

Seminar Paper

The Effects of Toe Angle on a Race Car

By Samuel Fripp

P146497

Contents

Abstract.....	3
Technical Abstract.....	3
Nomenclature	3
1-Introduction	3
2-Toe Angle	4
2.1-Applications of Toe Angle	4
3-Methodology	4
3.1-Driver in the Loop	4
3.2-Design of Experiment	5
3.2.1-Variance and Standard Deviation	5
3.3-Equipment	5
3.3.1-R Factor.....	6
3.3.2-Car.....	6
3.3.3-Track	6
3.4-Testing Procedure.....	7
4-Conclusion.....	8
5-Plans for the Future	8
6-Bibliography.....	8

Abstract

This Seminar paper goes over what toe angle is, it's importance to how the car drives and it's potential benefits along with how it will be tested. This paper will provide details on the equipment used for the testing including the carb and track used in the simulator for the testing along with looking at experimental methods like Design of Experiments and Driver in the Loop in order to get the most out of the limited testing time. Future steps that need to be taken are mentioned at the end of the paper.

Technical Abstract

This seminar paper will explain what toe angle is and how it affects the handling characteristics of the car along with possible benefits of having the optimal toe angle. This paper will also include experimental methods such including Design of Experiments, Driver in the Loop and Variance and Standard Deviation. The equipment used such as the simulator and the software used such as R Factor and Motec. Future plans for the rest of the available time will be mentioned also.

Nomenclature

S^2 : Variance

S : Standard Deviation

X_i : Term in Data Set

$\bar{X}$: Sample mean

$\sum$: Sum

n : Sample size

1-Introduction

This seminar paper will focus on toe angle, why it has been chosen for the dissertation and how the toe angle is going to affect the performance of the car. The toe angle is probably one of the more overlooked parts of the car and hopefully the seminar and the dissertation paper itself should provide insight into how much of an impact toe angle makes on a car's handling characteristics. This paper will also explain how the toe angle will be tested and the equipment used for the testing. The aims of this assignment are to see what toe angle is best for producing the fastest lap overall and what toe angle will produce the best setup for the driver as the fastest setup may prove to be less controllable and therefore less consistent which in a racing scenario.

2-Toe Angle

Toe angle is the angle of the wheels along the longitudinal axis of the vehicle. Toe-out occurs when the wheels are angle so the front of the wheel points outwards, this causes the car to turn in more quickly, however this reduces the car's straight-line stability possibly making the car more twitchy. Having toe in, when the front of the wheel is facing inwards, can reduce this problem as it gives more straight-line stability but at the cost of reduced turn in. Toe angle is usually measured in degrees and can be both positive and negative. The more negative the toe angle, the greater the toe out, the more positive the toe angle, the greater the toe in. Another thing to note is that a more toe in or toe out generally produces more tyre wear as it produces more friction with the tyres although this can potentially be used to heat up the tyres more quickly. An important thing to note that toe is usually measured when the vehicle is static because the toe angle is dynamic when driving and can change constantly.

2.1-Applications of Toe Angle

Toe angle can be used in a racing environment to improve turn-in on corner entry or improve controllability of the car. This can also help with developing cars that are safer by improving the car's ability to avoid accidents or improve stability reducing the chance of crashes. Understanding toe angle can also help reduce tyre wear which can be helpful in racing situations where getting the tyres to keep going another few laps might allow for a wider range of strategies and can also save money for both racing teams and people driving on the roads if the wear is minimized. The reduced tyre wear can also help the environment as reduced tyre wear means less tyres needed over the lifespan of a car and therefore less of the planet's resources are needed to make tyres.

3-Methodology

3.1-Driver in the Loop

The testing procedure will be done on a simulator using a method of testing known as driver in the loop. Driver in the loop is basically when a driver tests a vehicle virtually. In the case of this experiment it involves a driver using a simulator to test the car.

