



An MCR Race Car DOL Lap-Time Model in VI-Grade: Box–Behnken DOE for Multivariable Sensitivity and Optimization

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Introduction

Simulation has become a cornerstone of modern motorsport, allowing engineers to reduce costs and track time by predicting vehicle behaviour before physical testing. This project develops and validates a Driver-Out-of-the-Loop (DOL) simulation model of the MCR race car using the VI-Grade / VI-CarRealTime platform.

Real vehicle parameters such as suspension geometry, spring and damper rates, tyre data, aerodynamics, and powertrain were incorporated to replicate on-track performance.

The model was first correlated against real-world test data to ensure accuracy. Once validated, it was used to investigate how change in key setup parameters influence handling, stability, and lap time. A Box-Behnken (DOE) was applied in MATLAB, focusing on 3 key factors.

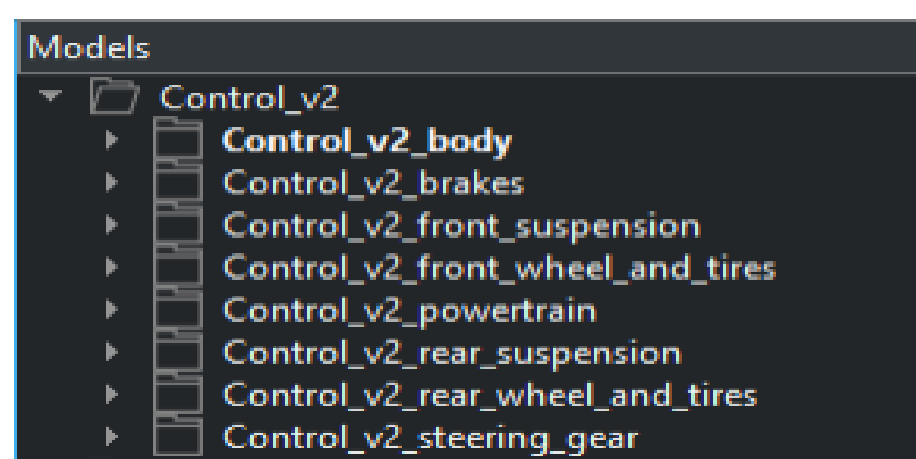
Methodology

Model Creation: A detailed VI-CRT model was built using the real MCR race car data. Subsystems included suspension, tyres, brakes, steering, aerodynamics, and powertrain.

Validation: The model outputs were compared against telemetry from real laps. Camber sweeps, toe variations, spring and damper rate changes, anti-roll bar stiffness, and aerodynamic ride-height studies were used to confirm realistic behaviour.

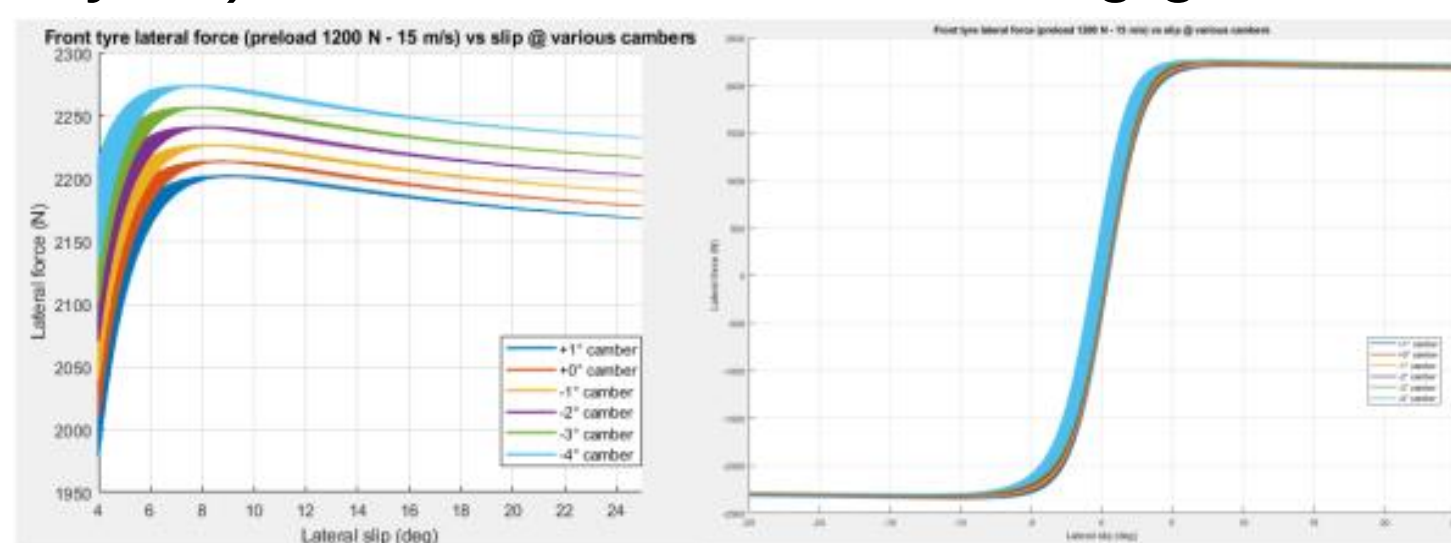
Sensitivity Tests: Controlled parameter sweeps showed how small changes affect load transfer, pitch/roll balance, steering feedback, and lap time.

