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Abstract

In contemporary Motorsport engineering, data-driven approaches and advanced simulation technologies have become more and more critical in the optimisation of race car performance. The paper provides a complete performance evaluation of a race car with Driver-in-the-Loop (DIL) simulation and MoTeC telemetry. The main objective was to assess the impact of aerodynamic configuration differences, mechanical configuration, and tyre settings on vehicle performance and driver behaviour. A formal experimental design procedure was adopted, with variables being carefully isolated and experimented with through a series of simulation sessions held at Pembrey Circuit. Key performance indicators were determined to measure both driver inputs and vehicle reactions, such as speed, acceleration, tyre conditions, and consistency of control.

The findings indicate a distinct improvement in performance over the course of the sessions, where aerodynamic gains resulted in the achievement of higher top speeds and mechanical and tyre optimisation, resulting in higher acceleration and stability. There was also a significant improvement in driver performance, indicative of confidence and adjustment to changes in setups. The paper concludes that optimum performance is only made possible through a balanced combination of aerodynamic efficiency, mechanical grip, tyre management and the skill of the driver. These results emphasise simulation-based testing as a very cost-effective and dependable method of performance optimisation in motorsport engineering.

1. Background and Engineering Context

Achieving optimal race car performance is a primary goal in motorsport engineering, requiring a deep understanding of vehicle dynamics and driver behaviour. Over time, performance optimisation has transitioned from relying largely on driver intuition and minimal track testing to becoming a more analytical and data-driven process. This evolution has been facilitated by advancements in simulation technologies, telemetry, and computational analysis tools, which enable engineers to assess performance with greater accuracy and reliability.

Driver-in-the-Loop (DIL) simulation stands out as one of the most significant advancements in this field. This technology allows a driver to operate a virtual car within a simulated racing environment, while engineers collect comprehensive telemetry data on the driver's inputs and the car's responses. This human interaction within a controlled and simulated setting provides a realistic and dynamic platform for testing. It enables engineers to investigate the impacts of modifications in vehicle setup on both performance and driver behaviour. Unlike real-world testing, DIL simulation alleviates many practical constraints such as high costs, safety risks, and limited track availability, making it an essential tool in modern motorsport engineering.

This report presents a systematic performance evaluation of a race car, utilising MoTeC telemetry data recorded during DIL simulations conducted at Pembrey Circuit. The objective of this research is to assess the impact of aerodynamic modifications, mechanical configurations, and tyre optimisation strategies on overall performance. Key aerodynamic parameters, such as wing angles and ride height, significantly influence drag and downforce, which in turn affect speed and stability. Additionally, mechanical aspects, including suspension characteristics and ride height, play a crucial role in maintaining the vehicle's contact with the track surface. Performance factors, including pressure and temperature, are essential for generating grip and ensuring consistent performance.

2. Literature Review

The integration of simulation technologies and advanced telemetry analysis has become a crucial aspect of modern motorsport engineering. As race cars grow increasingly complex, the utilisation of computational tools has emerged as a vital component for analysing performance and optimising setup configurations by engineers. The simulation of Driver-in-the-Loop (DIL) systems and data acquisition techniques allows engineers to conduct controlled experiments, enabling them to isolate variables and explore their impact on vehicle dynamics as well as driver behaviour. This method significantly reduces the costs, risks, and time associated with real-world testing while still providing valuable performance insights (Perez, 2025).

One of the most significant factors influencing a racecar's performance, particularly at high speeds, is aerodynamic efficiency. The interplay between drag and downforce plays a crucial role in determining the vehicle's behaviour on the track. Downforce increases the vertical load on the tyres, thereby enhancing grip and improving cornering capabilities. However, as downforce rises, aerodynamic drag typically increases as well, which can reduce straight-line speed. This creates a trade-off that must be carefully managed when configuring the vehicles. Achieving an ideal aerodynamic balance is essential, as an imbalance in front and rear downforce can adversely affect handling characteristics. Excessive rear downforce may lead to understeer, while insufficient rear stability can result in oversteer, particularly during high-speed cornering. Consequently, aerodynamic tuning is not only about maximising grip but also ensuring that the vehicle behaves predictably and stably (Arranz Marsal, 2021).

