Faculty of Technology, Design & Environment
School of Engineering, Computing & Mathematics

OXFORD BROOKES UNIVERSITY

Assessment cover

Module No:	**ENGR7008**	Module title:	**Laptime Simulation and Race Engineering**

Assessment weighting:	**50%**	Assessment title:	**Laptime Simulation and Race Engineering**

Banner assignment identifier	**CWS2WEEK13**	Due date and time:	**7 May 2025 (Wednesday, Week 13), 1 pm**

Estimated total time to be spent on assignment:	**50 hours per student**

LEARNING OUTCOMES

On successful completion of this assignment, students will be able to achieve the following learning outcomes (LOs):
LO 1: Apply an in-depth knowledge base of engineering in order to synthesise race car performance.
LO 2: Select and use appropriate computational and analytical methods in evaluating the race car performance.
LO 3: Formulate and produce computer simulations of race car lap times.
LO 4: Evaluate the relative importance of different design parameters and quantify the impact of these variables on different racing formula using modelling evidence to support the analysis, which is substantiated by technical information available in the wider literature.
LO 5: Demonstrate transferable/professional skills such as technical report writing (including effective and concise communication) and problem-solving with complete and incomplete data sets, either working in team settings or as individuals.

FOR ENGINEERING ONLY Engineering Council AHEP4 LOs assessed (from S1 2024/25 Onwards)	
M1	Apply a comprehensive knowledge of mathematics, statistics, natural science and engineering principles to the solution of complex problems. Much of the knowledge will be at the forefront of the particular subject of study and informed by a critical awareness of new developments and the wider context of engineering
M2	Formulate and analyse complex problems to reach substantiated conclusions. This will involve evaluating available data using first principles of mathematics, statistics, natural science and engineering principles, and using engineering judgement to work with information that may be uncertain or incomplete, discussing the limitations of the techniques employed
M3	Select and apply appropriate computational and analytical techniques to model complex problems, discussing the limitations of the techniques employed
M4	Select and critically evaluate technical literature and other sources of information to solve complex problems
M16	Function effectively as an individual, and as a member or leader of a team. Evaluate effectiveness of own and team performance
M17	Communicate effectively on complex engineering matters with technical and non-technical audiences, evaluating the effectiveness of the methods used

STUDENT NAMES

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Statement of Compliance
By submitting this assessment I declare that the work submitted is my own and that the work I submit is fully in accordance with the University regulations regarding assessments. *(6. Assessment and progression - Oxford Brookes University and 4. Conduct and engagement - Oxford Brookes University)*

Use of AI Tools: You are required to use this form to declare which AI tools you have used and how you have used them. Please complete the form and attach it to your submission as an Appendix, if you have used such tools.

FORMATIVE FEEDBACK OPPORTUNITIES

Teaching team will be available to provide face-to-face formative feedback for this assignment during the timetabled seminar sessions.

SUMMATIVE FEEDBACK DELIVERABLES

Deliverable content and standard description and criteria	Weighting out of 100%
Introduction	**5%**
Aerodynamics Development: Methodology	**10%**
Aerodynamics Development: Results and Discussion	**15%**
Vehicle Dynamics Development: Methodology	**10%**
Vehicle Dynamics Development: Results and Discussion	**15%**
Powertrain Development: Methodology	**10%**
Powertrain Development: Results and Discussion	**15%**
Conclusions	**5%**
Presentation	**5%**
Group reflection section (200 words): • Propose further work that would offer improvements and enhancements, with a clear summary of how the group functioned as a team and evaluation of team performance. • Evaluate personal learning and development in terms of technology/hardware/software/group work.	**10%**

1. Introduction

The objective of this project is to optimise the performance of a Formula 1 car in accordance with the upcoming 2026 FIA technical regulations. To achieve this, the team is provided with a 2024-spec baseline vehicle model, which requires extensive adjustments to meet the new regulatory framework. The simulation and development process are carried out using AVL RACETECH VSM, a professional lap time simulation tool widely used in motorsport engineering. The optimisation work is structured across three core departments: Aerodynamics, Powertrain, and Vehicle Dynamics. Each area is assigned specific parameters and responsibilities, all contributing to the overall vehicle performance.

The Aerodynamics department focuses on modifying the 3D aero maps originally based on the 2024 car. These maps are adapted to reflect anticipated changes in drag and downforce levels for 2026, including the integration of active aerodynamic systems such as front and rear DRS. Ride heights, DRS activation, and flap angle adjustments (front and rear wing angles of attack) are also fine-tuned to complement aero efficiency and balance.

The Vehicle Dynamics team works on the vehicle's dimensions, suspension kinematics, mechanical setup and handling characteristics. Parameters such as suspension geometry, springs, dampers, anti-roll bars, camber, caster, toe angles, tyre dimensions and pressures are optimised to improve mechanical grip, corner balance, and responsiveness across the stint.

The Powertrain department adapts the existing electric motor and battery models, redesigning power and torque maps to align with 2026 targets while maintaining the original system efficiency. Gearbox ratios and differential settings are carefully adjusted to maximise traction, acceleration, and energy recovery across different sections of the track. While basic cooling strategies for the RESS are maintained, the focus is on optimising drivetrain response and efficiency to meet the performance demands of the 2026 regulations.

Lastly, the Driver model within VSM is configured with different styles for qualifying and race scenarios. A more aggressive input profile is used for qualifying simulations to exploit the car's full potential, while a smoother, more consistent style is applied for race simulations to ensure long term performance and energy management.

This project takes a collaborative and practical approach to optimising a Formula 1 car, recognising how closely connected all areas of the car are. Instead of treating each department as separate, the work brings together Aerodynamics, Powertrain, Vehicle Dynamics, and Driver input to build a complete picture of the car's performance. The main goal is not only to meet the 2026 FIA regulations, but also to understand how to get the most out of the car by adjusting key parameters and testing different setups. With every simulation, the team explores how changes in one area affect the others, helping to make better decisions and improve overall lap time.

Working this way reflects how real F1 teams operate solving complex problems through teamwork, testing, and constant learning. In the end, this project is not just about finding the fastest setup, but also about gaining insight into the engineering process and learning how different parts of the car work together to create performance.

2. Aerodynamics Development

2.1. Methodology

2026 Regulations Set-Up

The 2026 regulations will introduce major changes to Formula 1 car aerodynamics, most notably the implementation of active aerodynamic systems. These systems will enable cars to achieve higher cornering speeds by controlling movable front and rear wings, adjusting drag and downforce in real time to optimise lap time. Since we were provided with a 2024 parameters baseline car, several key modifications were necessary to ensure compliance with the 2026 technical regulations and to prepare the car for performance optimisation.

