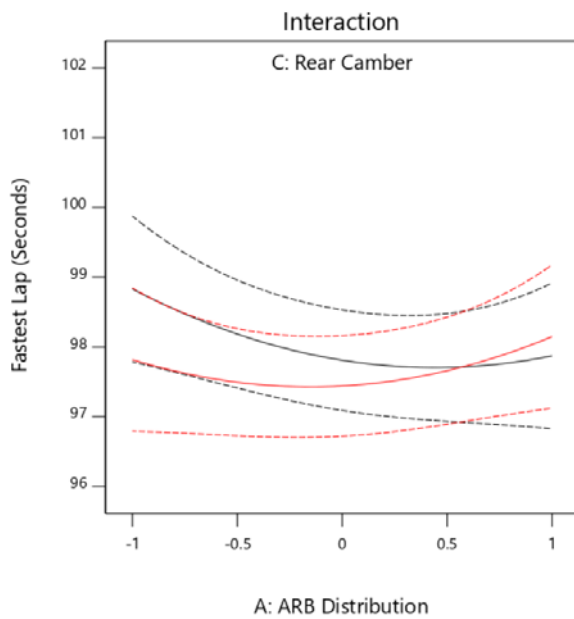


Figure 4-21 - Interaction diagram for AC in DOE 1

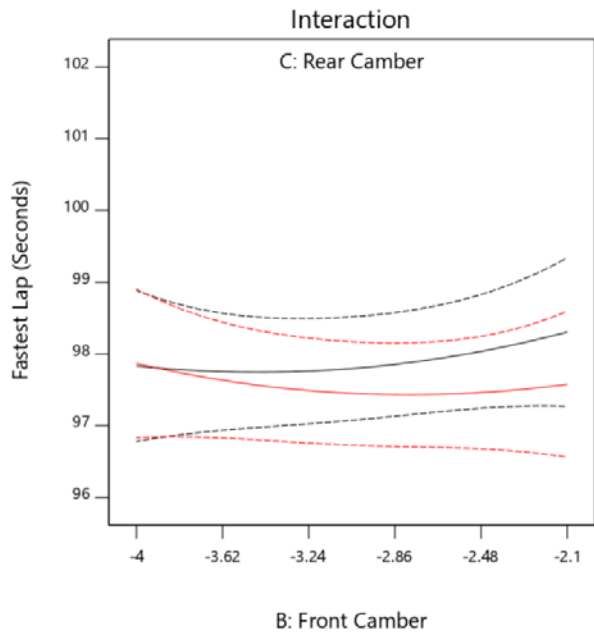


Figure 4-22 - Interaction diagram for BC in DOE 1

Figures 4-17 through to 4-19 show what design expert feel is the interaction each of those factors has on the lap time however as stated in them the factor is involved in other interactions, it is best to look at the interaction between the factors to see what the outcome would be.

The prediction for this test is that the front and rear camber should have little to no interaction with each other whereas the ARB will have strong interactions with both of the other factors.

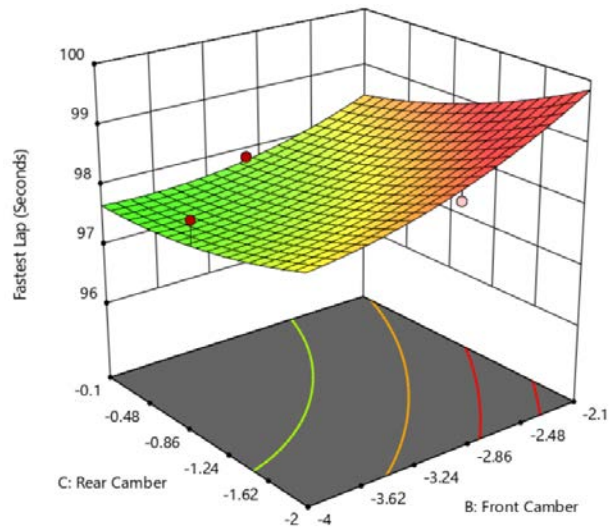


Figure 4-23 - Response surface at -1 for DOE 1

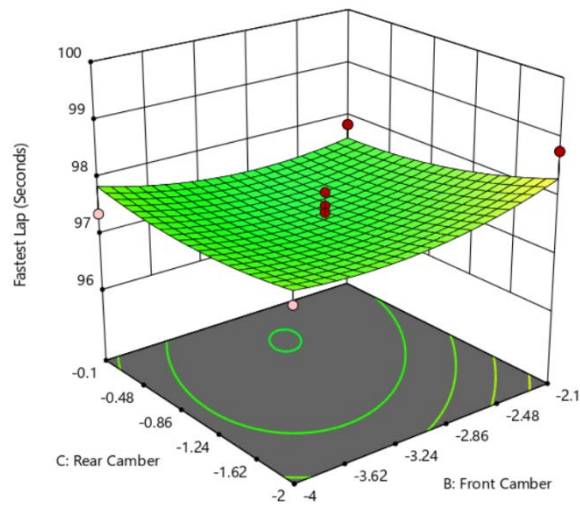


Figure 4-25 - Response surface at 0 for DOE 1

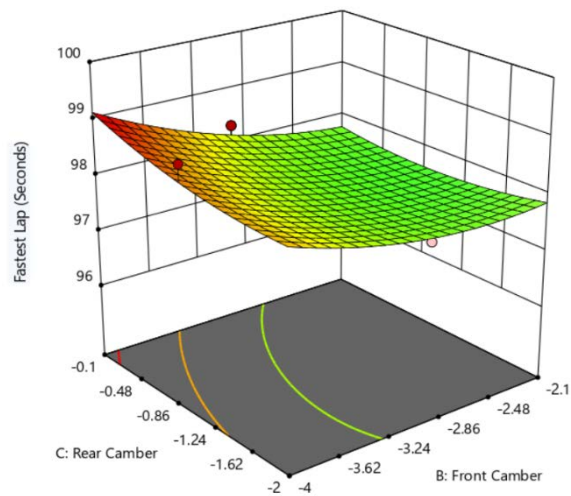


Figure 4-24 - Response surface at +1 for DOE 1

What Figures 4-20 through 4-22 shows is as per the prediction that the ARB has an interaction with the individual cambers whereas the front and rear camber have very little interaction with each other.

Figures 4-23 through to 4-25 then show the response surface diagram for the fastest lap and allow the user to see the predicted lap time when adjusting the ARB factor in this case between the range of -1 and +1. Meaning that at any combination of the three factors it can be seen what the predicted result is meaning that if the camber needed to be changed to preserve the tyre due to it over heating on the inside edge due to increased camber then this allows the engineer to look at the new desired camber and see what the predicted time will be and if any alterations can or need to be made to reduce the lap time.

Solutions

8 Solutions found

Number	ARB Distribution	Front Camber	Rear Camber	Fastest Lap	Average Lap	Driver Rating	Desirability	
1	0.028	-2.944	-0.567	97.396	97.710	8.691	0.524	Selected
2	0.025	-2.951	-0.568	97.396	97.710	8.688	0.524	
3	0.030	-2.944	-0.574	97.396	97.711	8.687	0.524	
4	0.030	-2.943	-0.574	97.396	97.711	8.688	0.524	
5	0.027	-2.943	-0.560	97.396	97.710	8.695	0.524	
6	0.028	-2.939	-0.558	97.396	97.710	8.698	0.524	
7	0.018	-2.951	-0.559	97.396	97.708	8.693	0.524	
8	0.020	-2.944	-0.558	97.396	97.708	8.697	0.524	

Figure 4-26 - Solutions for DOE 1

The software created solution shown in Figure 4-26 cannot be directly imported to the simulator as the setup can only be adjusted with pre-defined settings and so the first step was to translate the optimised setup from the software into a setup that can be applied to the vehicle. With this done the test was run and the results can be seen below:

Table 4-1 - Test results from DOE 1 optimised

DOE Test 1		
Predicted		
Fastest time	01:37.396	97.396
Average time	01:37.710	97.710
Driver rating	9	
Test Results		
Lap 1	01:37.728	97.728
Lap 2	01:37.559	97.559
Lap 3	01:37.922	97.922
Fastest Time	01:37.559	97.559
Average Time	01:37.736	97.736
Rating	8	
Difference		
Fastest Time	00:00.163	0.163
Average Time	00:00.026	0.026
Rating	1	

The results are 0.163 seconds away from the software when looking at the fastest lap, however this is within 0.17% of the predication and so whilst the driver did not better the best time from the first test it does show that the software has been very accurate in its prediction in this case.

4.2.2 DOE 2

	Std	Run	Factor 1 A:Spring Distribt...	Factor 2 B:Aero Distributi...	Factor 3 C:static Ride Hei...	Response 1 Fastest Lap Seconds	Response 2 Average Lap Seconds	Response 3 Driver Rating
	14	1	0	0	0	97.66	97.84	8
	3	2	-1	1	0	100.02	100.46	5
	17	3	0	0	0	97.59	97.91	7
	15	4	0	0	0	97.17	97.57	9
	5	5	-1	0	-1	97.43	97.81	7
	4	6	1	1	0	99.42	99.74	5
	10	7	0	1	-1	99.11	99.46	5
	11	8	0	-1	1	108.46	110.07	1
	13	9	0	0	0	97.12	97.23	9
	9	10	0	-1	-1	108.88	109.39	2
	6	11	1	0	-1	97.64	98.12	7
	1	12	-1	-1	0	105.89	106.55	3
	2	13	1	-1	0	106.79	108.13	2
	7	14	-1	0	1	98.37	98.45	7
	8	15	1	0	1	96.96	97.53	9
	16	16	0	0	0	97.2	97.7	8
	12	17	0	1	1	99.76	100.61	5

Figure 4-27 - Information table for DOE test 2

Figure 4-27 shows a much wider range of fastest lap times compares to Figure 4-16 with there being 12 seconds between the quickest and slowest times.