Optimization: MATLAB was used to run a Box-Behnken DOE, producing response surfaces and interaction plots for lap time prediction. This allowed identification of the most influential setup factors and the research for an optimised configuration.

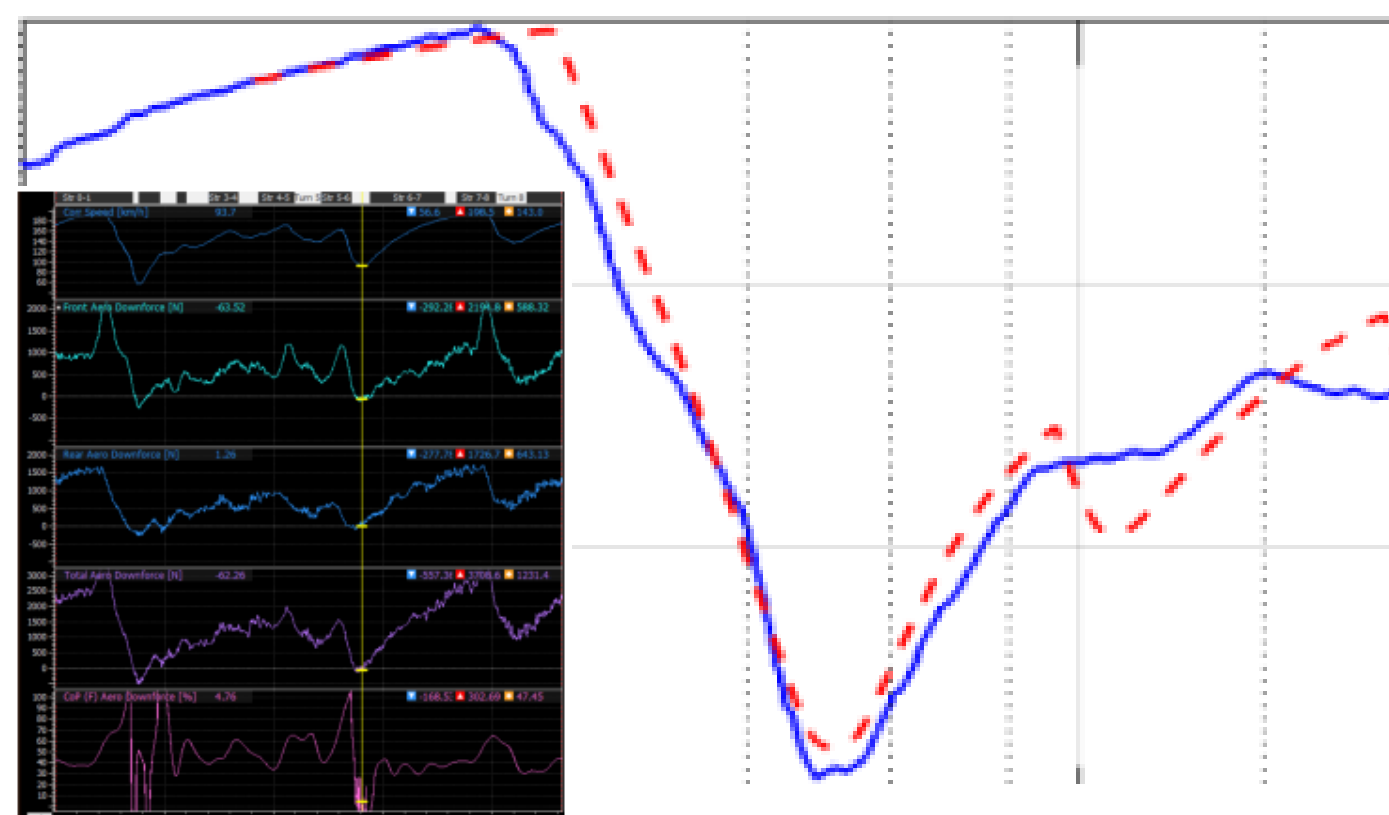


VI-CarRealTime Model of the MCR Race Car Subsystems

