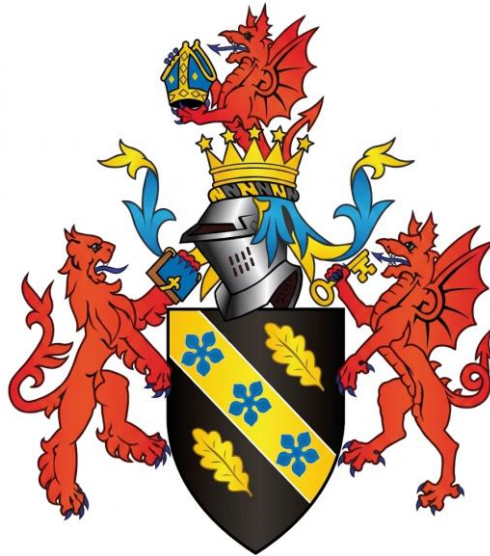




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Contents

1. ABSTRACT	3
2. Introduction	4
3. Test Plan Development.....	5
4. Driver and Vehicle Performance Metrics.....	7
5. Simulation Execution and Data Analysis (MoTeC)	8
6. Driver performance Evaluation	13
7. Performance Progression Across Sessions	14
8. Vehicle Performance Evaluation.....	15
9. Recommendations for Improvement.....	16
10. Simulation vs Real World Comparison.....	18
11. Conclusion	19
12. References.....	21

1.ABSTRACT

This study presents a performance assessment of a Formula 3 race car using Driver-in-the-Loop (DIL) simulation and MoTeC telemetry data collected at Donington Park GP. The objective was to analyse the interaction between driver inputs and vehicle response to identify performance limitations and optimise setup parameters. A structured test plan was implemented, focusing on aerodynamic configuration, mechanical grip, and tyre behaviour across multiple simulation sessions. The results showed that improvements in performance were achieved through a combination of setup optimisation and driver adaptation, although issues such as tyre slip, braking instability, and load transfer imbalance were observed. While the simulation provided reliable performance trends, limitations exist due to the simplified representation of real-world conditions. Overall, the findings highlight the importance of balancing aerodynamic efficiency, mechanical stability, and driver control to achieve optimal race performance.

2. Introduction

This study presents a performance assessment of a Formula 3 race car using Driver-in-the-Loop (DIL) simulation and MoTeC telemetry data collected at Donington Park GP. The objective is to analyse the interaction between driver inputs and vehicle response to identify performance limitations and propose optimisation strategies. The DIL simulator enables controlled testing of vehicle setup changes while capturing high-resolution telemetry data, allowing detailed analysis of both driver behaviour and vehicle response. The study is based on simulation data collected at Donington Park GP, a circuit that provides a mix of high-speed sections and technical corners, enabling comprehensive assessment of vehicle dynamics. The study evaluates vehicle performance by analysing driver inputs and vehicle response, focusing on throttle control, braking behaviour, tyre slip, suspension movement, and thermal characteristics.

Results from the experiments conducted have been critically analyzed using basic engineering principles, such as dynamics and load transfer, as well as tyre friction. Furthermore, the study recognizes some of the limitations involved in conducting simulations in DIL as opposed to real world testing, especially when dealing with variables such as track evolution, tyre wear behavior, and driver psychological load.

3. Test Plan Development

The test plan was formulated to systematically analyse the effects on the vehicle's dynamic handling capabilities with respect to low speed and high speed cornering maneuvers based on changing its mechanical grip and suspension system configurations. The aim of the tests was to increase the efficiency of completing a lap on the track by improving car handling, providing increased traction, and building driver confidence. This test was broken down into three stages: evaluating the spring rates, analyzing the dampers sweep, and sensitivity testing ride height and rake (Huang et al., 2023).

In stage one, a series of spring rates were analyzed through ten minutes of testing. In this process, front and rear spring rates were varied using step by step approach to find the best combination to develop a consistent mechanical foundation of the vehicle. The testing process included two warming up laps and three laps with full throttle applied to the car. According to driver reports, default spring setup provided acceptable results during cornering maneuvers.

The second stage comprised a 15 minute damper sweep aimed at tuning the bump and rebound characteristics of the front axle. The aim was to enhance the car's stability when transitioning through processes like braking, turn in, and kerb interaction. Five laps were performed in each of two configurations one soft and the other stiff. The driver felt an average performance level in cornering, noting a slight enhancement in performance following a reduction in the front suspension by 1mm. This indicates that damping primarily affects load transfer rate rather than overall grip generation.