The first step involved updating the aerodynamic maps for drag and downforce at both the front and rear. These maps are defined as 3D surfaces [Figure 1] that take into account the car's front and rear ride heights and provide the corresponding aerodynamic coefficients. Based on official estimates published on the Formula 1 website, which suggest a 55% reduction in drag and a 35% reduction in downforce for 2026 cars, these maps were scaled accordingly to reflect the expected drop in aerodynamic loads under the new regulations, (Barretto, 2024). Moreover, as stated in Article C10.1.4, which dictates the legality of ride heights, the height must be within 10 mm at the front and within 30 mm at the rear of the ride height of the reference car when presented for scrutineering. In the present case, this starting point has been decided to be the height of the 2024 baseline, so the value will be between 25 mm and 45 mm at the front, and 30 mm and 90 mm at the rear.

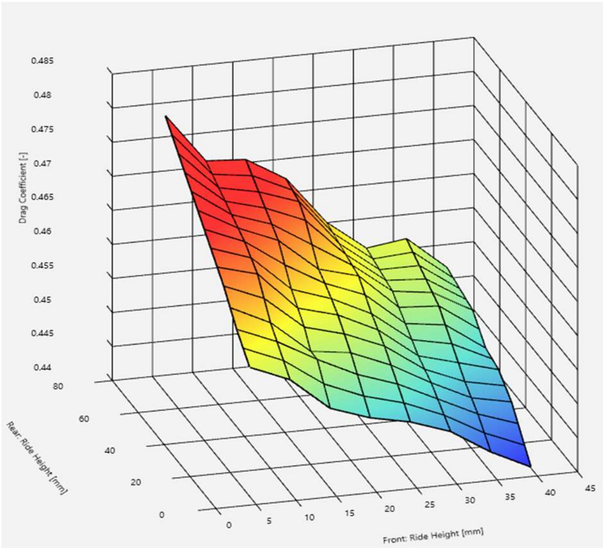

Figure 1: 3D Aero map of the baseline drag adapted to the 2026 regulations.

Additionally, with the 2026 rules allowing DRS activation on both the front and rear wings (article C3.10.10), a dual DRS system was configured in VSM. A baseline lap was used to identify the straight sections of the Red Bull Ring, allowing the creation of a custom DRS activation function within the "Run Configuration" inside VSM. This function switches the DRS on (value = 1) during straights and off (value = 0) in all other segments, mimicking real deployment patterns.

To capture the aerodynamic changes caused by DRS deployment, the polynomial functions used within VSM to model drag and downforce offsets, as a function of flap position, were also adjusted. These functions define how drag and downforce vary with the DRS activation and were edited to reflect the performance drop caused by its activation. As shown in Figure 2, this was achieved by modifying the linear coefficients of the polynomials for both front and rear wings, reducing drag and downforce accordingly when DRS is activated.

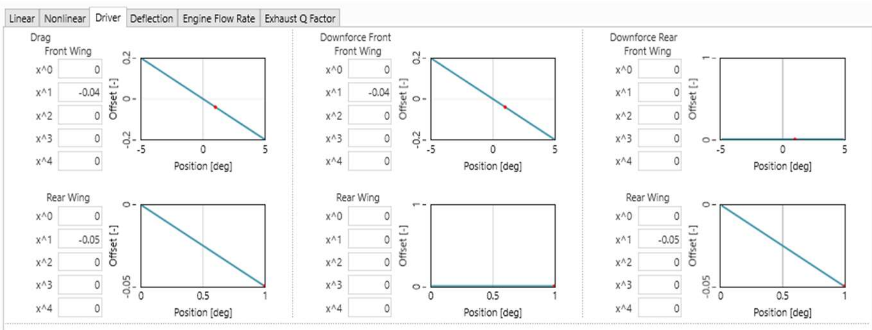

Figure 2: DRS configuration in AVL VSM. (Own work, 2025)

Straight Line Test

To initiate the aerodynamic analysis, a straight-line test was performed using a 3000-metre-long virtual track within VSM. The baseline vehicle model corresponds to the 2026 regulations, following the coordinated updates across the aerodynamics, powertrain, and vehicle dynamics departments to ensure legal compliance. This test aimed to evaluate the drag reduction achieved through DRS activation on a straight, prior to conducting any full-lap simulations on the Spielberg circuit.

A target drag reduction of 20–25% was assumed for the complete vehicle setup. This estimate is based on a report by Willem Toet, which provides a reference point for expected DRS performance. Although the report focuses on rear-wing DRS only, and there are currently no available studies quantifying the effect of front-wing DRS under 2026 regulations, the chosen reduction range is intended to represent the combined aerodynamic impact of both systems. (Willem, 2013).

For this test, the DRS activation strategy was implemented as shown in Figure 3. The DRS system is triggered when the signal reaches a value of 1 and switches off when the value returns to 0, as previously stated. To ensure reliable aerodynamic data, DRS activation begins at 1000 metres, once the car has achieved a stable and representative speed. It remains active until approximately 1900 metres, covering the main section of the straight [Figure 3]. This configuration provides a controlled environment to accurately evaluate the effects of drag reduction during high-speed running, without interference from braking or acceleration phases near the start and end of the straight.

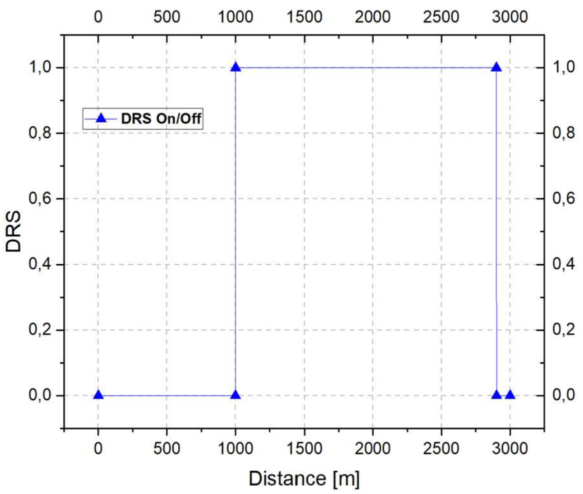

Figure 3: Straight line DRS activation zone.

The test was conducted under four different simulation configurations, as shown in Figure 4. Each run represents a different setup or iteration designed to progressively approach the desired aerodynamic performance, 20-25%.

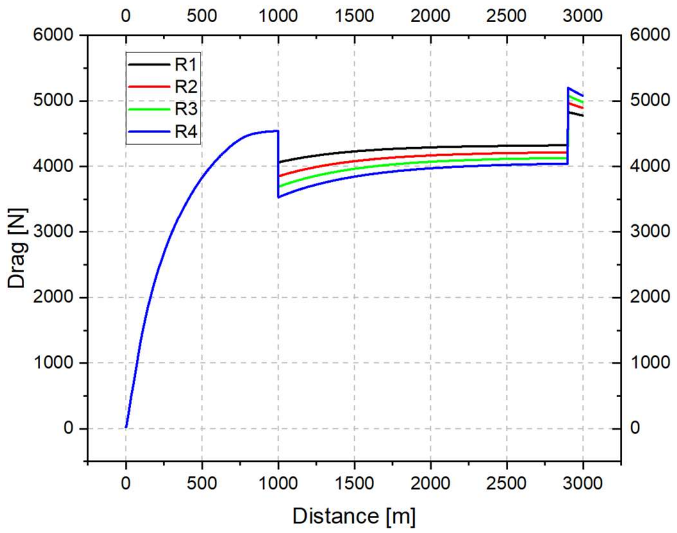

Figure 4: Drag behaviour with the activation of the DRS.