The prediction for the interaction between the factors is that the aero distribution will have a big interaction with the static ride height of the vehicle whereas the spring distribution will not have such a big interaction with either of the other factors.

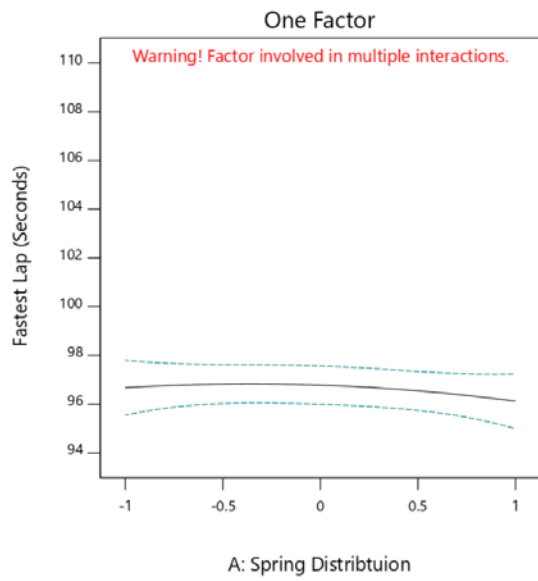


Figure 4-29 - One factor interaction for A in DOE 2

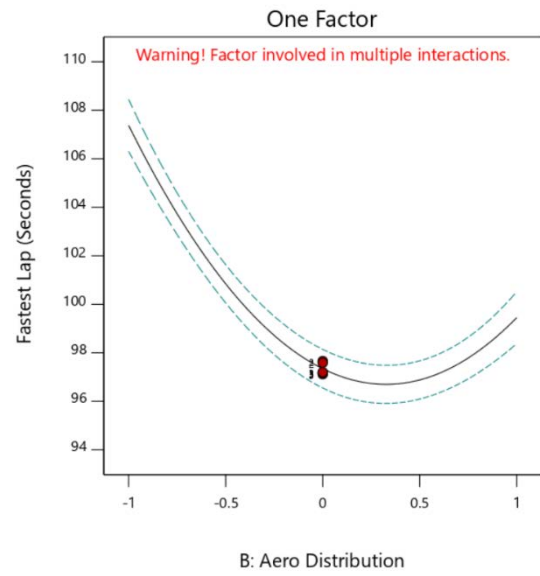


Figure 4-28 - One factor interaction for B in DOE 2

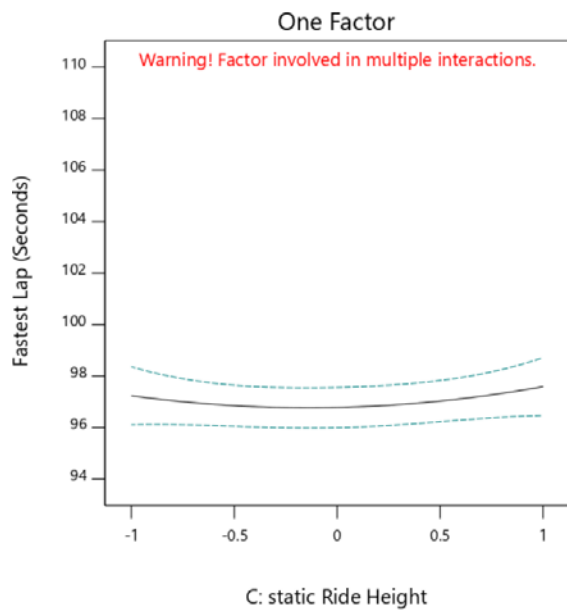


Figure 4-30 - One factor interaction for C in DOE 2

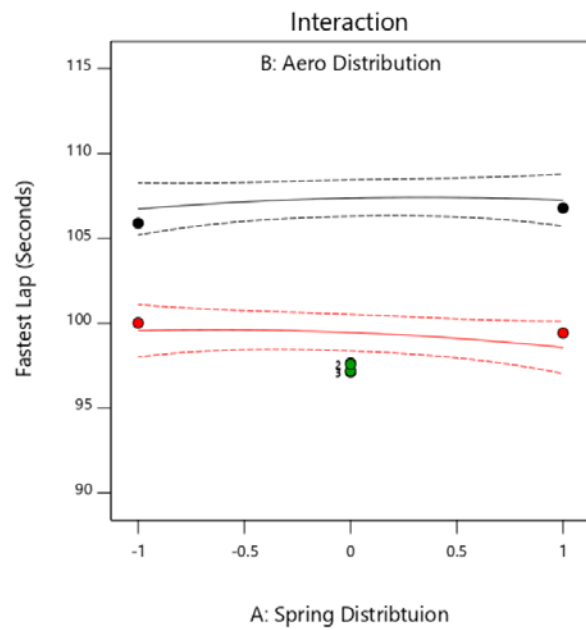


Figure 4-31 - Interaction for factors AB in DOE 2

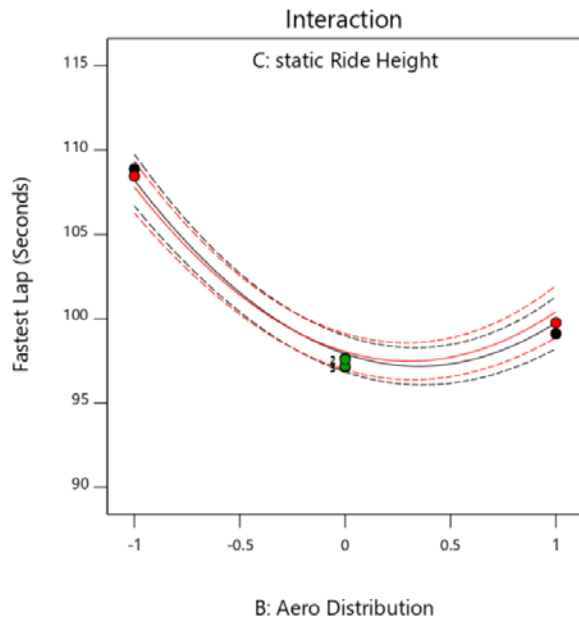


Figure 4-32 - Interaction for factors BC in DOE 2

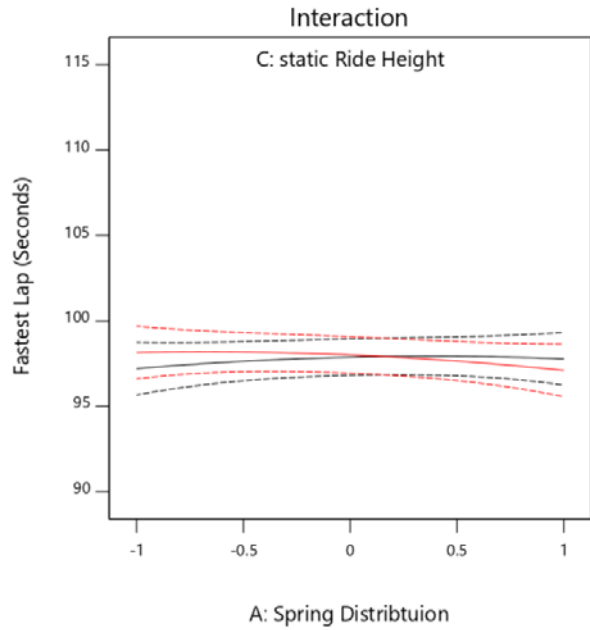


Figure 4-33 - Interaction for factors AC in DOE 2

As predicted for the static ride height and aero distribution there is a big interaction where the factors follow the exact same curve through the range and also the lack of interaction between the spring rate distribution and aero distribution however, against the prediction is the interaction between the spring rate distribution and the static ride height even though it is a small interaction.