An essential aspect of performance is mechanical grip, which becomes particularly crucial in situations where aerodynamic forces are less significant, such as low-speed corners and acceleration zones. The suspension system plays a pivotal role in maintaining stable contact between the tyres and the track. Parameters like ride height, spring stiffness, and damping properties directly influence how the vehicle responds to load transfer during braking, cornering, and acceleration. Lowering the ride height can enhance aerodynamic efficiency by maximising airflow beneath the car, but it also makes the vehicle more susceptible to surface irregularities and increases the risk of bottoming out. In contrast, raising the ride height can reduce aerodynamic performance while improving the vehicle's compliance on

uneven surfaces. Similarly, softer spring configurations tend to provide greater mechanical grip, as they allow for increased tyre contact with the road. Although it may affect the stability of the vehicle by making it move the body more. This means that engineers have to strike a good balance between these factors to reach a good compromise between grip, stability and responsiveness (Simons, 2025).

Tyre performance is widely regarded as the most crucial factor in the overall performance of a vehicle, as the tyres are the only components making direct contact with the track. To achieve optimal performance, tyres must operate within specific temperature and pressure ranges. When tyre temperatures drop too low, the rubber compound fails to reach its ideal operating temperature, leading to diminished grip and traction. Conversely, if temperatures rise excessively, overheating can occur, resulting in a loss of grip and accelerated wear.

Tyre pressure also plays an essential role, affecting the size and shape of the contact patch. Lower pressures can increase the contact area, potentially enhancing grip; however, they may also lead to instability and excessive heat generation. Conversely, higher pressures improve responsiveness and stability but reduce the total contact area, which can compromise grip. Therefore, effective tyre management is vital for maintaining consistent performance throughout a race or simulation session (Liu et al., 2022).

A crucial aspect of performance optimisation is driver behaviour. Regardless of how finely tuned a vehicle may be, it cannot perform at its best without consistent and precise driver inputs. The primary areas of focus for driver performance include smooth throttle operation, effective braking control, and steady steering. Sudden or inconsistent inputs can destabilise the car, leading to reduced grip and longer lap times. Additionally, driver adaptation becomes essential when vehicle setups are altered; drivers must adjust their driving style to align with the modified characteristics of the vehicle. Simulation environments are particularly valuable for studying driver behaviour, as they allow for repeated testing in a controlled setting. This facilitates the identification of patterns in driver inputs and their interaction with vehicle dynamics.

While simulation offers certain advantages, it still has limitations in accurately reflecting the complexities of the real world. Simulation models often oversimplify or fail to fully account for factors such as tyre degradation, track evolution, and environmental variability. Additionally, elements like rubber accumulation and temperature fluctuations can significantly influence grip levels, yet they are challenging to model with precision. Therefore, although simulations can provide valuable insights into performance trends and aid in optimising setups, it is essential to interpret the results with these limitations in mind (Sakhnevych et al., 2021).

3. Experimental Design and Testing Protocol

A thorough and systematic approach was employed throughout the investigation process to ensure the reliability and validity of the results obtained from the tests conducted. Following the adopted testing procedure, the method of variable isolation was utilised. This process involved changing only one parameter at a time while keeping all others constant. Such a strategy is crucial in motorsport engineering, as it makes the effects of setup modifications on speed and stability more apparent and easier to interpret.

The tests were carried out using three distinct approaches, each designed to assess a specific aspect of vehicle performance. The first approach involved making adjustments to the front and rear wings, as well as the rear ride heights, to understand the impact of aerodynamic pressure on speed and stability. The second approach focused on examining mechanical grip and suspension behaviour, with variations made to ride height and spring rates. Lastly, tyre performance optimisation was achieved by altering tyre pressures.

Each setup underwent numerous tests, with at least five laps performed for each alteration made. This method reduced the impact of the driver's inconsistency and ensured that all data gathered reflected the average performance of the car. The analysis of telemetry data was done by the MoTeC system, giving valuable information about the behaviour of the car and the driver's inputs.