The results obtained are the following:

Table 1: Results from the DRS test on a straight line.

Tests	DRS Off [N]	DRS On [N]	Drag Reduction [%]	Time [s]
R1	4830.44	4321.6	10.53	34.731
R2	4970.64	4274.28	14.014	34.512
R3	5080.94	4129.15	18.73	34.346
R4	5199.49	4042.71	22.24	34.178

Lower drag values during DRS activation translate into faster straight-line performance, as reflected in the lap times. Run R4, with the highest drag reduction of 22.24%, achieves the shortest time of 34.178 s. Additionally, the graph shows that after DRS deactivation near the end of the straight, the drag increases more sharply in R4. This is due to the higher speed reached, which leads to a proportionally greater aerodynamic resistance once the system closes. Every simulation value with better drag reduction shows this tendency compared to R1.

2.2. Results and discussion

Maximising performance requires finding the optimal combination of key aerodynamic parameters. In this case, the most influential inputs are front and rear ride heights, as well as the angles of attack for the front and rear wings. These settings directly affect the drag and downforce levels experienced by the car and therefore play a critical role in determining its aerodynamic balance and overall efficiency.

Since the car development process was carried out in parallel across the three departments, changes made in the Vehicle Dynamics and Powertrain sections also influenced aerodynamic behaviour. This interdependence highlights the importance of iterating across multiple configurations to ensure coherence between systems.

The optimisation process began with a baseline setup, followed by a series of simulations using a wide range of ride heights and wing angles. As the analysis progressed, the parameter ranges were progressively narrowed to focus on more precise combinations. This allowed the team to identify the most effective aerodynamic setup. The evolution of this iterative process is summarised in Table 2.

Table 2: Optimisation Jobs and time values.

	Wing [°]		Ride Height [mm]		
Jobs	**Front**	**Rear**	**Front**	**Rear**	**Time**
J1	1.5	3	30	40	68.133
J2	1.1	2.9	37	48	68.168
J3	1.2	3	40	46	68.163
J4	1.3	3.1	28	44	68.110
J5	1.5	3.5	25	37.5	68.073
J6	1.5	3.2	29	30	67.620
J7	1.5	3.2	30	30	67.617

As shown in Table 2, the lap time improves progressively as the aerodynamic configuration is refined. Early jobs (J1–J3) used broader parameter ranges and resulted in lap times above 68.1 seconds. As iterations advanced, more balanced and lower ride heights combined with consistent front and rear wing angles led to better aerodynamic performance.

A significant improvement can be observed between jobs J5 and J6, where the lap time drops from 68.07 s to 67.61 s. This change correlates with a noticeable reduction in rear ride height, from 44 mm to 30 mm, which increases the ground effect. According to Bernoulli's principle, reducing the gap between the car floor and the track surface accelerates airflow beneath the car, lowering pressure and increasing downforce. This effect contributes to greater cornering stability and improved lap time, (McBeath, 2017).

Jobs J7 and J8, which share similar configurations, achieved the best lap times at around 67.617 seconds, indicating an optimal trade-off between drag and downforce within the allowed parameter space.

This best time achieved comes from a set-up fully optimised from the aerodynamic development point of view. With the configuration that obtains this time, the aerodynamic balance obtained varies from 39.5% to 41.5% along the circuit [Figure 5]. Looking at this distribution, it can be observed that the aerodynamic balance shifts rearward on the straights, while on the slow curves, the aerodynamic balance tends to a more neutral distribution. During straights, rear stability and traction should be prioritised with a lower front balance to reach higher straight-line speeds while preventing excessive front tire wear, (Wordley and Saunders, 2005). On the other hand, increasing the front balance in corners means increasing the front axle downforce, thus improving turn-in responsiveness and mid-

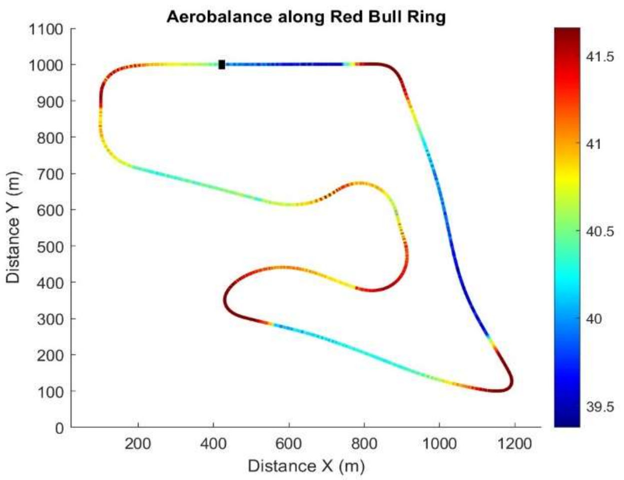

Figure 5: Aero balance distribution along the Red Bull Ring.

corner grip. In the case of this study, the reduction on the front balance in the straights is mainly achieved with the activation of the DRS. Even though both rear and front wings utilise it under the 2026 regulations, the rear wing still plays a more dominant role in overall downforce generation. In this setup, the induced downforce loss from DRS activation affects the front wing proportionally more, causing the aerodynamic balance to shift rearward on the straights. This shift reduces front axle loading and increases rear end stability, which is desirable for high-speed sections. When DRS is deactivated in braking zones, the balance returns forward, enhancing cornering response and grip, (McBeath, 2017).

Table 3 presents a detailed aero map showing the lap times obtained for different combinations of front and rear ride heights, with fixed wing angles of 1.5° at the front and 3.2° at the rear. The purpose of this matrix is to evaluate how changes in vertical setup affect overall aerodynamic performance and lap time.

From the results, it is evident that lower ride heights generally lead to better lap times, particularly when both front and rear are set around 30 mm. This combination enhances ground effect efficiency by accelerating airflow under the car, increasing downforce without significantly raising drag. The best lap time, 67.617 seconds, is achieved with a ride height of 30 mm at both the front and rear, indicating a well-balanced aerodynamic platform.

As the ride height increases in either direction, performance gradually declines. This trend reinforces the sensitivity of the car to vertical setup and highlights the importance of fine-tuning these parameters during optimisation. The aero map provides a valuable reference for identifying performance trends and guiding future setup decisions within the regulatory constraints, (Hendy, 2019).

Table 33: Aero map with time laps.