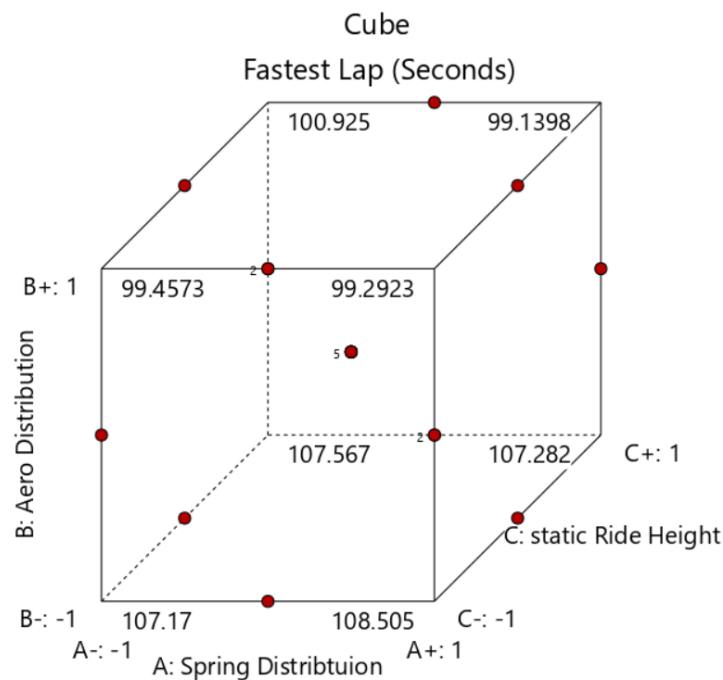


Figure 4-34 - Cube for DOE 2

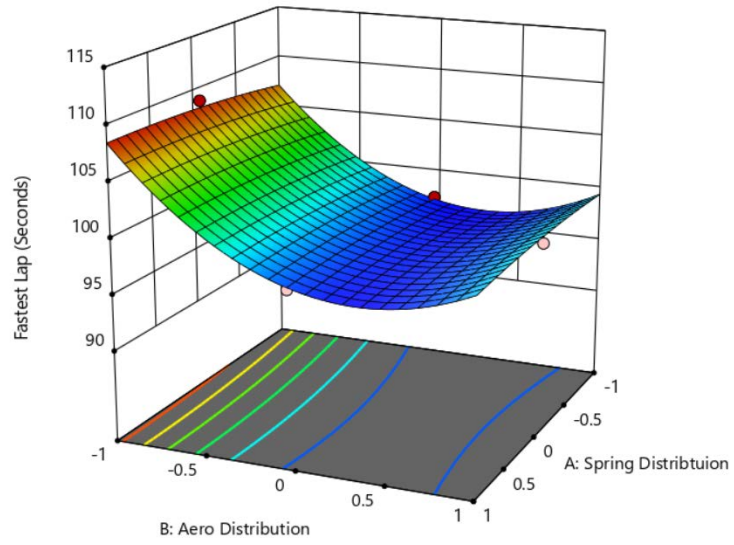


Figure 4-35 - Response surface at -1 for DOE 2

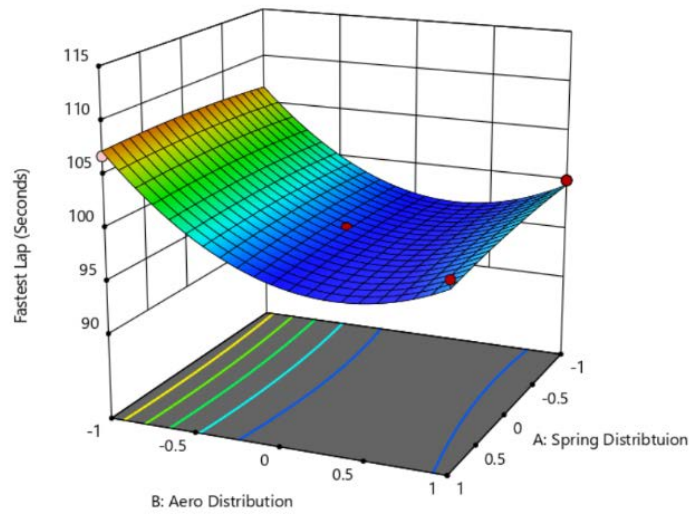


Figure 4-36 - Response surface at 0 for DOE 2

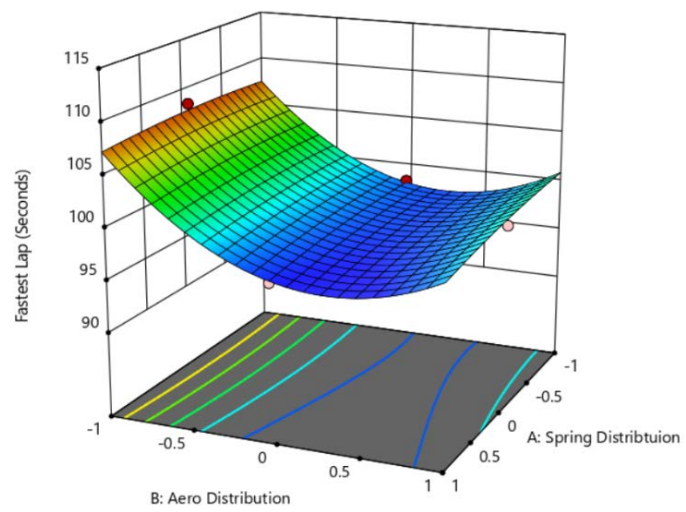


Figure 4-37 - Response surface for +1 in DOE 2

Figures 4-35 through to 4-37 show that throughout the range that any tests run with the aero distribution moving towards -1 will result in a sharp increase in lap times. The reason for this is that this reduces the rear aero resulting in the car being very oversteers and the driver is then unable to carry a high minimum speed through corners and in high speed bends now has to have a much larger lift or even brake in order to stop the car for over steering. The evidence for this can be seen in the throttle trace in Figure 4-38 where just in turn 1 the driver loses nearly a second compared to a run where the Aero distribution was set to 0, the driver has to wait for a long time and be very gentle on reapplication of the throttle to ensure that the car will not oversteer.

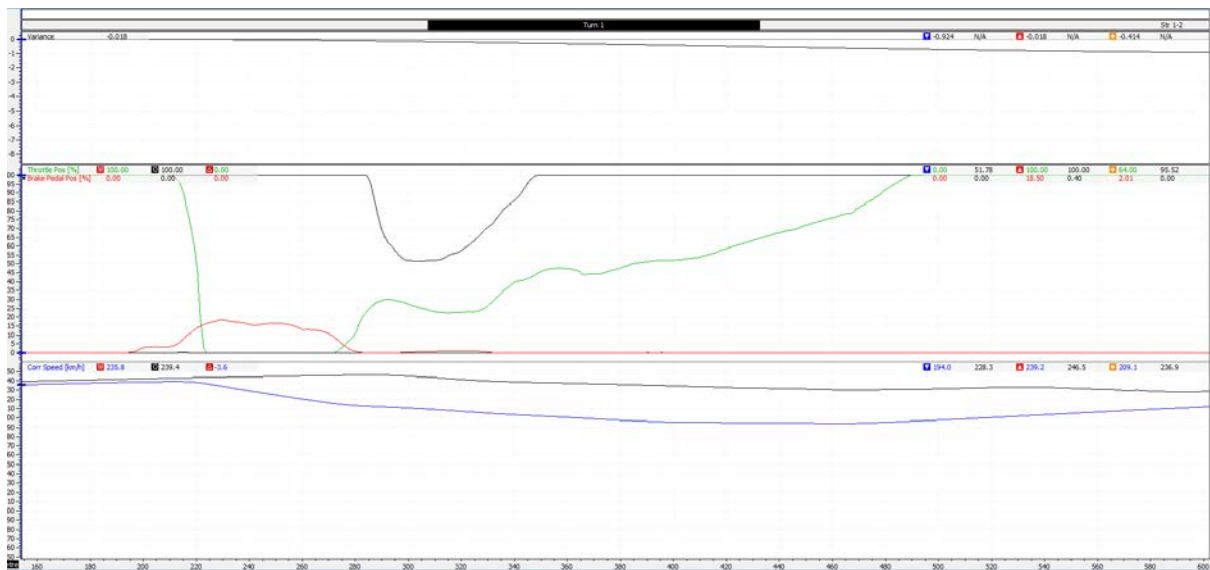


Figure 4-38 - Throttle trace comparison for DOE 2 in T1

Solutions

9 Solutions found

Number	Spring Distribtuion	Aero Distribution	static Ride Height	Fastest Lap	Average Lap	Driver Rating	Desirability	
1	-1.000	0.247	-0.353	96.450	96.584	8.054	0.866	Selected
2	-1.000	0.248	-0.346	96.451	96.585	8.054	0.866	
3	-1.000	0.248	-0.360	96.449	96.584	8.052	0.866	
4	-1.000	0.248	-0.339	96.451	96.585	8.054	0.866	
5	-1.000	0.248	-0.367	96.448	96.583	8.051	0.866	
6	-1.000	0.255	-0.353	96.446	96.581	8.046	0.866	
7	-1.000	0.239	-0.340	96.458	96.590	8.063	0.866	
8	-1.000	0.240	-0.371	96.454	96.588	8.059	0.866	
9	-1.000	0.254	-0.375	96.444	96.581	8.044	0.866	

Figure 4-39 - Solution for DOE 2

Table 4-2 - DOE 2 solutions results

DOE Test 2		
Predicted		
Fastest time	01:36.450	96.450
Average time	01:36.584	96.584
Driver rating	8	
Test Results		
Lap 1	01:37.821	97.821
Lap 2	01:36.654	96.654
Lap 3	01:37.696	97.696
Fastest Time	01:36.654	96.654
Average Time	01:37.390	97.390
Rating	8	
Difference		
Fastest Time	00:00.204	0.204
Average Time	00:00.806	0.806
Rating	0	

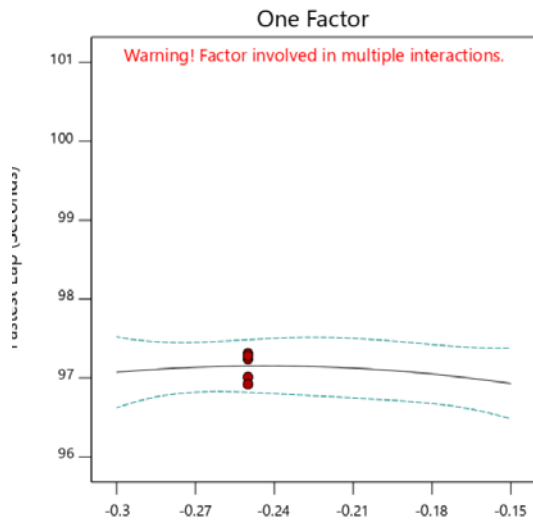
In a similar trend to Table 4-1 the predicted time is very close to the actual time the driver has been able to produce, in this case it is 0.204 seconds which is 0.21% difference whereas the average lap time is 0.806 seconds apart which could have been that the driver had made a mistake on one or both of the laps lowering the average.