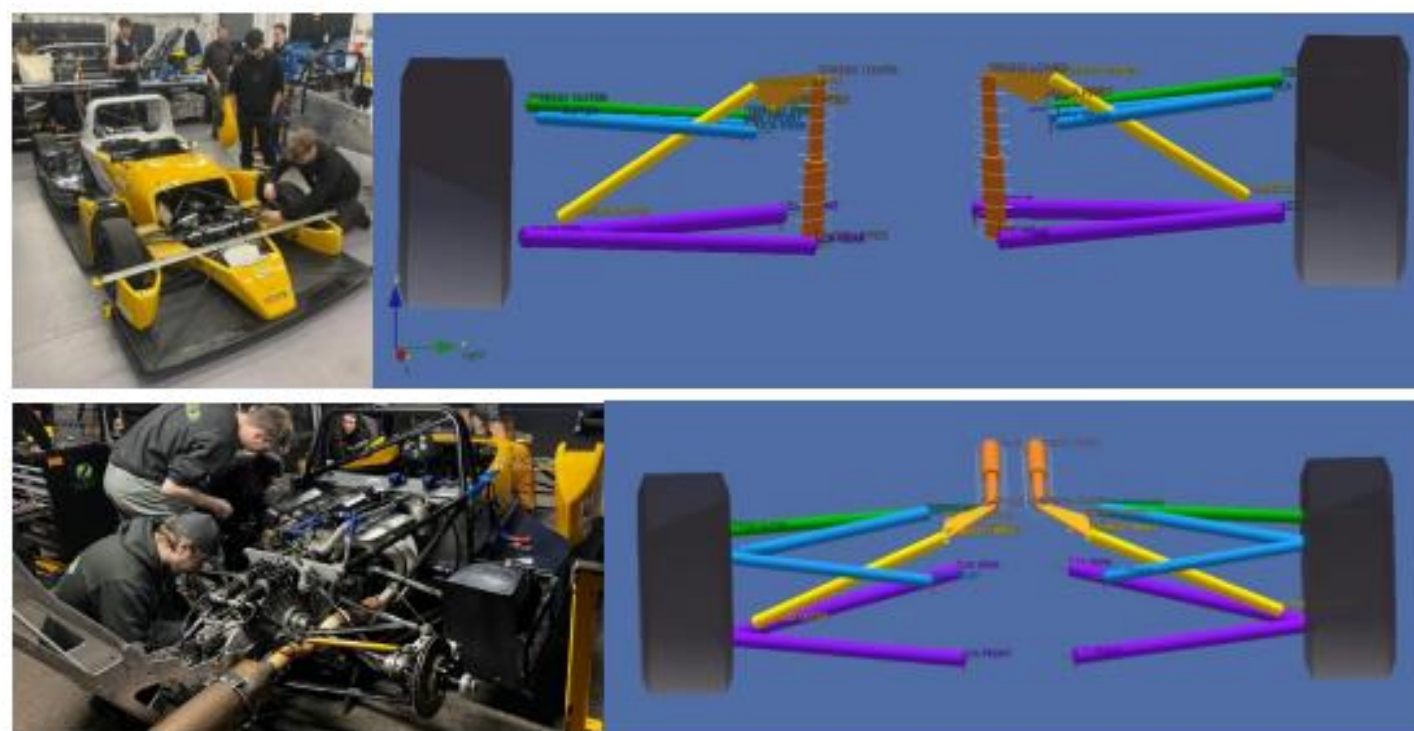
The initial phase focuses on building the simulation model by systematically inputting the real car's data, organized by folder, corresponding to key vehicle subsystems: Body (Aerodynamics), Brakes, Front and Rear (Suspension & Tyres), Powertrain, and Steering gear.