		Front Ride Heights (mm)				
		25	30	35	40	45
Rear Ride Heights (mm)	30	67.805	67.617	67.6795	67.6685	67.6765
	35	67.749	67.7105	67.7595	67.7515	67.756
	40	67.748	67.822	67.7975	67.7945	67.8105
	45	67.7895	67.842	67.833	67.841	67.8505
	50	67.852	67.852	67.8505	67.863	67.9515
	55	67.8745	67.875	67.877	68.006	67.952
	60	67.8775	67.8895	67.9045	67.97	67.972
	65	67.9	67.9135	68.01	67.985	67.9905
	70	68.041	68.0085	67.9915	68.004	68.0125
	75	68.027	67.9995	68.018	68.0245	68.0685
	80	68.0095	68.046	68.039	68.104	68.16
	85	68.046	68.059	68.0985	68.189	68.195
	90	68.0755	68.1335	68.2085	68.3015	68.2135

3. Vehicle dynamics development

3.1. Methodology

2026 Regulation changes

All the regulation articles mentioned in this section refer to the FIA 2026 F1 Regulations (Fédération Internationale de l'Automobile, 2025).

Vehicle Weight (C.4.1): Minimum weight of 726kg + tyres. Tyre weight has been estimated at 46kg (Barretto, 2024), thus achieving a static weight of 773.5kg, accounting for fuel burnt during the lap.

Weight Distribution (C4.2): Front weight must be between 44 and 46% of the Vehicle Weight.

Dimensions (C2.3, C10.7.2 and C10.10.1): Wheelbase is restricted to a maximum length of 3,400mm, maximum wheel-track was set to 1,540mm and 1,470mm for the front and back, respectively.

Wheel alignment (C10.3): Toe angle must be between 23 and -21 degrees; caster needs to be less than 5 degrees and camber is limited per track specifications. The camber limits imposed for the 2024 Austrian GP (Wittich, 2024) were -3 and -1.75 degrees for the front and the rear, respectively [Table 4].

Tyres (C10.8): As tyre specifications are determined by the tyre supplier, no grip values were modified, however, following regulation changes (Barretto, 2024), tyre sizes were reduced from 18' to 16', and tyre width were reduced by 25mm and 30mm for the front and rear, respectively. The minimum tyre pressures set for last year's Austrian GP (Wittich, 2024) were 1.58bar and 1.38bar for the front and rear, respectively [Table 4].

Table 44: Tyre pressure and camber limits for the 2024 Austrian GP

	Minimum starting pressure			Expected stabilized running pressure	Camber limit
	Slicks	Intermediate	Wet		
Front	23.0 psi	23.0 psi	21.0 psi	≥25.5 psi	-3.00°
Rear	20.0 psi	21.0 psi	18.5 psi	≥22.5 psi	-1.75°

Skid-pad tests

To initiate the vehicle dynamics analysis, two circular skid-pad tests were performed using both a 50 and a 200-meter radius tracks within VSM, maintaining a constant speed of 80 and 170kph, respectively. This test aimed to evaluate the vehicle's steady-state cornering behaviour and handling characteristics in both low and high-speed corners, prior to conducting any full-lap simulations on track.

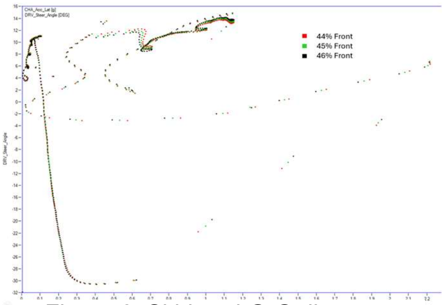

Figure 6: Skid-pad G-G diagram.

Although an initial front weight balance near the midrange target of 45% is more desirable to allow flexibility for setup changes across different circuits during the season, testing revealed that a rearwards distribution had superior performance. As shown in the GG diagram [Figure 6], a 44% front weight balance achieved both higher lateral and longitudinal accelerations.

Comparing the steering angle to the lateral acceleration [Figure 7], the 44% weight balance requires less steering angle to achieve equivalent levels of lateral acceleration compared to the other setups, indicating improved front axle grip and yaw responsiveness, achieving a more balanced and responsive vehicle, especially under high lateral load conditions.

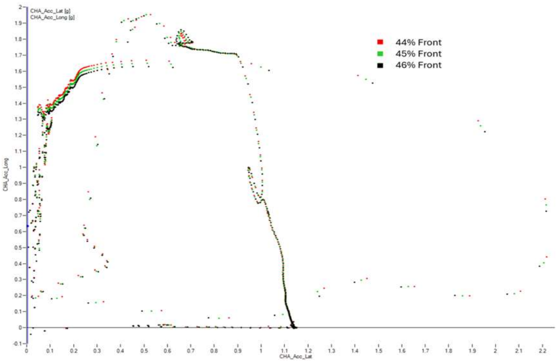

Figure 7: Steering angle VS lateral acc.

Variable optimizations

After implementing the initial changes to conform to the 2026 regulations, an initial baseline simulation was run on the Spielberg track, with a time of 70.499s.

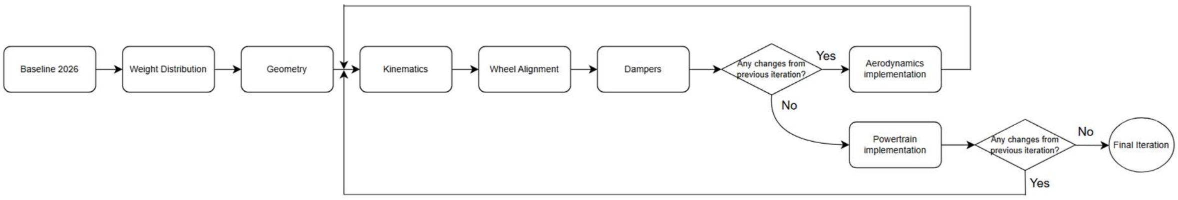

Figure 8: Iterative process for the vehicle dynamics department

An iterative methodology in collaboration with the aerodynamics department was used [Figure 8], to optimize the vehicle's handling accounting for the downforce improvements made by the aerodynamics improvements. Initially, the weight distribution and vehicle dimensions optimizations were provided to the aerodynamics and powertrain departments. Multiple iterations were made to further optimize the vehicle dynamics parameters, accounting for the improvements made in other departments [Figure 9], ultimately, the Spielberg's lap time was improved in 3.125 seconds from the base lap time, going down from 69.909s to 66.784s.

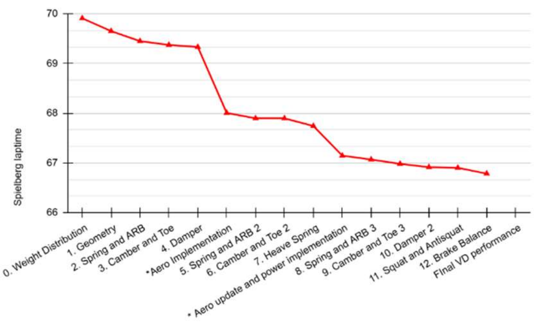

Figure 9. Vehicle dynamics lap time evolution over iterations.

3.2. Results and discussion

The first parameter obtained was the vehicle's wheelbase. After running multiple iterations with different wheelbase lengths [Figure 10], it was found that the best value was 3,320mm, 80mm below the regulatory limit. By reducing the wheelbase, the weight balance was changed, ensuring improved balance and performance of the vehicle (Seward, D, 2015). This value was used as reference for the baseline with 2026 technical regulations.