4.2.3 DOE 3

	Std	Run	Factor 1 A:Toe Front	Factor 2 B:ARB Distribution	Factor 3 C:Spring Distrib...	Response 1 Fastest Lap Seconds	Response 2 Average Lap Seconds	Response 3 Driver Rating
	14	1	-0.25	0	0	97.01	97.16	9
	17	2	-0.25	0	0	97.28	97.48	8
	2	3	-0.15	-1	0	97.55	97.71	8
	3	4	-0.3	1	0	98.44	98.97	5
	7	5	-0.3	0	1	96.86	97.2	9
	4	6	-0.15	1	0	98.85	99.45	4
	15	7	-0.25	0	0	96.92	97.29	9
	8	8	-0.15	0	1	97.61	97.9	8
	13	9	-0.25	0	0	97.24	97.56	8
	11	10	-0.25	-1	1	98.11	98.51	7
	6	11	-0.15	0	-1	96.83	97.2	9
	5	12	-0.3	0	-1	97.19	97.38	8
	10	13	-0.25	1	-1	97.82	97.92	7
	9	14	-0.25	-1	-1	98.81	98.87	5
	1	15	-0.3	-1	0	98.92	99.31	5
	16	16	-0.25	0	0	97.31	97.48	9
	12	17	-0.25	1	1	100.12	100.65	5

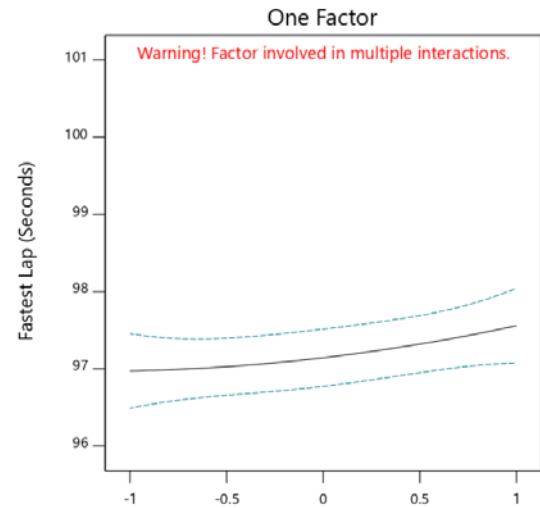
Figure 4-40 - Information table for DOE 3

The prediction for the interaction between the factors is that there will be interaction between all three factors within this test as they will all influence the front end of the vehicle.



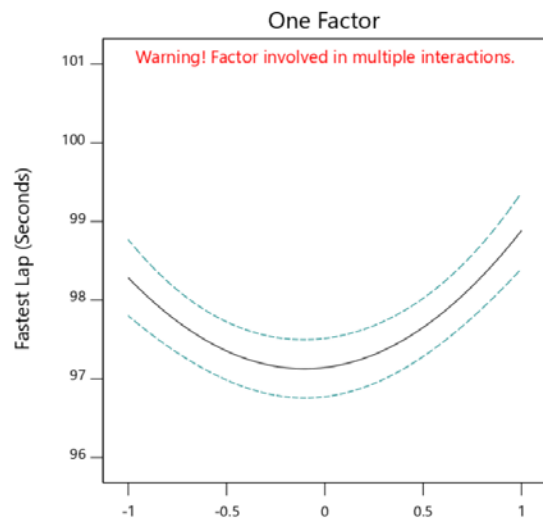
A: Toe Front

Figure 4-46 – Interaction for factor A in DOE 3



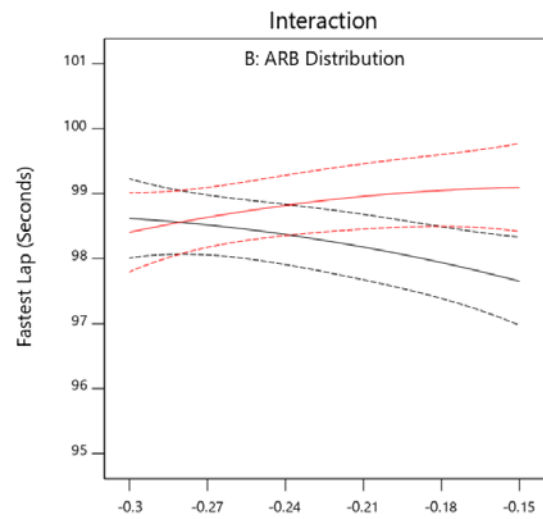
C: Spring Distribution

Figure 4-45 – Interaction factor for C in DOE 3



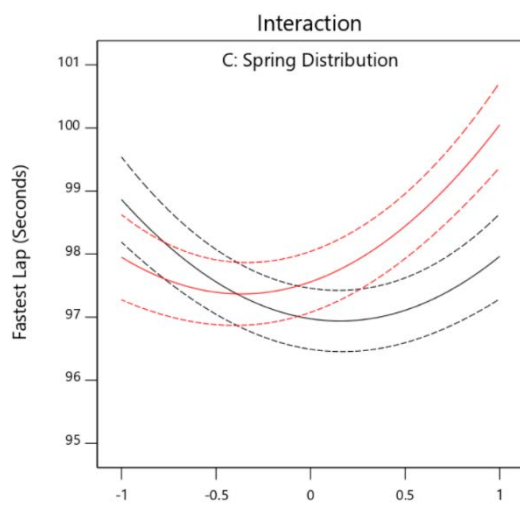
B: ARB Distribution

Figure 4-44 – Interaction for factor B in DOE 3



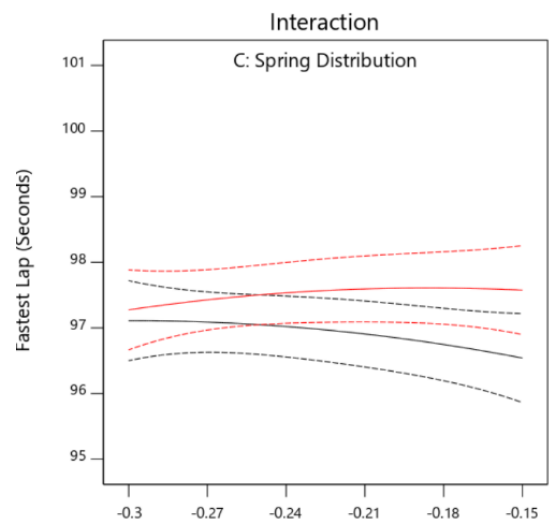
A: Toe Front

Figure 4-43 – Interaction factors for AB in DOE 3



B: ARB Distribution

Figure 4-42 – Interaction factors for BC in DOE 3



A: Toe Front

Figure 4-41 – Interaction factors for AC in DOE 3

As per the prediction, in Figures 4-44 through to 4-46 it can be seen in all figures that the interaction by the factors follow a very similar path throughout the range.