4. Technical Goals and Performance Targets

The primary objective of the testing plan was to analyse how different vehicle setups influence performance. It was essential to explore the relationship between aerodynamic adjustments and speed, assess how mechanical modifications impact stability and grip, and evaluate the effects of tyre pressure variations on the car's overall performance.

5. Distinct Testing Phases

Plan 1: Baseline and Aerodynamic Sensitivity

The initial round of testing aimed to establish a baseline and assess aerodynamic sensitivity. The stock car was evaluated over 13 laps to set a performance benchmark. The rear wing was then adjusted from a setting of 7 to 1, with each configuration tested for 5 laps. Increasing the rear wing provided enhanced stability, but at the cost of increased aerodynamic drag. Conversely, reducing the rear wing allowed for higher speeds, though this came with the trade-off of decreased stability, which was not ideal.

In addition, adjustments were made to the front wing, changing it from settings of 3 to 5 and 3 to 1, to evaluate front-end grip and handling performance. Furthermore, the rear ride height was modified from 5.4 mm to 5.1 mm and then to 4.9 mm, respectively.

Plan 2: Mechanical Grip and Platform Control

Phase two involved testing the mechanical grip and suspension performance. The rear ride height was incrementally raised to 5.4 mm and 6.6 mm to assess their effects on stability and centre of gravity. The front ride height was adjusted within a range of 3.8 mm to 4.7 mm to evaluate its impact on turn-in characteristics.

Additional tests included varying the spring rates to analyse their influence on mechanical grip. Specifically, the rear spring rate was adjusted from 80 mm to both 76 mm and 84 mm, while the front spring rate was lowered to 66 mm. The softer springs enhanced grip, whereas the stiffer springs improved the stability of the platform, albeit at the expense of tyre contact.

Plan 3: Tyre Optimisation and Fine-Tuning

The final stage involved optimising tyre performance. We evaluated the impact of tyre pressure on grip and temperature. Increasing the tyre pressure from 90 kPa to 97 kPa enhanced traction but reduced responsiveness. Conversely, lowering the tyre pressure had the opposite effect, impacting both traction and the vehicle's stability.

Another aspect that needed optimisation was the use of asymmetric pressure settings to address handling issues. Asymmetry can be achieved by adjusting the pressure on either side of the vehicle. Setting the front tyres to 95 kPa and the rear to 96 kPa resulted in an improved understeer/oversteer ratio.

6. Control and Kinematic Indicators

The evaluation of performance was conducted by assessing both the driver's capabilities and the vehicle's attributes. For the driver's performance, key measures included throttle stability, steering stability, braking efficiency, and vehicle stability at high speeds. In terms of the vehicle's performance, the factors considered encompassed maximum speed, acceleration, tyre temperature and pressure, ride height, suspension, and slip ratio. This comprehensive approach ensured that all pertinent aspects of performance were taken into account for the assessment.

7. Data Acquisition Process

This essay will concentrate on the significance of providing drivers with ample time to acclimate to new settings during simulator sessions. It will examine the psychological and physiological factors that contribute to this adaptation and how these adjustments can ultimately impact overall performance metrics in virtual racing environments.

8. Telemetry Interpretation

Data Presentation

The performance results across the three sessions are summarised in Table 1.

Table 1: Performance Comparison Across Sessions

Parameter	Session 1	Session 2	Session 3
Speed (km/h)	176.1	194.9	193.7
Engine RPM	6109	6761	6723
Acceleration (m/s ²)	1.3	1.46	1.58