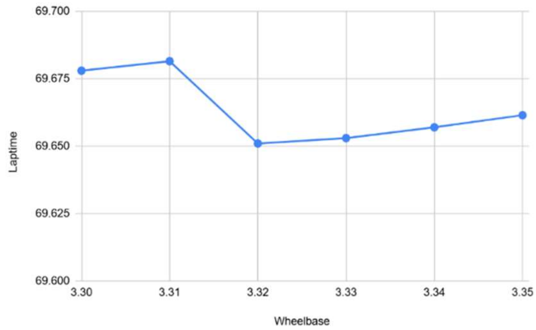

Figure 10: Lap time for different wheelbase length.

The iterative process [Table 5] allowed us to optimize the parameters according to the work done in other departments.

Table 5: Vehicle Dynamics iterative parameters.

	1st Iteration	2nd Iteration	3rd Iteration	Units
Front Spring Stiffness	160	111	120	N/mm
Rear Spring Stiffness	440	410	270	N/mm
Front Heave Spring Stiffness	-	1165	1165	N/mm
Rear Heave Spring Stiffness	-	175	175	N/mm
ARB Front	115	135	195	Nm/deg
ARB Rear	330	355	357	Nm/deg
Front Camber	-3	-3	-	Degrees
Rear Camber	-1.75	-1.75	-	Degrees
Front Toe	-0.075	-0.075	-0.15	Degrees
Rear Toe	-0.2	-0.2	-0.02	Degrees
Front Damper Force	0.25	0.25	1.25	Offset to original map
Rear Damper Force	0.75	0.75	0.5	Offset to original map
Front Anti-Dive	-	-	0.75	Offset to original map
Rear Anti-Dive	-	-	0.5	Offset to original map

The springs are a particularly important parameter, as they improve the vehicle's comfortability, which directly improves the vehicle's handling. (Ralph Pütz and Ton Serné, 2022). The results for front spring stiffness, 120N/mm, and rear spring stiffness, 270N/mm, were the fastest among other combinations. For the anti-roll bars, 195Nm/deg for the front and 357Nm/deg for the rear values were set.

Compared to commercial car spring stiffness and ARB torsional stiffness (Shariati, A., Taghirad, H.D. y Fatehi, A., 2004), values for F1 for 2026 technical regulation are much stiffer.

The heave spring values, which are directly related to the heave (translational) and pitch (rotation) motion. (Genta, A., 2016). The final values were reduced from the original values used and tend to 1165 N/mm in the front and 175 N/mm in the rear.

The final camber values tend to the maximum allowed by Pirelli for last year's Austrian GP (Wittich, 2024), -3 deg in the front and -1.75 deg in the rear. A negative camber increase grip. (Seward, D 2015). Toe final value was set to -0.15 deg in the front and -0.02 deg in the rear. Improving significantly the lap time.

Damper values, which prevent oscillation or vibration from the spring and acts directly between the sprung and un-sprung masses (Seward, D 2015), were varying with the spring stiffness and the final values were set to 1.25 offset in the front, and 0.5 offset in the rear. This offset was done from original damping curve, and the damping force map can be seen in [Figure 11]. These results set a lower damping in the rear and a harder damping in the front and give the required stability to the car.

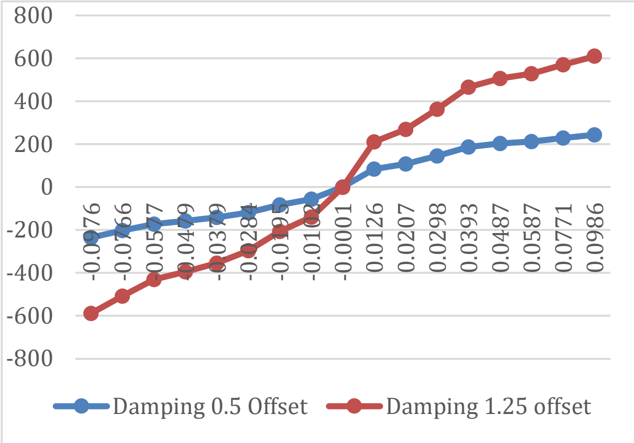

Figure 11. Force Damping map.

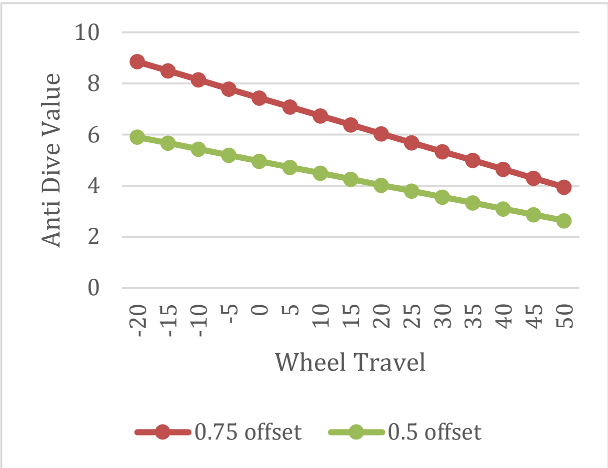

Figure 12. Anti-dive Squat Map.

Regarding the Anti-Dive squats, the value ended as a 0.75 offset in the front and 0.5 offset in the rear from the original map. This anti-dive and squat design minimise the squat (lift) and dive (lift down) of the vehicle.

Analysing the final performance of the vehicle using Drive race, the G-G diagram [Figure 13] plots the lateral and longitudinal accelerations among the lap. The 2026 optimised vehicle achieve higher lateral acceleration values, meaning that the cornering is faster and more optimised. The longitudinal accelerations are higher for the 2024 baseline vehicle, as it has more power and accelerates faster.

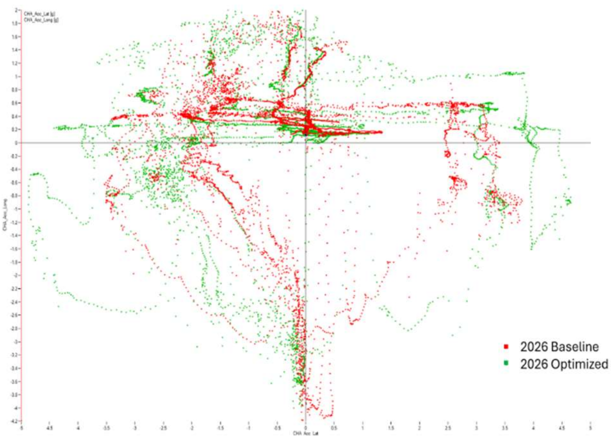

Figure 13. G-G diagram for 2026 baseline and optimised vehicles.

From the AVL Drive Multi-lap tab [Figure 14], analysing the roll angle, the lateral acceleration and the over/understeer channels you can see how the optimised top speed is lower than the baseline due to power regulation modifications. You can also see that the cornering, braking and acceleration is faster in the optimised vehicle.