One of the advantages of this are that some variable e.g. track temperature can be controlled that otherwise wouldn't be able to. This is backed up by a report by J.C.F. de Winter which states that it improves not only controllability but reproducibility and standardization of test conditions. The report also states that it is easier to collect data, allow more extreme conditions to be tested whilst removing potential physical risks and a good opportunity for feedback and instruction. The ease of collecting data in testing is immediately noticeable and very useful for collecting more data in a shorter space of time. The extreme conditions is another obvious advantage as the extreme conditions could be potentially dangerous or even fatal in real life but in a simulator the risks are significantly reduced. The improved feedback ties into the ease of collecting as it allows easier, quicker and more efficient and potentially accurate data analysis which allows the testers to give more informed information to the driver.

There are however also downsides to using this method of testing. De Winter states a lack of fidelity on a simulator. This can be a problem as it may affect the results as well as demoralize the driver as they may not be satisfied with the lack of feel with the simulator. Another downside is that the simulator will not be 100% accurate when compared to real life conditions, it is very close in accuracy, therefore the differences will be small but may be enough to create a large effect on the results. De Winter also suggests that there is a “lack of research demonstrating validity of using simulators” However this report was made in 2012 and simulators have improved since then and more research has been done into the validity of simulators.

3.2-Design of Experiment

Design of experiment is a method of creating an experiment while minimizing errors in the experiment while maximizing the efficiency and speed of the experiment. This is achieved by looking at the factors that affect the experiment and how those factors affect the results of the experiment. These factors are split into controllable factors and uncontrollable factors. Controllable factors are factors that can be changed or kept constant and do not change by themselves. Uncontrollable factors cannot be controlled and can potentially have affect the results if not properly accounted for.

3.2.1-Variance and Standard Deviation

One way to check how much the uncontrollable and controllable variables affect the results is to work out the variance and standard deviation of the results. The variance is calculated by using the equation $S^2 = \frac{\sum(X_i - \bar{X})^2}{n-1}$. This equation basically means finding the difference between each term in the data set and the mean squared then adding them altogether then dividing it all by the sample size minus 1. The mean is calculated by adding every term in the data set then dividing it by the sample size.

The next part is to work out the standard deviation. Thankfully the standard deviation is just the square root of the variance so the equation works out to be $S = \sqrt{S^2}$. The standard deviation is the normal range from the mean. If the term lies within the standard deviation it is a normal data term. If it lays outside the standard deviation it is a more extreme data term. Generally the less data terms that lay outside the standard deviation, the more consistent the data is.

3.3-Equipment

The software that is being used to analyze the data is called Motec i2 Pro. The software was made by Motec and is designed with a simple user interface to show the data as clearly as possible and provide the user with a wide range of possibilities of graphs, gauges and reports.

The simulator itself is based on a f1 chassis tub with motors for force feedback and pedal adjustment inside the nose. The screen is curved to provide the driver with a more realistic view of the track. And monitors are used to show a live feed along with other live data which is then stored in a data log folder to be saved and then used on Motec.

The driver has been chosen because they are both fast and consistent which should allow for good sets of data results.

3.3.1-R Factor

The simulator runs on a professional version of R factor which was first released back in 2004 which provides very realistic handling physics along with low latency and ease of use. It is also compatible with Motec meaning the data can be logged and transferred very quickly Motec allowing for more time for analysis.

3.3.2-Car

The car being used for the test is the GP2 car. The GP2 car in question was introduced in 2011 and it's chassis is made by Dallara which is 5065mm long, 1800mm wide and has a height of 1072mm. The naturally aspirated V8 produces 612bhp and can rev up to 10,000RPM. This power lets the GP2 car accelerate from 0-60mph in just 2.9 seconds and reach a top speed of 209mph. The power is delivered through a longitudinal 6 speed sequential box and paddles are used to change gear.