Front Tyre Lateral Force (preload 1200 N) vs Slip at various camber angles



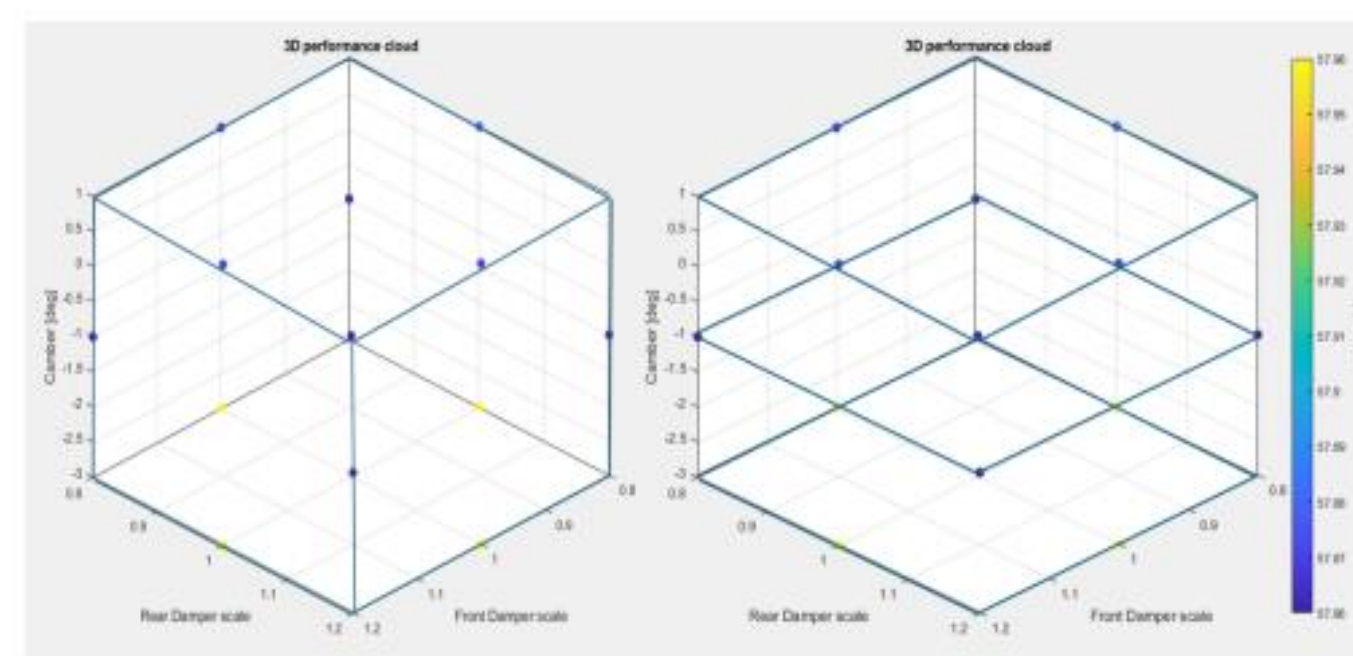
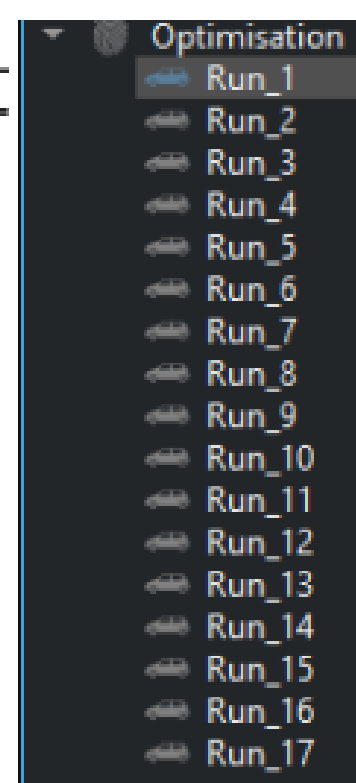
Speed vs Distance Graph of the Real Data against the Vehicle simulation showing the same rate of increase in speed as it accelerated