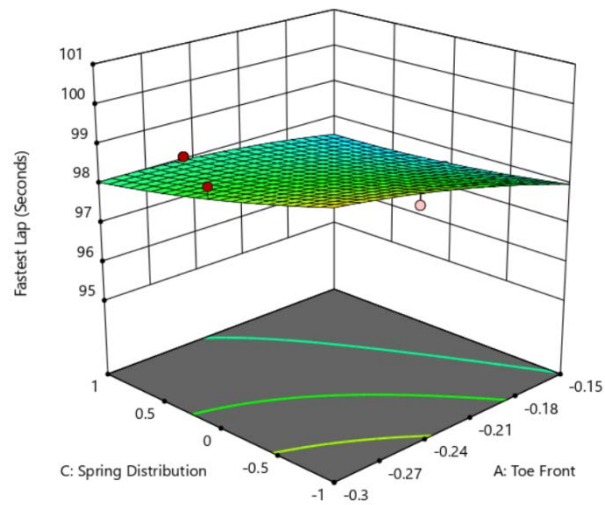


Figure 4-47 - Response surface -1 DOE 3

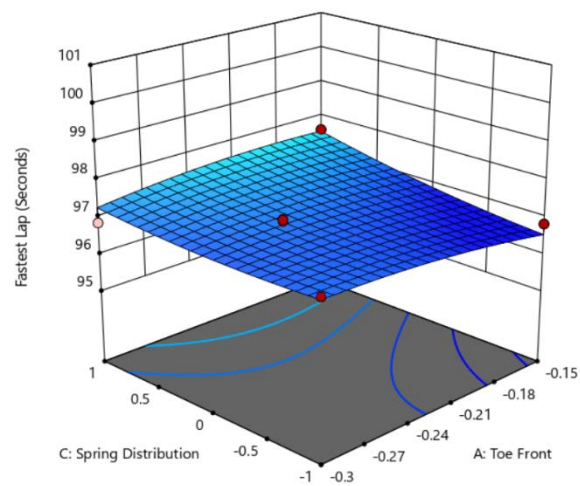


Figure 4-48 - Response surface 0 DOE 3

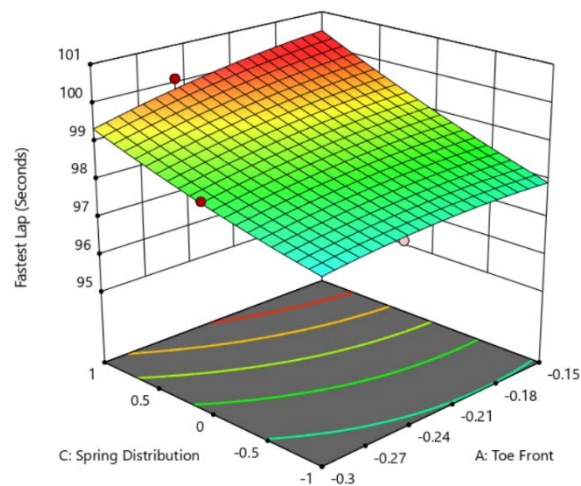


Figure 4-49 - Response surface +1 DOE 3

Solutions

4950 Solutions found

	Number	Toe Front	ARB Distribution	Spring Distribution	Fastest Lap	Average Lap	Driver Rating	Desirability	
	1	-0.150	-0.052	-1.000	96.547	96.823	9.336	0.780	Selected
	2	-0.150	-0.059	-1.000	96.548	96.823	9.339	0.780	
	3	-0.150	-0.059	-1.000	96.548	96.823	9.339	0.780	
	4	-0.150	-0.045	-1.000	96.546	96.823	9.333	0.780	
	5	-0.150	-0.059	-1.000	96.549	96.823	9.340	0.780	
	6	-0.150	-0.061	-1.000	96.549	96.823	9.340	0.780	
	7	-0.150	-0.042	-1.000	96.545	96.823	9.331	0.780	
	8	-0.150	-0.066	-1.000	96.550	96.823	9.343	0.780	
	9	-0.150	-0.038	-1.000	96.545	96.823	9.329	0.780	

Figure 4-50 - Solutions for DOE 3

Table 4-3 - Results for solutions DOE 3

DOE Test 3		
Predicted		
Fastest time	01:36.547	96.547
Average time	01:36.823	96.823
Driver rating	9	
Test Results		
Lap 1	01:37.173	97.173
Lap 2	01:37.540	97.540
Lap 3	01:37.739	97.739
Fastest Time	01:37.173	97.173
Average Time	01:37.484	97.484
Rating	7	
Difference		
Fastest Time	00:00.626	0.626
Average Time	00:00.661	0.661
Rating	2	

Following a similar trend to Table 4-1 and 4-2 the results predicted by the DOE software are very close to that of what was actually achieved in the test. In this particular example the driver was 0.626 seconds slower than predicted. Which is a 0.65% difference.

4.2.4 Verification of results

What has been proved in the 3 DOE tests is that the software has been able to accurately provide a setup and predict a time that the driver is able to be within 1% of, before completing the tests the predication was made as to what setup the software would provide as a faster solution. Looking at DOE 2 where the driver was able to achieve the overall fastest time from all tests the setup chosen

by the software was:

Aero distribution = 0.247 which equates to setting 7 for the front wing and 11 for the rear

Spring distribution = -1 which equates to the stiffest front spring and softest rear

Static ride height = -0.353 which equates to a front ride height of 2.7 and rear of 4.3

What this setup looks to achieve is to take away some of the front downforce which will give the car slightly more understeer at high speed especially when combined with increased rear wing meaning the car will be stable through the fast corners. The stiff front spring will mean that there is more weight transfer across the front axle and so a higher lateral load pushed onto the outside front tyre which will also give a little understeer however the softer rear spring will mean that there is less weight transfer at the rear of the vehicle helping with rotation at turn in in low speed corners. The static ride height change increases the overall height and adds in 10mm of rake which will complement the downforce and also the additional rear height coupled with the softer rear springs will mean that the car should have good traction when accelerating out of the corners.

To look at the difference between the fastest session when using the original setup where the driver achieved a 1:37.271 and the 1:36.654 achieved using the above setup, the KPI's have been referred back to.

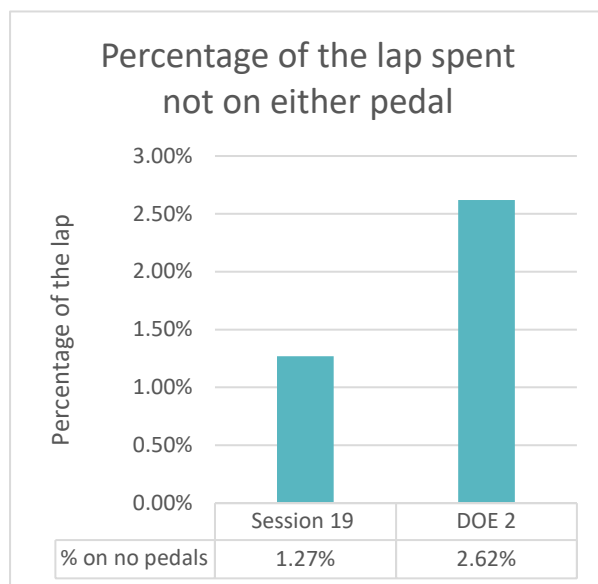


Figure 4-51 - Percentage of the lap spent not on either pedal for DOE 2

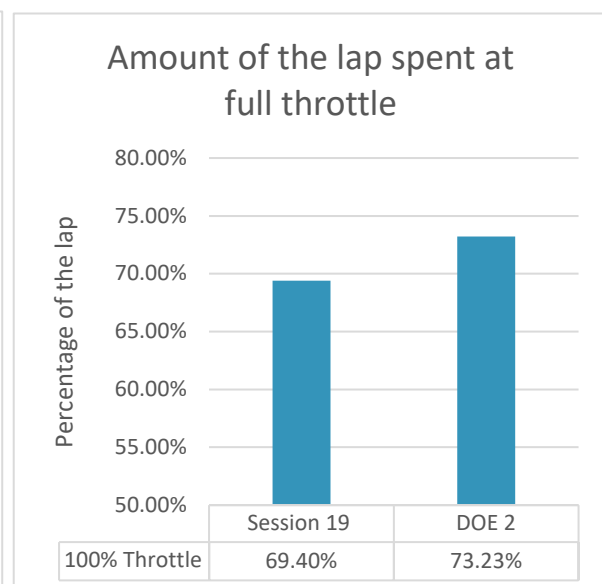


Figure 4-52 - Amount of lap spent at full throttle for DOE 2



Figure 4-54 – Throttle comparison for S19 to DOE 2

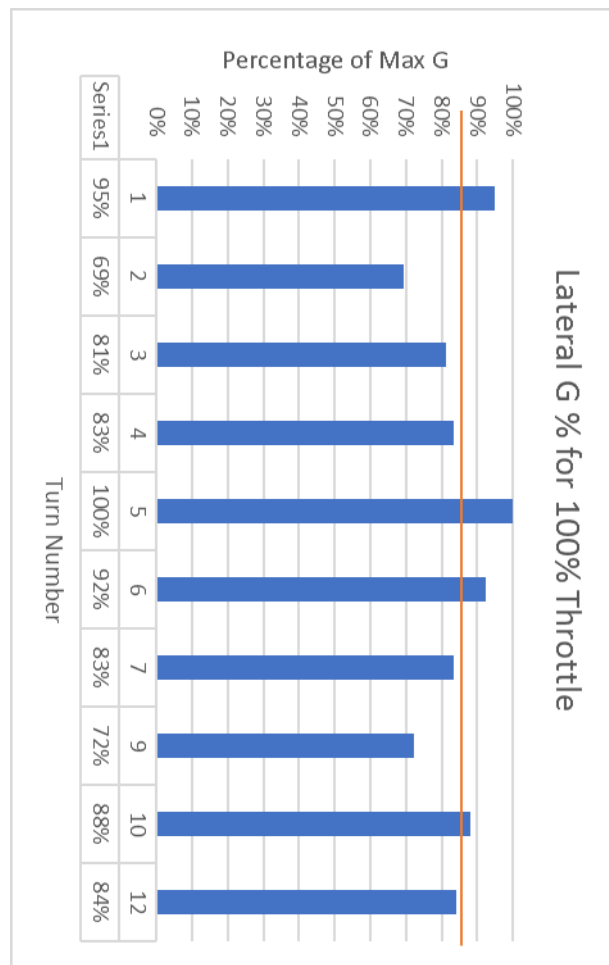


Figure 4-53 – Lateral G for 100% Throttle for DOE 2

What Figures 4-51 through to 4-54 show is that the driver was able to utilise a lot more of the throttle with this setup, as seen by the 3.83% increase in full throttle over the lap even though the time spent not using either pedal has doubled. The big difference is the fact the driver is able to get on full throttle sooner and a lot more positively that he could when using the standard setup in session 19.

For further validation of the software predictions the driver also went to Brands Hatch GP, chosen due to the fact that it is a contrasting circuit to Snetterton will a lot of undulation and faster turns to see if the setup provided was better for the car as a whole or just circuit dependant.

Firstly the driver ran 40 laps until he was comfortable with the layout of the circuit and in a position where he felt his pace had reached a suitable level. Recording a fastest time of: 1:14.229.

The driver then tested each of the three setups from the DOE tests giving the following results:

Tables 4-4 to 4-6 show similar trends to the fastest lap times when looking at the results for the DOE setups, where the setup has actually been able to improve the performance of the car and allow the driver to achieve a faster time. The fastest time seen is an improvement of 0.431 seconds.