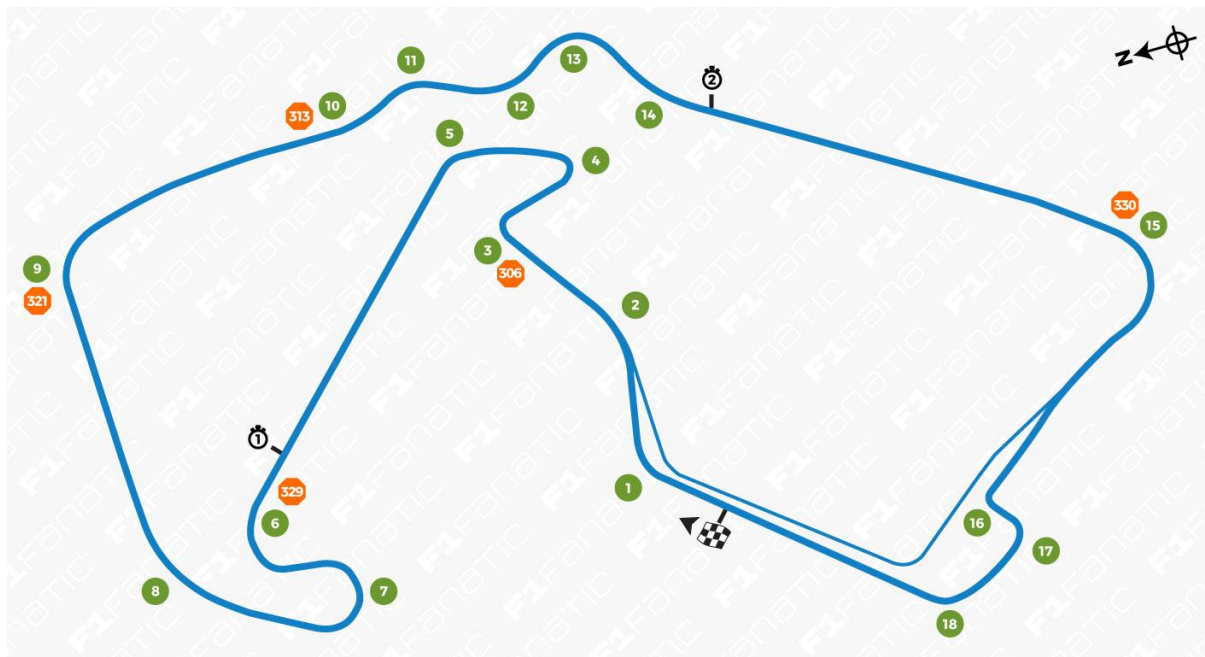


Callum Rowes (2011)

3.3.3-Track

The track used for the test is the Silverstone GP circuit. Silverstone was first created in 1943 out of an old WW2 bomber station. Over the years it has hosted many major motorsport events including Moto GP and Formula 1. The current iteration of the circuit has been in use since 2010 and consists of 21 corners over 3.7 miles. The track was chosen for this experiment because it has a good mixture of high and low speed corners which will allow the toe angle to be thoroughly be tested as well as producing high tyre wear which will

allow the differences in degradation of the tyre to become more noticeable more quickly. It is also a track that the driver has become very familiar with which allows for more consistent results.



Race fans (2016)

3.4-Testing Procedure

The test itself consists of 1 warm-up lap and then a 5-lap stint at race pace at each toe angle. The reason for going at a race pace is that it will give consistent results which will give a better understanding of how controllable the car is to drive. A qualifying stint would show the best setup ultimately but would provide less consistent results so would not give as clear picture on what setup is better for the driver. The test was going to be initially run with 2 warm up laps but the car ended up only needing 1 lap to get up to racing temperatures so the second warm up lap was ditched to save time.

The range of toe angles being used is between 2 and -2 degrees decreasing in 0.5 degree increments. The reason for this is that that is the maximum range that can be implemented on R Factor. The first run will be done using the stock setup will become the control for the experiment, then the car will be setup with a toe angle of 0 degrees on the front and rear for the second stint. The next set of stints will be for the front toe angle gradually decreasing each stint in 0.5 degree increments from 2 to -2 degrees. The front toe is then zeroed and the test is repeated but this time adjusting the rear toe angle and then again with front and rear toe angle being adjusted simultaneously.