In the lateral acceleration channel, you can see how the optimised achieve higher lateral acceleration values although having less top speed.

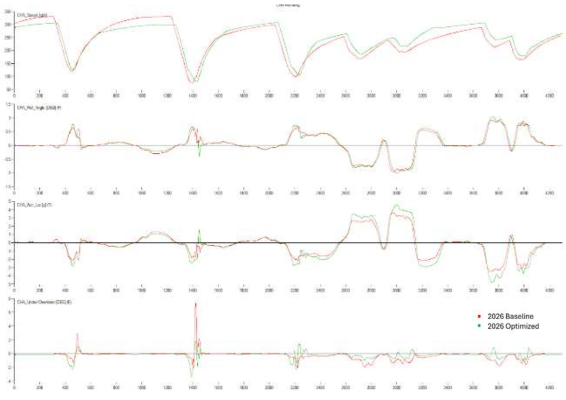

Figure 14. Vehicle handling comparison with baseline

You can also see in the Under/Oversteer channel that the optimised vehicle has less peaks, meaning that the car is more stable and drivable. However, the optimised vehicle tends to understeer a little bit. This is an area of improvement for further development and better performance.

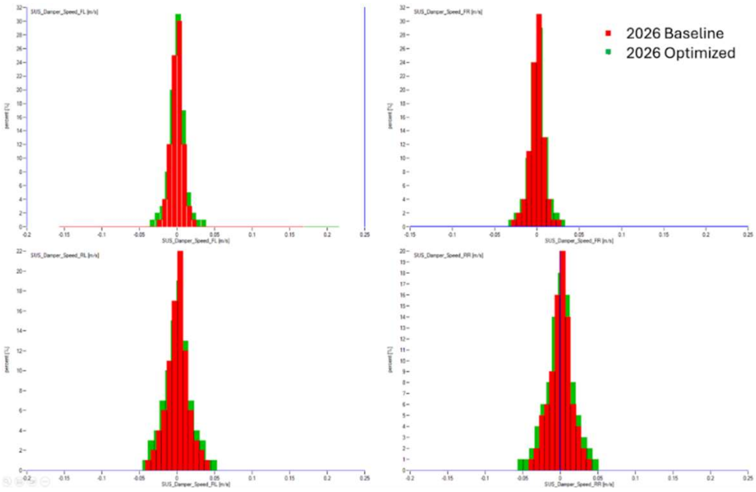

Figure 15: Damper speeds comparison with baseline.

The optimized damper curves improve onto the baseline, as they more closely follow an ideal Gaussian bell shape [Figure 15] (Milliken and Milliken, 1995).

This balanced distribution enables better mechanical grip through corners, more consistent handling during transitions, and improved driver confidence, key advantages for the lighter, less downforce-dependent 2026 F1 cars.

As seen before in the multichannel, the roll angles achieved in the optimised vehicle are higher than the baseline.

However, by looking into the roll gradient graph [Figure 16], a comparison between the roll angle with lateral accelerations, you will see that the optimised vehicle improves on corner stability as the gradient is more horizontal than the baseline (Segers, J.2014).

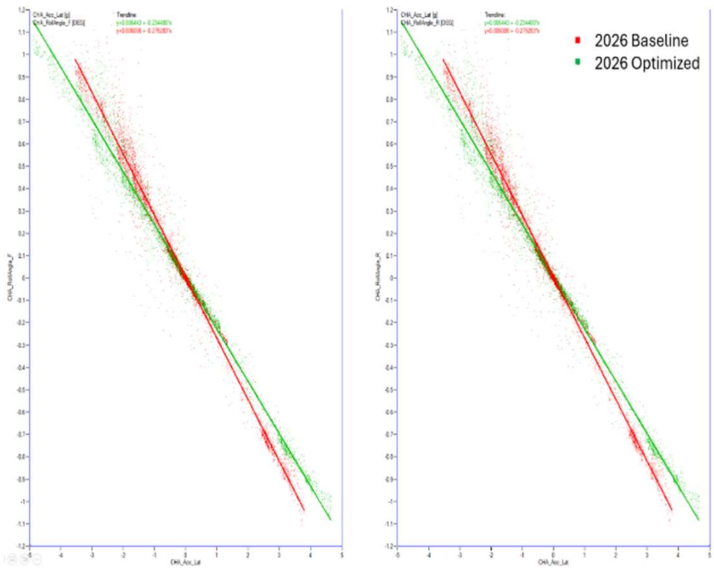

Figure 16: Roll gradient comparison with baseline.

4. Powertrain development

4.1. Methodology

The optimisation of the powertrain system was conducted through a structured process, ensuring that the car meets the 2026 FIA technical regulations and the objectives to maximise car's performance. The methodology focused on implementing the regulation changes, conducting parameter optimisations, and performing integration with the Vehicle Dynamics (VD) and Aerodynamics sections.

4.2. Regulation compliance

The initial phase was conducted by changing the parameters involved in the newest 2026 FIA technical regulations, regarding the power unit. The first two main changes are involved in the power of both electric and combustion engines. The electric engine's maximum power is changed to 350kW from the original 120kW, according to the article C5.2.8 of the technical regulations (FIA, 2025). In the Internal Combustion Engine's (ICE) case the power has been decrease to 400kW, from the original 550kW, as Barreto (2024) stated. For both engines, each torque map was changed, using the equation 1, calculating with its respective maximum power for each engine's angular velocity.

$$T = \frac{P}{RPM * 2\pi/60}\ (Nm)$$

The MGU-H was removed, as Kanal (2022) stated, and regarding the Energy Storage (ES), the maximum releasee and recuperation per lap via MGU-K was set to 9MJ, with 4MJ of allowable deployment and recovery via the ES, according to the article C5.2.2 of the technical regulations (FIA, 2025) and Bayram and Samuel (2025).

The maximum discharge power also was changed, according to the article C5.2.8 of the technical regulations, where it is stated that maximum discharge power should be changed according to car's speed:

- P(kW) = 1800 – 5 * car speed (kph), if car speed (kph) < 340kph.
- P(kW) = 6900 – 20 * car speed (kph), if car speed (kph) ≥ 340kph.
- P(kW) = 0, if car speed (kph) ≥ 345kph.

With the increase on the maximum MGU-K power deployment, as well as on the deployment energy limit per lap, as well as the reduction of the ICE power, an efficient energy deployment strategy becomes even more relevant than in the baseline.

The Red Bull Ring is a high-speed track, with long straights, heavy braking zones and a big percentage of the circuit at full throttle (Briel, 2024). These low-speed corners followed by full-throttle zones are ideal for energy deployment, but also the small amount of heavy braking zones difficult the regeneration of energy.