This last phase dealt with ride height and rake sensitivity for a period of 15 minutes. The process entailed an increase in the front ride height by 2 mm in the first two laps, then an increase in the rear ride height by 2 mm in the next two laps. This would have changed the rake angle of the car. It was noted that the traction and cornering abilities of the car had greatly improved, and the driver performed better in this setting. An increase in the front ride height prevents bottoming out, while increasing the rear ride height will help improve aerodynamic rake, front end downforce, and understeer.

4. Driver and Vehicle Performance Metrics

In order to make sure that a holistic assessment is made, performance indicators from the driver and the vehicle were considered. Driver related performance indicators include the throttle position, brake pedal pressure, steering wheel percentage, gear choice, and G forces. These parameters provide insight into how effectively the driver manages acceleration, braking, and cornering.

Metrics considered during performance were the engine RPM, engine temperature, braking temperature, tire temperature, slip percentage of the tires, tire pressure, suspension travel distance, damper speed, and ride height. All these metrics have to be known by one who wants to know how the vehicle behaves under different input and environmental factors. They are important because they give an insight into performance behavior (Rottenbacher, 2025).

5. Simulation Execution and Data Analysis (MoTeC)

In the analysis of the telemetry data collected by the MoTeC, significant variations have been observed between out lap and in lap performances. Specifically, in the in lap, the car has achieved an average speed of approximately 165.48 km/h compared to 58.84 km/h recorded in the out lap. Additionally, the car's engine revs per minute have increased from around 3676 rpm to 5784 rpm, with the highest rev recorded at 7683 rpm. This indicates improved aerodynamic efficiency, reducing drag and enabling higher straight line speed. From the Figures 1 and 2 above, it is clear that while Figure 1 represents the telemetry data channels analyzed, Figure 2 demonstrates the variance in speed, engine RPM, and driver input data between the out lap and in lap.

Figure 1: MoTeC Telemetry Channels Overview for F3 Vehicle

Channels	Out Lap	In Lap	Out Lap
Cursor			
Time	-0:35.6...	-0:35.6...	-0:35.6...
Outing Time	-0:35.6...	-0:35.6...	-0:35.6...
Distance [m]	-1347	-1568	-1347
Outing Distance...	-1347	-1568	-1347
Time/Distance Graph			
Engine RPM [rpm]	3676	5784	3676
Corr Speed [km/h]	58.8	165.5	58.8
'Corr Speed' Datum Measurements			
Cursor Value (k...	58.8	165.5	58.8
Datum Value (k...	190.0	212.9	190.0
Cursor Diff	-131.2	-47.4	-131.2
Cursor Avg	124.4	189.2	124.4
Cursor Slope	3.680	1.330	3.680
Interval Min	58.5	90.0	58.5
Interval Max	215.9	212.9	215.9
Interval Avg	135.9	158.4	135.9
Interval Range	157.4	122.9	157.4

Logged			
Gear	1	4	1
Engine RPM [rpm]	3676	5784	3676
Clutch RPM [rpm]	3676	5784	3676
Eng Oil Temp [°C]	45.77	55.06	45.77
Engine Temp [°C]	43.96	50.40	43.96
Engine Overheating	0	0	0
Fuel Level [l]	19.977	19.754	19.977
G Force Lat [G]	0.023	-0.399	0.023
G Force Long [G]	-0.000	1.250	-0.000
Throttle Pos [%]	48.40	0.00	48.40
Brake Pedal Pos [%]	0.00	28.45	0.00
Clutch Pedal Pos [%]	0	0	0
Steering Wheel Pct [%]	-1.31	2.02	-1.31
Steered Angle [°]	0	0	0
Wheel Rot Speed FL [ω]	61.24	168.75	61.24
Wheel Rot Speed FR [ω]	61.34	166.50	61.34
Wheel Rot Speed RL [ω]	57.76	158.18	57.76
Wheel Rot Speed RR [ω]	57.74	157.82	57.74
Acceleration [m/s²]	0.25	12.91	0.25
Ground Speed [km/h]	58.84	165.48	58.84