In Figure 4-55 where the coloured trace is the standard setup time and the black trace the DOE setup shows that the driver is able to use a lot more of the throttle throughout the lap, and at turn 6 when he had to have 2 lifts to navigate the corner on his previous best time the setup allowed the driver to take it without a lift. The driver does suffer with throttle application the exit of some corners, turn 4 being the worse where the driver has to balance the throttle on towards the exit of the turn for approximately 1.5 seconds before he can go back to full throttle.

Looking at both data traces it is clear that there could be obvious improvements in how the driver applies the throttle and so with some feedback the driver could look to potentially improve further however this test .

Table 4-4 - Brands Hatch GP Test 1 results

Test 1 Results		
Lap 1	01:15.833	75.833
Lap 2	01:15.930	75.930
Lap 3	01:15.610	75.610
Fastest Time	01:15.610	75.610
Average Time	01:15.791	75.791
Rating	5	

Table 4-5 - Brands Hatch GP Test 2 results

Test 2 Results		
Lap 1	01:15.506	75.506
Lap 2	01:14.853	74.853
Lap 3	01:14.821	74.821
Fastest Time	01:14.821	74.821
Average Time	01:15.060	75.060
Rating	8	

Table 4-6 - Brands Hatch GP Test 3 results

Test 3 Results		
Lap 1	01:15.363	75.363
Lap 2	01:14.154	74.154
Lap 3	01:13.798	73.798
Fastest Time	01:13.798	73.798
Average Time	01:14.438	74.438
Rating	8	



Figure 4-55 - Brands Hatch GP Data trace

5 Further Work

Further work that could be conducted is to take validate the results from the driver development part of the project would be to take a driver with similar experience and take them to the same circuit and get them to do the same amount of laps in similar sessions, however this time the driver would be left to natural development to see how they could improve by themselves over the same amount of time and compare this natural rate of progression to the engineered driver to see the difference.

There is still some improvement to look at with the throttle on corner exit, whilst the driver has improved his minimum speeds it may be the case that the driver isn't hitting the apex which is why the car is then drifting towards the outside of the circuit quicker resulting in the driver has to hold or slightly back out of the throttle on the corner exit. The best way to asses this would be by having access to a video input that could by sync'd with the data and reviewed. Another potential step would be to take the driver to the track in an actual car and then see if the skills learnt here can be directly applied to the track.

For the design of experiment part of the project the further work would be to again look at validating the results by testing at a third circuit with more slow corners, in order to see if the setup suggested in DOE 2 could still work in that environment. Within the software there is also the option to run the same Box-Behnken model but with up to 7 factors at 3 levels. By running 1 test combing 7 factors it would allow the software to get a fuller picture of the adjustments available within the setup and this should allow the software to develop a more advanced setup for the entire car.

6 Conclusion

The original aims set out in this project were to look at engineering the driver by assessing the use of data analysis as a driver development tool, using KPI's and to determine the viability of design of experiment software to aid in car setup.

The first aim of assessing the use of data analysis as a driver development tool using KPI's has been met, it has been seen in the results that from session 1 through to session 19 that the driver has made a significant improvement by reducing his fastest time by 4.825 seconds. This has been by monitoring performance against the KPI's throughout the project which have provided areas of focus leading to the improvements in performance. In doing so it has proved that data analysis is a useful tool in engineering the driver.

The second aim was to determine the viability of design of experiment, the results from this project have proved that by it is a viable tool it the aid of car setup. This was proven by being able to predicate results that were within 1% of the time the driver was able to achieve, when validating the test against a different circuit to see if improvements could be made by using the suggested setup the results found were very similar in the fact that driver was able to find an improvement in his time by using one of the suggested setups from the design expert software. The results of both tests prove that design expert can be used as a valid tool to streamline the setup of the vehicle.

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8 Appendix

Driver: Joel Thomas
Circuit: Snetterton 300
Intervention: 1, driver vision



Points:

- Inputs are messy, visually watched the drive on the sim and can see that not looking far enough ahead, which is why the inputs are messy
- Getting driver to read chapter 16, Vision of the book: Ultimate speed secrets.

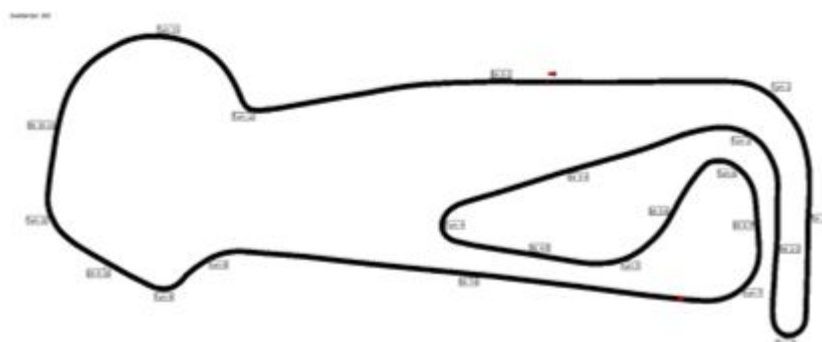
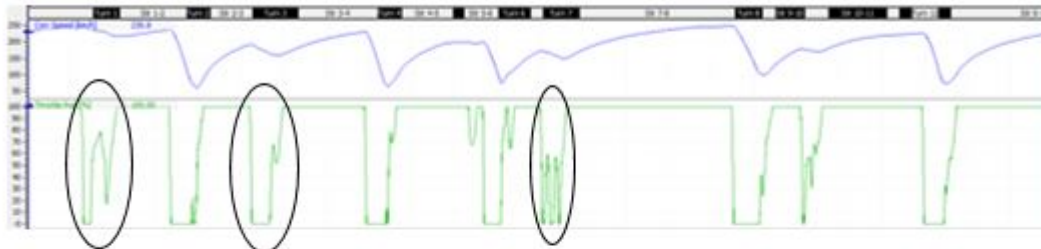


Figure 8-1 - Intervention sheet 1

Driver: Joel Thomas
 Circuit: Snetterton 300
 Intervention: 2, Throttle at Turns 1, 3 and 7



Points:

- Turn 1 – Too much of a lift.
 - Time at 0% throttle is .490 seconds with a distance of 33m
 - Time between 100% throttle is 2.621 seconds and 169m
 - Trace shows throttle is off on off. Needs to be once on stay on.
- Turn 3 – Too much of a lift.
 - Time at 0% throttle is 1.718 seconds with a distance of 85m
 - Time between 100% throttle is 3.294 seconds and 156m
 - Maybe consider carrying throttle for longer and using the brake to shift weight rather than a long lift.
- Turn 7 – on and off throttle too much.
 - Be positive with the throttle, once you have applied it then do not come back off.
 - Look at vision on that particular bend.
 - 100% throttle is applied at 84% of max lateral G so around the correct area, maybe the same as T3 consider a slight dab of brakes to help transfer weight to the nose before turning in as distance between 100% throttle is 127m

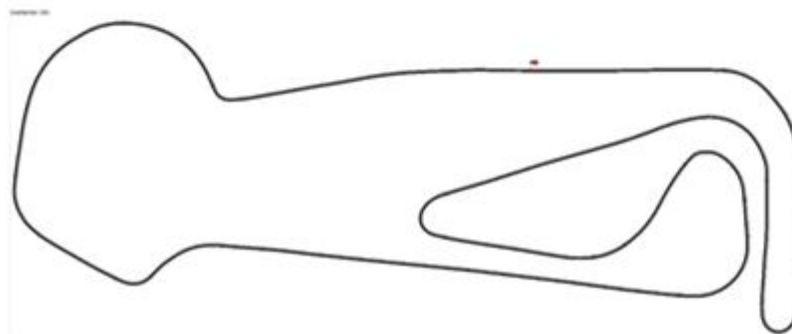
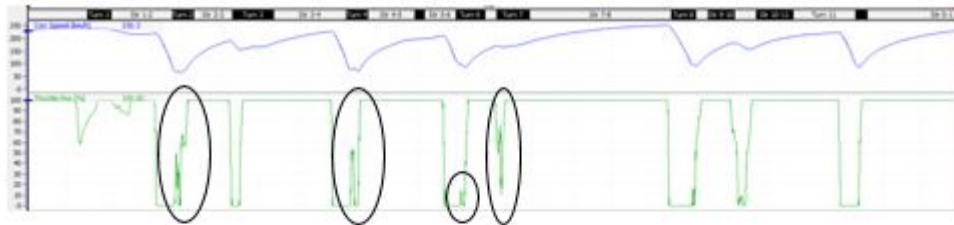


Figure 8-2 - Intervention sheet 2

Driver: Joel Thomas
 Circuit: Snetterton 300
 Intervention: 3, Throttle Application (T2, 4, 6 & 7)



Points:

- T2 – Messy throttle application, need to squeeze on throttle smoothly and quickly, application here is too aggressive.
- T4 – On/Off throttle, the 2nd application is then very quick, consider a slightly longer time to get to 100% throttle which would allow smoother corner exit.
- T6 – small on/off throttle blip, once on throttle should not be coming back off.
- T7 – Better than previous runs however need to work on throttle pickup smoothness.