Figure 1: Session 1

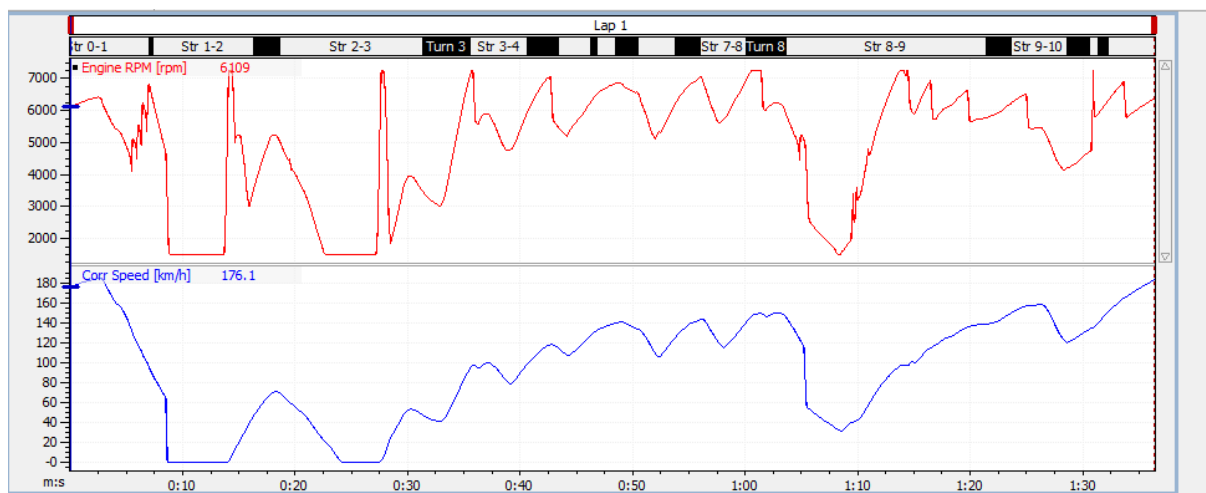


Figure 2: Session 2

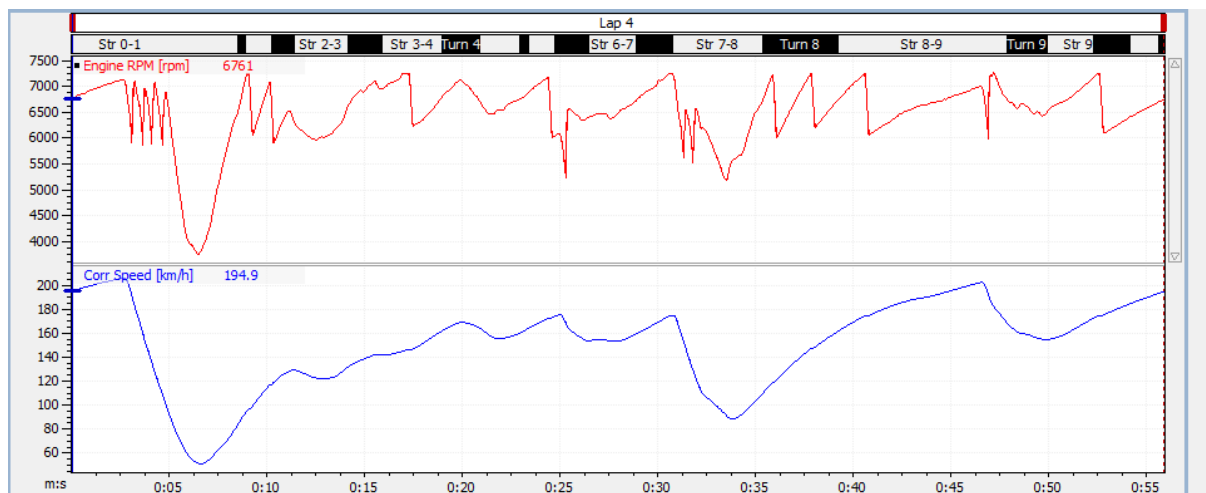
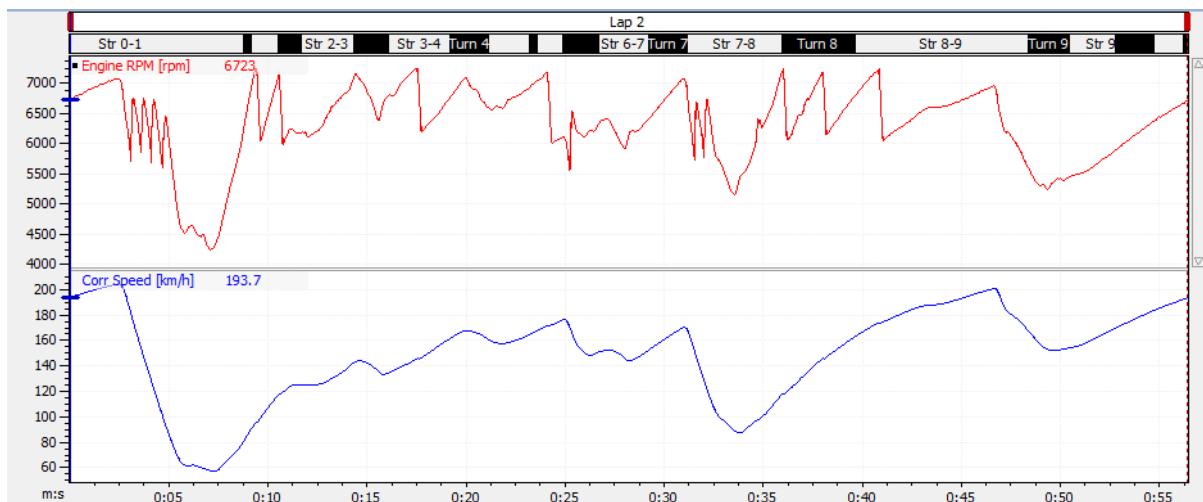