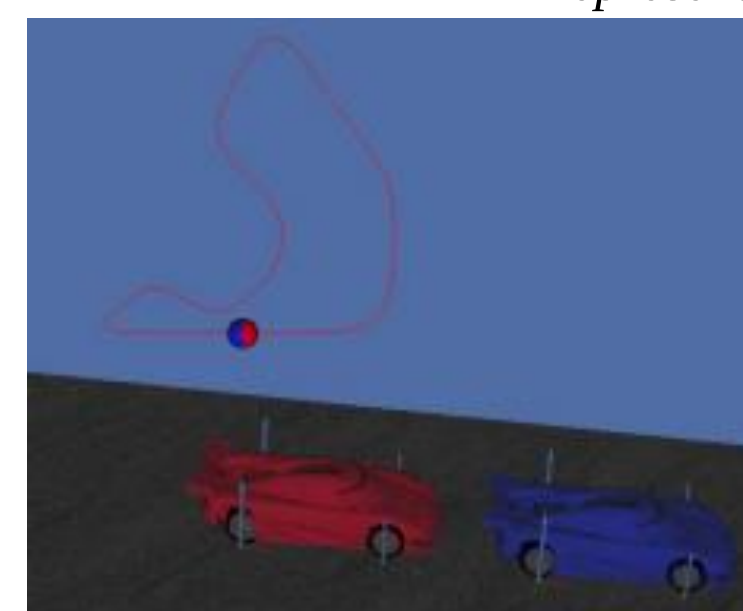
Front and Rear Suspension Setup – Double Wishbone Pushrod System

DOE Box-Behnken Runs [Front Damper Scale Factor – Rear Damper Scale Factor – Camber Angle]

DOE Box-Behnken Runs 3 Variables - FDS - RDS - Camber						
Run	x1 FDS	x2 RDS	x3 Camber	FDSscale	RDSscale	Front and Rear Camber deg
1	0	0	0	1	1	-1
2	1	0	1	1.2	1	1
3	-1	-1	0	0.8	0.8	-1
4	0	0	0	1	1	-1
5	0	-1	-1	1	0.8	-3
6	0	0	0	1	1	-1
7	0	0	0	1	1	-1
8	1	-1	0	1.2	0.8	-1
9	0	-1	1	1	0.8	1
10	1	0	-1	1.2	1	-3
11	-1	0	1	0.8	1	1
12	0	1	-1	1	1.2	-3
13	1	1	0	1.2	1.2	-1
14	-1	1	0	0.8	1.2	-1
15	0	1	1	1	1.2	1
16	0	0	0	1	1	-1
17	-1	0	-1	0.8	1	-3

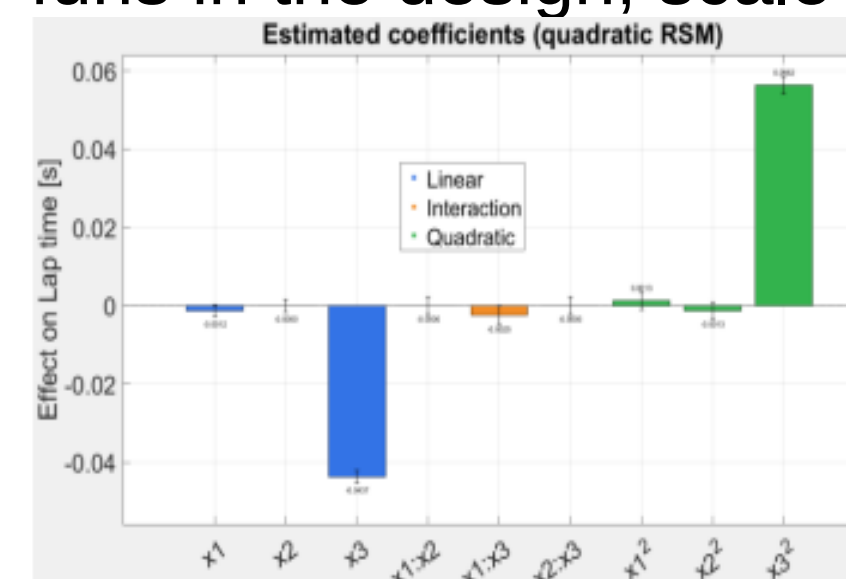


3D Performance Cloud 3 Variable Coordinates Cube Representation.



VI-Animator Red Car Final Vehicle Model vs Blue Car Theoretical Best using a slightly different racing line for both vehicle models, where TB was 0.1s faster at the end of the lap

The design was implemented using an inbuilt function which returns a numeric matrix containing the factor lever for all runs in the design, scale from -1 to 1.



Estimated Coefficients and their influence on the Lap Time where according to the DOE model Camber affects in a higher degree than the Damper Rate

Conclusion

By combining high-fidelity modelling with statistical optimisation methods, it is possible to create a Vehicle Model able to replicate physical and lap time as the real car as well as to show that camber as a dominant factor for lap time modelling.

Suggested Further Work

Multi-objective optimization using additional setup variables and circuits.

Acknowledgements

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