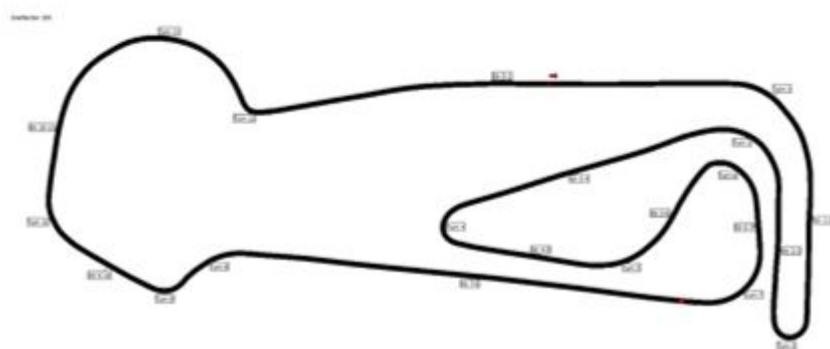
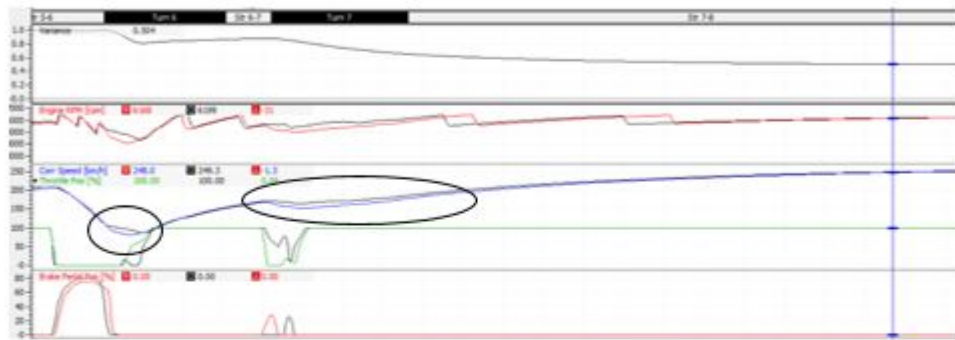


Figure 8-3- Intervention sheet 3

Driver: Joel Thomas
 Circuit: Snetterton 300
 Intervention: 4, minimum speed T6 and T7



Points:

- Coloured is fastest overall lap, black is previous best 0.9 of a second between them.
- Lost .5 of a second in this section
- Minimum speed in T6 is higher resulting in the first loss however the delayed throttle does lose some time, T7 more speed is carried resulting in a gain all the way down the back straight.
- Work on Carrying and exiting with more speed on T7, most important corner on the circuit as has the longest straight after it.

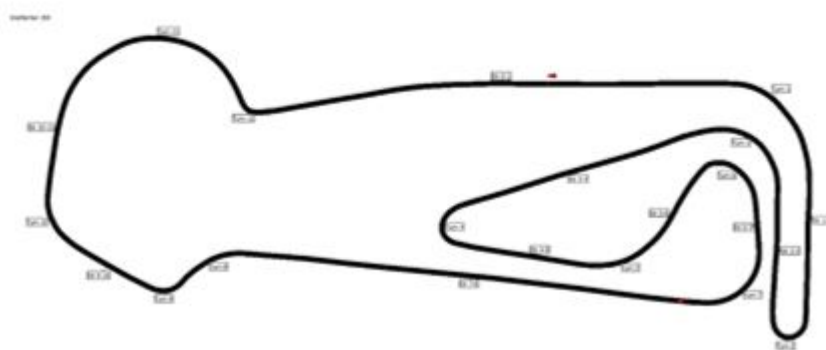
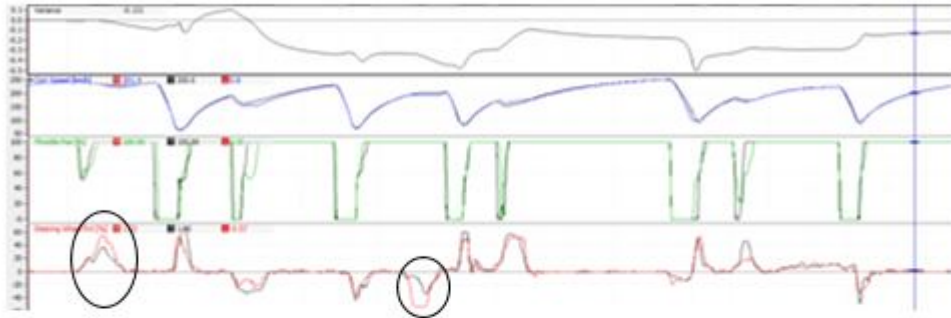


Figure 8-4 - Intervention sheet 4

Driver: Joel Thomas
 Circuit: Snetterton 300
 Intervention: 5, Steering input T1 and T5



Points:

- Coloured line is latest run and black line is fastest lap
- Steering input is too high for T1 and T5 costing time as with the high steering lock the car will be understeering and scrubbing too much speed costing time in the following straight.
- Work on being smoother and more precise with turning in rather than just trying to turn in as quickly as possible

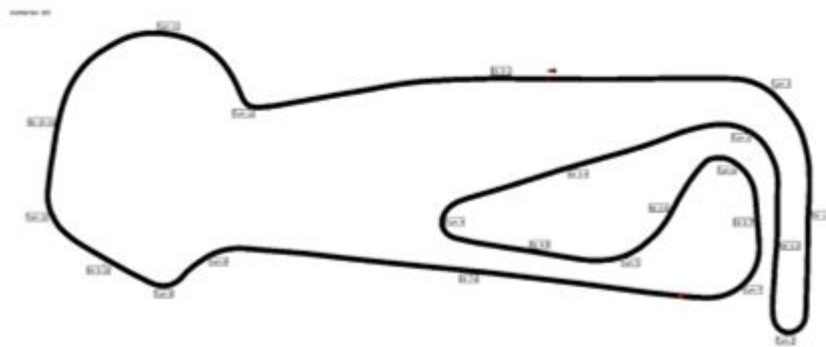
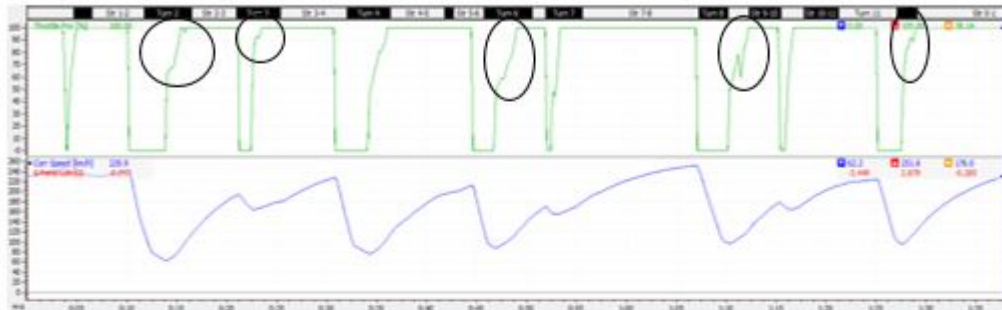


Figure 8-5 - Intervention sheet 5

Driver: Joel Thomas
 Circuit: Snetterton 300
 Intervention: 6, throttle pick up on corner exits



Points:

- Throttle pick up is messy
- Smoother throttle on the exit of corners will result in a more balanced car on the exit of the bend
- Need to work on this for the majority of corner exits

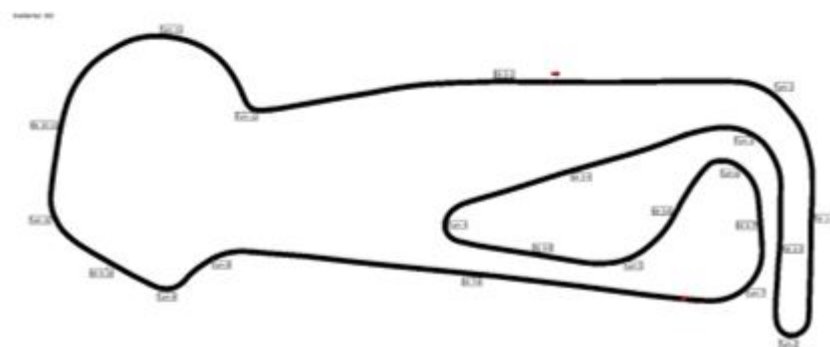
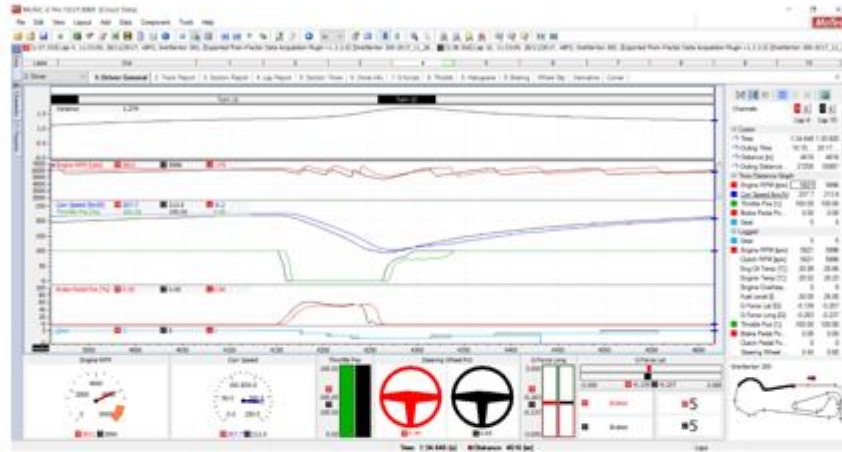