Figure 3: Session 3

The data indicate a clear trend in performance. Session 1 serves as the baseline, exhibiting slower speeds and engine power. In Session 2, there is a significant improvement in both speed and RPM, suggesting enhanced aerodynamic efficiency. Session 3 demonstrates comparable speeds but features quicker acceleration, indicating improved traction and grip.

Driver Performance Analysis

Driver performance improved throughout the sessions. Drivers used the throttle more, showing increased confidence and better traction. Their steering input remained steady, indicating stable vehicle performance. This consistent driver input shows their ability to adapt well to changes in the vehicle setup.

Vehicle Performance Analysis

Enhancements in the car's performance were primarily achieved through modifications to its aerodynamics and mechanics. Improved aerodynamics significantly contributed to increased speed, while advancements in mechanical components and tyre design facilitated improvements in acceleration and stability. However, the high slip values observed on the rear tyres indicate ongoing stability issues with the vehicle.

9. Discussion

Performance optimisation needs a mix of aerodynamics, mechanical features, and tyre performance. While aerodynamics helps increase speed, improving acceleration and stability also relies on mechanical and tyre changes.

10. Recommendations for Improvement

Driver Training

The improvement in driver training will focus on enhancing skills in managing the throttle and brakes. This will include techniques for optimal vehicle control, enabling drivers to effectively adjust acceleration and deceleration for better performance and stability, especially in dynamic situations. Drivers will also learn to assess road conditions for safer and more efficient driving.

Vehicle Setup Adjustments

Optimising the vehicle setup will focus on increasing rear downforce through adjustments to the rear wing and aerodynamics. Additionally, fine-tuning the suspension system—such as spring rates and dampers—will enhance stability and grip, resulting in improved handling and performance on the track.

Integrated Strategy

To achieve consistent performance improvements, it's essential to effectively integrate driver training and vehicle setup optimisation. Comprehensive training enhances the driver's skills and awareness, while fine-tuning aspects like tyre pressure, suspension, and aerodynamics ensures the vehicle is suited to its environment. This combination fosters sustained and reliable performance gains.

11. Analysis of Simulator Fidelity and Practical Constraints

While DIL (Driver-in-the-Loop) simulation offers valuable insights, it cannot fully replicate real-world conditions. Factors like tyre wear and environmental changes are difficult to simulate accurately. This underscores the importance of validating simulation results through real-world testing to truly understand vehicle performance under various conditions.

12. Summary of Engineering Findings

The research findings indicate that implementing a systematic testing approach, which incorporates Distributed Interactive Learning (DIL) simulation alongside telemetry analysis, can effectively pinpoint performance limitations and identify potential areas for enhancement.

Specifically, the aerodynamic configuration of the vehicle has a considerable impact on its overall speed, emphasising the importance of optimising this aspect for better performance. In contrast, the study reveals that the mechanical setups—such as suspension and weight distribution—combined with tyre settings, hold greater significance in improving key performance metrics like acceleration and stability. By focusing on these elements, teams can strategically make adjustments to enhance vehicle handling and responsiveness on various tracks.

13. References

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