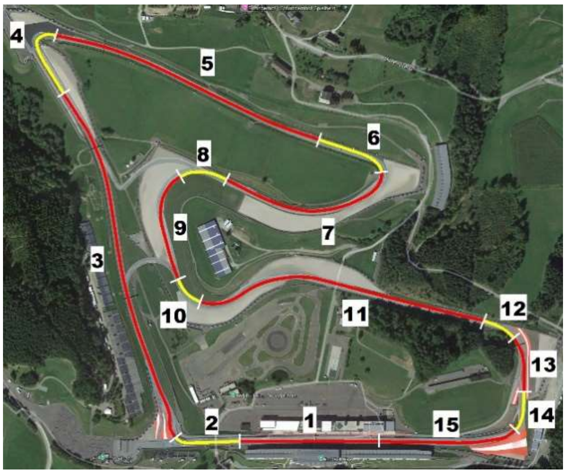

Figure 17: Red Bull Ring divided energy sectors.

In order to design the energy deployment map 15 different sectors have been created to differentiate acceleration and braking zones [Figure 17]. The specific distance from the finish line at which each sector starts is shown in Table 10. Two key deployment sectors are identified at sectors 3 and 5 being these the heavier braking zones followed by a big acceleration. Energy liberation at this point will help significantly the performance. Other sectors like 11 & 15 at full-throttle or 7 with a great acceleration will also be relevant for the strategy.

Li-ion batteries have an optimal operation temperature (Muthukrishnan, 2024), according to Bao (2024) for high performance vehicles this value is around 40ºC, while others like Gross & Clark (2011) use inlet cooling temperatures of 40ºC and output between 3ºC and 10ºC higher than the inlet. Taking also into account that the baseline model presents inlet and outlet temperatures of 40ºC and 50ºC respectively, an outcome of a cell temperature of 40ºC is considered to be realistic.

In order to achieve this, the inlet and outlet temperatures will remain the same as the baseline model. The work by Tizón-Otero & Samuel (2018), regards the relation between the inlet area and the cooling of the cells and the drag. In a circuit like the Red Bull Ring, low drag is key in order to achieve a good time. Thus, the reduction of the inlet will be sought, according also to Tizón-Otero & Samuel (2018) cooling inlets in F1 tend to be smaller than the used on the baseline, between 0.015 and the minimum of 0.008m2, for this case the smallest possible inlet will be used.

The area of the radiator cell is another factor affecting the cooling of the batteries, as Anderson (2023) states, teams normally aim for a inlet that is a 20-25% of a radiator cell area. Another factor concerning the cooling is the coolant’s flow rate, according to Gross & Clark (2011) a usual flow rate for high performance vehicles is set between 10 and 20L/min, which in AVL, taking into account the rpm taken as reference is 1000 will be equivalent to a Pump capacity of 2.95E-07(m^3/s)/rpm.

Lastly, the weight of the ICE, gearbox, ES enclosure and MGU-K were set to 134kg, 40kg, 35kg and 16kg, respectively, according to articles C5.5.1, C5.17.9 and C.18.7 (FIA, 2025), and Mansell (2024). Once the changes of all the sections were ready, a baseline file was created, and all the optimisations started from that file.

4.3. First optimisation of parameters with baseline file

The first optimisation of the parameters was conducted in parallel with the VD and Aerodynamics sections, to certify that all subsystems evolve simultaneously.

In this first optimisation, in the gearbox’s case, the mode was changed to *Ratio*, as less parameters would be analysed with this option. This is because more time would the *Jobs* need when running the analysis. After that, to optimise the gearbox, gear ratios have been analysed starting from the first ones, as analysed by Bera (2019). This was done to find the maximum acceleration and fuel efficiency (Eckert et al., 2014), trying to maintain the rpm inside the torque band of the ICE. The optimisation also has been done trying to reach the maximum speeds of a F1 car, by using all gears.

Higher gear ratios have been used in low gears to improve acceleration, whereas the higher gears will have lower ones to determine the maximum speed of the vehicle. Gears have been analysed in pairs, for example, started analysing the first two gears, then the 2nd and 3rd gears, and continuing like this consecutively. Lastly, the final gear ratio was analysed.

For the energy strategy study, an initial strategy will be developed for the 2026 baseline model, to have some notion of the most relevant sectors.

4.4. 2nd optimisation with Vehicle Dynamics and Aerodynamics setup

For the second optimisation, conducted in series, first a strategy optimisation will be done after the aero implementation in the VD model, then, the gear ratios were analysed, following in both cases the same strategy of the first optimization, but according to the setup, considering the lap time.

After this, simulations for the differential were done, as this analyses the torque distributed in inner and outer tyres of the rear axle (Honda Racing F1, 2009). In this case two *Jobs* have been done. The first one regarding the ramps in power and brake phases, representing the entry and exit of corners. A bigger inclination in a ramp would mean that the differential is more opened, meaning that wheels are allowed to rotate at different speeds. Higher lock in corner exit would mean that the vehicle would have better traction but making the car harder to drive. When braking, a locked differential will help to rotate the car, but instability would be enhanced.

Later, as clamping has been enabled, an analysis for the maximum torque of both power and brake ramps, to control how the Limited-Slip Differential (LSD) resists relative motion between both rear wheels by clamping internal components to avoid, for example, wheelspin (Tremlett, A.J. et al., 2015).

There will be two analyses of differentials, one for the first optimised gearbox, and then the second optimised gearbox, and depending on the results, in terms of suitability for the calendar, a gearbox will be selected, as this part is fixed for all the circuits, according to the article C9.4 of the technical regulations (FIA, 2025).

Once the gear ratios and differential data are introduced, the final strategy will be developed updating the values of the previous one, to fit the implemented changes. Just before the RESS cooling optimisation.

Taking into account the null effect RESS cooling management has on the final time, as efficiency remains the same, the optimum cooling setup will be introduced in the team simulated lap as the penultimate step, only before the driver. In order to compare different alternatives, a job will be run modifying the inlet area, the radiator area, and the pump capacity.

4.5. Results and discussion

4.5.1. MGU Torque maps

Analysing the results of the simulations, it can be seen how the maximum electrical power recovered by the MGU-K is around 322kW. This indicates a loss of around a 5% between the mechanical and electrical power.

To guarantee the maximum allowed energy absorption of 350kW by the energy storage, the torque map has been modified, changing the maximum torque from 168.8Nm to 177.685Nm, in order 368.421kW are mechanically absorbed, and due to the losses 350kW will be absorbed in the storage. This modification however won't impede the deployment of 322kW of mechanical power but would guarantee a higher energy absorption.

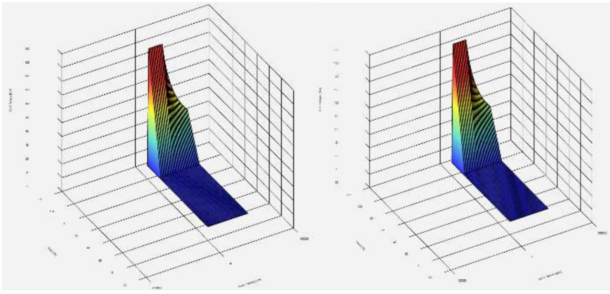

Figure 18: MGU-K DMD Torque Map 350kW vs 368.48kW.

When analysing the updated results, it can be seen how 350kW of electrical power are absorbed this time. However, no change in time exist between the simulation with the previous map and this one, neither in further laps. This is an indication that AVL doesn`t relate the absorbed power with the deployed power, as we will see further in the report.