Figure 8-6 - Intervention sheet 6

Driver: Joel Thomas
 Circuit: Snetterton 300
 Intervention: 7, T12 speed on to the straight



Points:

- Coloured is fastest lap, black is a previous lap
- Black lap was slower overall however 2 tenths to be found in the last bend
- Focus on speed up the following straight, slower and earlier apex have allowed you to get on the power earlier and more positively, gaining 4km/h at the start finish

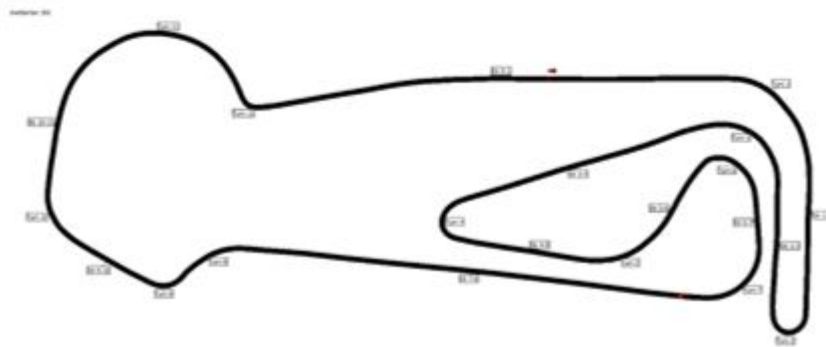
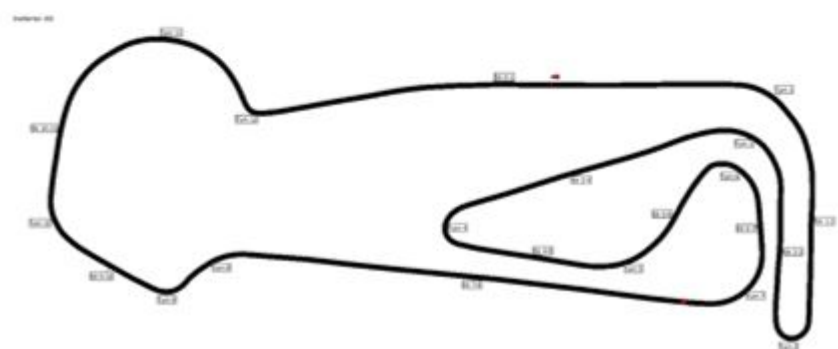


Figure 8-7 - Intervention sheet 7

- Throttle pick up is messy
- Smoother and more positive throttle pick up out of corner exits, look to get to full throttle as quickly as possible



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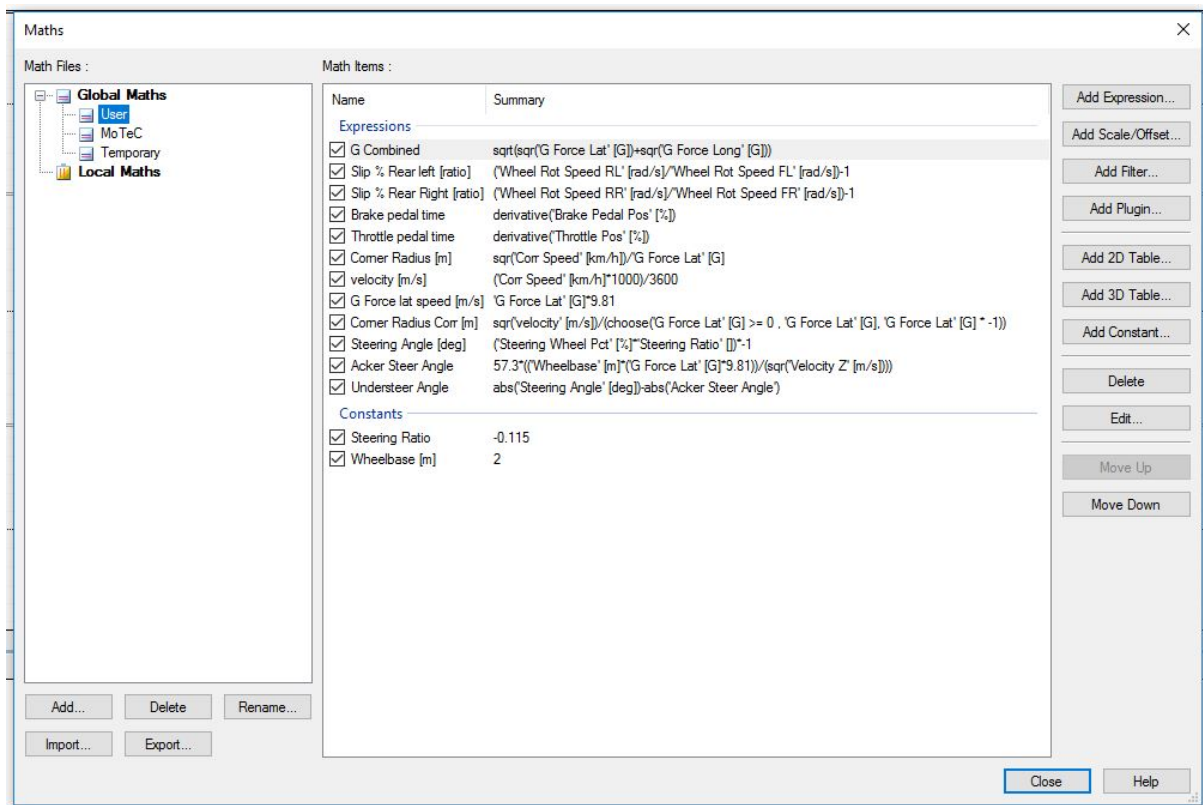


Figure 8-9 - Motec Maths channels

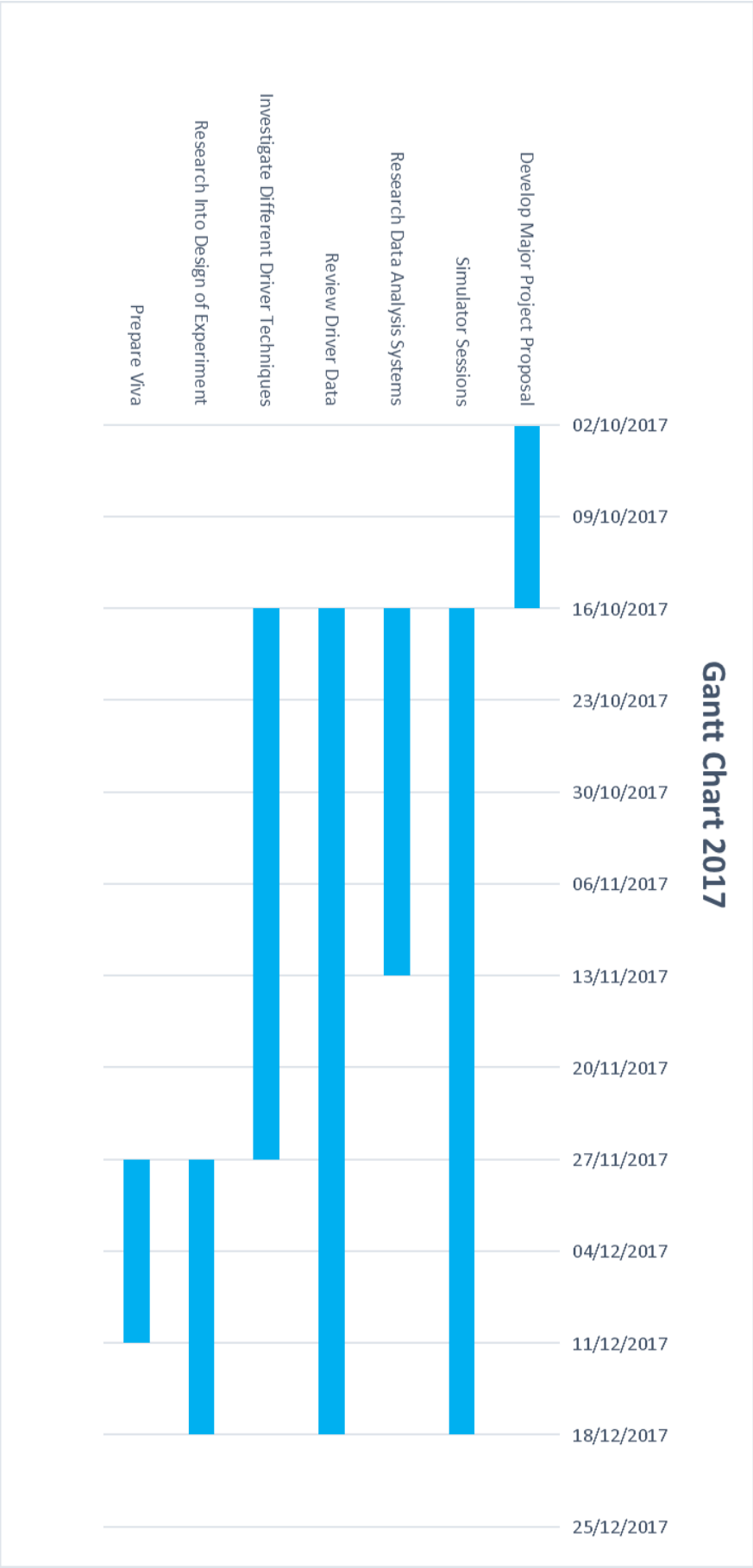


Figure 8-10 - Gantt chart 2017



Figure 8-11 - Gantt chart 2018