Contingencies have also been put in place depending on how the data turns out and will be implemented if there is enough time. The first contingency is if the data peaks at a certain toe angle within the test range. The next step will be to look at the toe angles between the optimal toe angle and the other toe angles tested either side in 0.1 degree increments, for example if the optimal toe angle of the angles tested was -1 degrees, then the test will be done in 0.1 degree increments between -0.5 and -1.5 degrees. The second contingency is if

the pace for the toe angle doesn't seem to peak which is to use the data to predict where the data would eventually peak and therefore where the optimal toe angle will potentially lie.

4-Conclusion

The conclusion is that Toe angle is an overlooked and interesting part of the car that could potentially provide benefits in stability and responsiveness of both road and race cars whilst helping to minimize tyre wear. Hopefully the testing will provide good insight into how much the impact of toe angle on a car is.

5-Plans for the Future

The plans for the future is to carry out the testing getting as much data as possible and then analyze the recorded data. The contingencies will be carried out if there is enough time after initial analysis. Once the data has been collected the analysis of all the data will begin.

6-Bibliography

K. Sundarajan (2000), "Design of Experiments-A Primer", [online], Available: <https://www.isixsigma.com/tools-templates/design-of-experiments-doe/design-experiments-%E2%90%93-primer/>, [Accessed 11/10/2018]

Ansible Motion (2017), "Driver-In-The-Loop ADAS Testing", [online], Available: <https://www.ansiblemotion.com/ansible-motion-automotive-driver-in-the-loop-simulation-news/driver-in-the-loop-adas-testing>, [accessed 18/10/2018]

Image Space Incorporated (2018), "R Factor", [online], Available: <https://www.rfactor.net/#about>, [accessed 20/10/2018]

J.F.C. de Winter, P.M. van Leeuwen and R. Happee (2012), "Advantages and Disadvantages of Driving Simulators: A Discussion", [Article] Available online: [https://www.measuringbehavior.org/files/2012/ProceedingsPDF\(website\)/Special%20Sessions/Measuring%20Driver%20and%20Pilot%20Behavior/de_Winter_et_al_MB2012.pdf](https://www.measuringbehavior.org/files/2012/ProceedingsPDF(website)/Special%20Sessions/Measuring%20Driver%20and%20Pilot%20Behavior/de_Winter_et_al_MB2012.pdf), [accessed 20/10/2018]

Jack Leslie (2015), "Here's how Formula 1 and GP2 Cars Compare", [Online], Available: <https://www.carthrottle.com/post/heres-how-formula-1-and-gp2-cars-compare/>, [Accessed 01/11/2018]

Motec (2018), "i2 Data Analysis", [Online], Available: <https://www.motec.com.au/i2/i2overview/>, [Accessed 20/10/2018]

Xian Cheng, Nan Xu and Konghui Guo (2017), "Tire Wear Estimation Based On Nonlinear Lateral Dynamic of Multi-Axle Steering Vehicle", [Report], Available online: <https://link-springer-com.ezproxy.uwtsd.ac.uk/content/pdf/10.1007%2Fs12239-018-0007-2.pdf>, [Accessed 07/11/2018]

Callum Rowes (2011), "GP2 Extra", [Online], Available:
<https://callumrowesgp2blog.wordpress.com/the-car/>, [Accessed 16/11/2018]

Race Fans (2016), "Silverstone-Circuit information", [Online], Available:
<https://www.racefans.net/f1-information/going-to-a-race/silverstone-circuit-information/>,
[Accessed 16/11/2018]

Ellis Johnson (1996), "Tires and Handling", [Book], Warrendale: Society of Automotive Engineers

Allan Staniforth (2006), "Competition Car Suspension", [Book], 4th Edition, Sparkford: Haynes

John C. Dixon (1996), "Tires, Suspension and handling", [book], 2nd Edition, London: Society of Automotive Engineering