Lap Distance [m]	168	1127	168
Brake Temp FL [°C]	36.9	219.2	36.9
Brake Temp FR [°C]	17.0	198.3	17.0
Brake Temp RL [°C]	37.9	193.0	37.9
Brake Temp RR [°C]	17.0	175.4	17.0
Ride Height FL [mm]	21.12	9.74	21.12
Ride Height FR [mm]	20.88	11.00	20.88
Ride Height RL [mm]	43.53	34.67	43.53
Ride Height RR [mm]	43.42	35.94	43.42
Suspension Pos FL [mm]	10.39	17.86	10.39
Suspension Pos FR [mm]	10.46	17.19	10.46
Suspension Pos RL [mm]	21.28	31.78	21.28
Suspension Pos RR [mm]	21.68	29.50	21.68
Steering Arm Force [N]	97	-663	97
Gyro Roll Angle [rad]	0.03372	-0.01209	0.03372
Gyro Pitch Angle [rad]	-0.02778	-0.04040	-0.02778
Gyro Yaw Angle [rad]	-1.3647	1.1931	-1.3647
Gyro Roll Velocity [ω]	-0.0061	-0.0095	-0.0061
Gyro Pitch Velocity [ω]	0.0049	-0.0119	0.0049
Gyro Yaw Velocity [ω]	-0.011	0.070	-0.011
Damper Velocity FL [mm/s]	-0.0	-13.1	-0.0

Damper Velocity FR [mm/s]	1.3	-14.0	1.3
Damper Velocity RL [mm/s]	5.6	-28.5	5.6
Damper Velocity RR [mm/s]	-1.2	-20.0	-1.2
Tire Load - FL [N]	1324	2406	1324
Tire Load - FR [N]	1331	2067	1331
Tire Load - RL [N]	1762	2515	1762
Tire Load - RR [N]	1933	1932	1933
Lat Force - FL [N]	29	-690	29
Lat Force - FR [N]	148	-470	148
Lat Force - RL [N]	-395	-1300	-395
Lat Force - RR [N]	552	32	552
Slide Pct - FL [%]	6.08	17.53	6.08
Slide Pct - FR [%]	2.24	23.45	2.24
Slide Pct - RL [%]	5.45	16.22	5.45
Slide Pct - RR [%]	5.42	12.33	5.42
Tire Press - FL [kPa]	109.69	112.30	109.69
Tire Press - FR [kPa]	109.60	111.35	109.60
Tire Press - RL [kPa]	109.69	114.19	109.69
Tire Press - RR [kPa]	109.73	113.95	109.73
Tire Temp - FL - I [°C]	30.11	46.30	30.11
Tire Temp - FL - M [°C]	29.79	43.58	29.79

Tire Temp - FL - O [°C]	29.86	44.12	29.86
Tire Temp - FR - I [°C]	29.48	44.63	29.48
Tire Temp - FR - M [°C]	29.19	42.10	29.19
Tire Temp - FR - O [°C]	29.22	42.65	29.22
Tire Temp - RL - I [°C]	30.54	55.25	30.54
Tire Temp - RL - M [°C]	30.06	51.17	30.06
Tire Temp - RL - O [°C]	30.19	52.26	30.19
Tire Temp - RR - I [°C]	30.88	55.40	30.88
Tire Temp - RR - M [°C]	30.36	51.25	30.36
Tire Temp - RR - O [°C]	30.52	52.23	30.52
Tire Wear - FL [%]	99.96	99.69	99.96
Tire Wear - FR [%]	99.97	99.73	99.97
Tire Wear - RL [%]	99.96	99.56	99.96
Tire Wear - RR [%]	99.95	99.56	99.95
Surface Type - FL	0	0	0
Surface Type - FR	0	0	0
Surface Type - RL	0	0	0
Surface Type - RR	0	0	0
Velocity X [m/s]	-0.005	0.304	-0.005
Velocity Y [m/s]	0.1319	0.4356	0.1319
Velocity Z [m/s]	-16.33	-45.95	-16.33

Rotation X [ω]	0.0049	-0.0119	0.0049
Rotation Y [ω]	-0.011	0.070	-0.011
Rotation Z [ω]	-0.0061	-0.0095	-0.0061

Maths:Internal			
Corr Dist [m]	168	1127	168
Corr Speed [km/h]	58.8	165.5	58.8

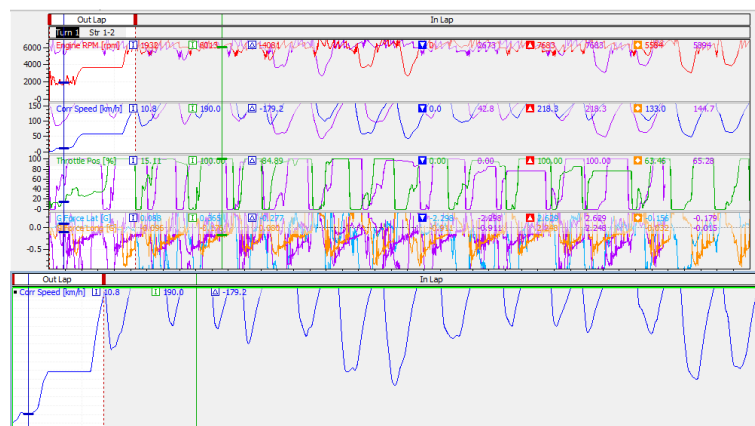


Figure 2: Comparison of Out Lap vs In Lap

On the contrary, the telemetry data shows that there are inefficiencies in driver operation. For example, the throttle position decreases suddenly to zero percent when the brake pedal is pushed at 28.45 percent. In terms of engineering knowledge, this indicates abrupt changes from acceleration to braking, causing rapid load transfer on the front axle and hence making the car unstable, with the car's tyres becoming

slippery. This assertion is confirmed by the high longitudinal acceleration value recorded at 12.91 m/s^2 .

Additional evidence can be found in the temperature of the brakes. The left front wheel brake is at 219.2°C while the right front wheel brake is at 198.3°C , showing an uneven load distribution on the wheels during braking. These are relatively high brake temperatures, hence, there is high thermal stress in the braking system which can result in brake fading during long races which can cause brake fade when driving continuously, as shown in Figure 3, where brake temperatures reach higher than 200°C at their maximum point.

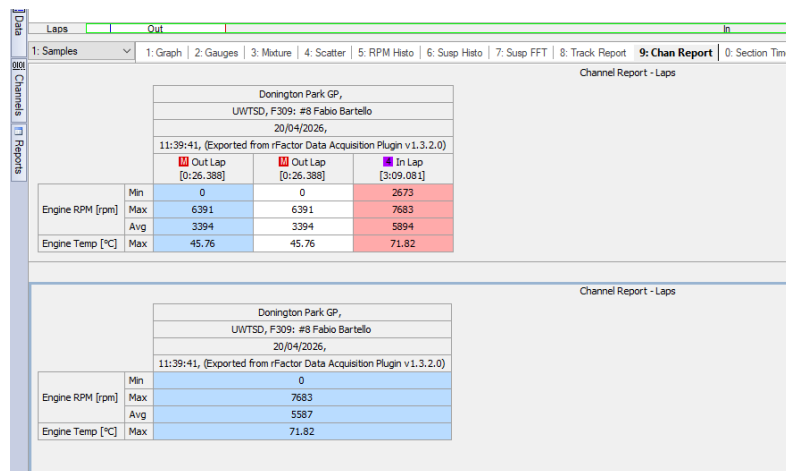


Figure 3: Channel report Lap

From the tyre data, it can be clearly seen that the tyres are limited in their performance capabilities. In this regard, the right front tyre has a slip percentage of 23.45%, indicating that the tyre is performing poorly, since it exceeds its limit of operation. The right front wheel also shows lower tyre loading compared to the front left tyre. Rear

6. Driver performance Evaluation

While the driver displays potential to reach competitive speed levels, there are inconsistencies in his driving style, which have a negative impact on his overall performance. For instance, the sharp change from acceleration to braking reveals inconsistency in his ability to modulate input. Such inconsistent inputs induce rapid load transfer, reducing tyre grip and compromising vehicle stability (Zicat et al, 2018). The steering input level seems to be low, implying that the driver might not be utilizing the available grip adequately. Similarly, the lower lateral G force suggests that the driver might not be utilizing the cornering potential of the car effectively. This indicates that the driver has not yet fully adapted to the vehicle's dynamic response under varying conditions.

7. Performance Progression Across Sessions

The performance of the vehicle and driver showed a clear progression across the three simulation sessions.

In Session 1, the focus was on familiarisation and baseline data collection using the Formula 3 vehicle, where initial observations indicated instability and inconsistent driver inputs.

In Session 2, structured testing was introduced, including baseline consistency runs and aerodynamic adjustments such as rear wing variation. These tests revealed that the vehicle exhibited oversteer behaviour, particularly during cornering phases, indicating a lack of rear stability.

In Session 3, further setup optimisation was conducted through suspension and ride height adjustments. It was observed that modifications to ride height and aerodynamic rake significantly improved traction and cornering stability. As a result, the vehicle demonstrated more balanced handling characteristics and improved driver confidence.

Overall, the progressive refinement of setup parameters across sessions resulted in improved vehicle stability, reduced oversteer, and enhanced overall performance.

8. Vehicle Performance Evaluation

There are some performance limitations for the vehicle regarding its brakes, tyres, and the way the suspension is set up. Firstly, high temperatures within the brakes mean that there is an excess of braking being performed, and there may be an imbalance with regard to brake bias.

Secondly, tyre slip and tyre temperature distribution are not even, which implies poor load distribution. This will decrease the traction of the car, causing understeer. Thirdly, the vehicle's suspension system affects both the aforementioned problems by compressing the front end.

9. Recommendations for Improvement

To optimize overall performance, Both driver inputs and vehicle setup must be improved together to maximise lap performance. Regarding driver performance, the emphasis should be made on optimizing the driver's input such that the dynamics of the vehicle operate within an optimal range in regard to its tires and aerodynamics. Throttle management in cornering exit is very important as it is through it that one can avoid sudden torque input that will make the wheels slip due to insufficient longitudinal traction. On the other hand, brake management should entail progressive pedal pressure and subsequent trail braking (Jiménez Elbal et al., 2024).

Uniformity in braking points is another key component since differences in the rate of entry will adversely affect the stability of the vehicle when entering a corner and limit the repeatability of its lap times. Simulator training in Driver-In-The-Loop (DITL) conditions, which provides repeated training on the same corner under uniform conditions, would support this need. Repetition will allow drivers to build up muscle memory to better identify braking zones, target apexes, and reengage the throttle at the appropriate times. In addition, steering precision should be refined to reduce unnecessary steering inputs that create tyre scrubbing and increase tyre temperatures (Vaz, 2025).

In terms of car setup, certain changes could be made to improve stability and grip of the vehicle. Specifically, the brake bias will play an important role in optimising the load transfer from front to rear tyres. Changes in brake bias by just a few degrees can have a profound effect not only on overheating of front tyres but also on vehicle stability during braking points.

Also important is the front suspension stiffness; by raising the front spring rates, one may prevent the vehicle from diving during braking. Furthermore, this will prevent any undesirable camber changes due to the load transfer to the axle during the turn. The result of this action will be more stable behaviour during braking and a consistent contact patch between tyres and the road, providing improved vehicle handling in turns.

An optimal choice of tyre pressure and camber setting can considerably improve overall vehicle performance. In order to achieve this, it is vital to correctly choose tyre pressures in such a way that ensures ideal deformation of the contact patch. Camber setting is equally important in order to guarantee uniform temperature distribution on the surface of the tyre. Any non uniform temperature pattern is an indication of inefficient usage of the contact patch during turns (Papaioannou et al., 2021).

Ride height and rake settings were found to be the most important setup variables because of their effects on the aerodynamics and balance of the car. Having a higher rear ride height than the front ride height provides better aerodynamics rake, increasing rear downforce and flow efficiency of the underbody area. Consequently, the change in the aerodynamics balance of the car makes the vehicle less prone to understeering, since there will be a better rear grip when cornering at medium or high speeds.

10. Simulation vs Real World Comparison

While the DIL simulator provides a controlled testing environment, several real-world factors are not fully represented, including tyre degradation, track evolution, and environmental variations. These factors significantly influence vehicle behaviour in real racing conditions. Therefore, although simulation results provide reliable trends, their accuracy is limited. To improve model validity, correlation with real-world telemetry data is required.

11. Conclusion

This investigation has provided ample evidence that Driver-in-the-Loop simulation represents an excellent setting to assess and refine the performance of a race car and its driver. Thanks to the telemetry data, it was possible to perform a comprehensive analysis of several important aspects of racing and find areas where there were problems that negatively affected performance. Specifically, the analysis indicated certain shortcomings in terms of the smoothness of braking, the consistency of throttle application, and steering accuracy, which directly affected the stability of lap times and performance while cornering. Furthermore, the analysis of the vehicle's dynamic properties showed that there were certain limitations in terms of the proper utilization of grip and aerodynamics.

The systematic test procedure used within the experiment allowed for a well organized assessment of the effect that the modification of specific setup elements had on overall car performance. The systematic modification of certain variables, including spring stiffness, damper adjustment, brake bias, and tires, made it possible to single out the variables' effect on performance. Within all variables tested, it was observed that modifications of ride height and aerodynamic rake had the greatest effect on overall car performance. An increase in ride height allowed better airflow through the underside of the vehicle and increased the generation of downforce at the back, leading to decreased understeering and increased traction at the exit of the corner. These improvements are expected to reduce lap time through enhanced cornering stability and improved traction during corner exit, resulting in overall better race performance. These findings demonstrate that optimal race performance is achieved

through a balanced integration of aerodynamic efficiency, mechanical grip, and driver control.

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