4.5.2. Rechargeable Energy Storage System

On the baseline model, the cell temperature starts at around 50ºC and starts deploying with the laps stabilising around a final value around laps 4-5. For the baseline this value is around 32ºC, while in the updated 2026 model before doing the cooling analysis, this sets on a similar value around 33ºC, as shown in *Figure 19.*

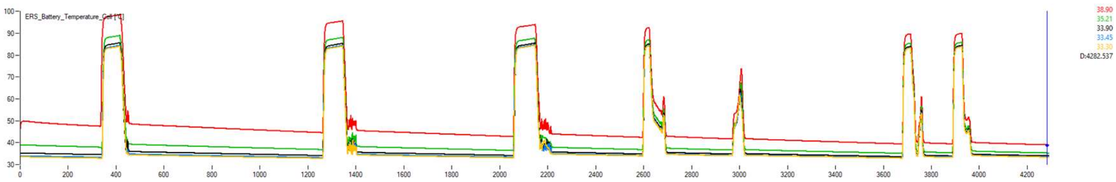

Figure 19: Baseline Cell temperatures laps 1 to 5

Once the job is finished, is it observed how the inlet area is the factor that influences more the cells temperature, while the effect of the radiators area and the pump capacity is appreciated on a lower scale. In all three cases, bigger values help to achieve smaller cell temperatures.

For our case, at 0.01 m2 of inlet, 0.05 m2 of radiator and a pump capacity of 2.95E-07(m^3/s)/rpm (20L/min), a stabilised temperature of 40ºC is achieved [Figure 20].

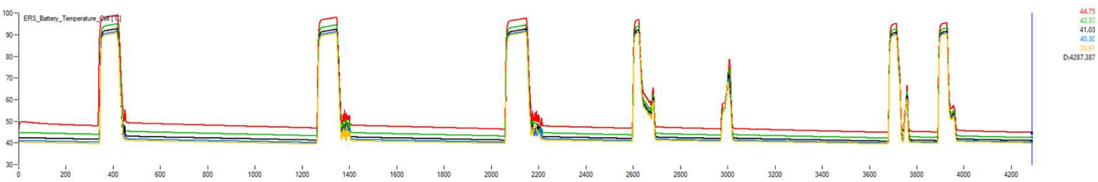

Figure 20: Optimised Cell temperatures laps 1 to 5

This reduction in the inlet area will theoretically help to improve the drag for this circuit, however, no change is appreciated on the final time, nor in the inlet reduction more a consequence of the drag improvement in AVL than a correlation between the two.

4.5.3. Gearbox and Differential

Tables 6 and 7 show the results for both optimised gearboxes and differentials, after the optimum setups from VD and Aerodynamics were obtained.

Table 6. Best gearboxes of both iterations with the best VD and Aerodynamic setup

Iteration	1	2	3	4	5	6	7	8	Laptime
1	3.236	2.7	2.1	1.7	1.4	1.214	1.057	0.929	66.883
2	2.796	2.3	1.6	1.4	1.19	1.046	0.953	0.843	66.067

Table 7. Differential setup for both iterations

	Ramp Angle (◦)		**Torque Limit (Nm)**		
Iteration	**Power**	**Brake**	**Power**	**Brake**	**Laptime**
1	53.33333	40	25	25	66.617
2	30	46.6667	27.5	20	66.03

According to the simulation results, the first gearbox iteration featured a more evenly distributed set of gear ratios and ensured that all eight gears were utilised throughout the lap [Figure 21]. In contrast, the final optimised configuration, which yielded the fastest lap time, did not require the use of 8th gear, indicating a lower maximum achievable speed. This suggests that the optimised setup is tailored more toward acceleration than outright top speed, which is acceptable for the Red Bull Ring layout.

Notably, the second iteration features an unusually large gap in 2nd gear, which is typically not recommended due to potential drivability issues. However, this drawback is mitigated by effective energy deployment during corner exits, particularly at slow-speed sections such as Turns 1, 3, and 4, resulting in improved overall acceleration.

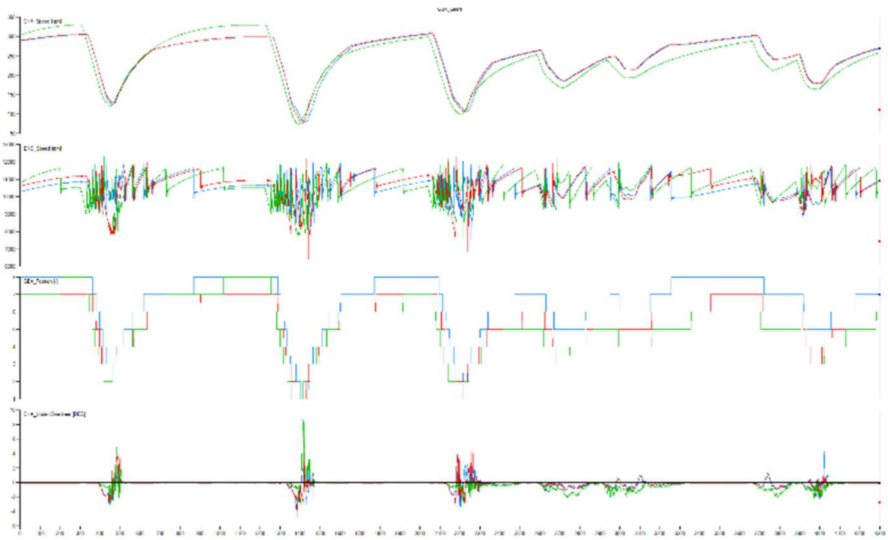

Figure 21. Difference between 1st (Blue), 2nd (Red) iterations and baseline (Green)

Furthermore, analysis of the understeer/oversteer behaviour reveals that the baseline setup exhibited a stronger understeering tendency. After both optimisation iterations, the car demonstrated a more neutral balance, with reductions in both understeer and oversteer tendencies. Lastly, adjustments to the final drive ratio showed no measurable effect on lap time, suggesting it was already well-suited to the powertrain and track characteristics.

Although the second iteration delivered the fastest lap time at the Red Bull Ring, the first iteration has been selected for final implementation. This configuration features a more evenly distributed gear ratio set and ensures full utilisation of all eight gears, offering better adaptability across a wider range of circuits, particularly those requiring higher top speeds. Additionally, the broader ratio spread results in lower average engine RPM across the lap, which is expected to reduce mechanical stress on the gearbox and improve long-term durability. Despite the slight performance trade-off at this specific track, the first iteration maintains strong drivability and acceleration response, making it the more robust and versatile choice for sustained race performance throughout the calendar.

4.5.4. Energy Management

Results of the baseline from 2024, show how the energy is equally released across all the acceleration zones, taking into account the maximum release is set to 7200kJ and the max power 120kW in the model. However, for the 2026 model, max power is increased, and max energy storage delta is set to 4000kJ. This results on all the available energy being deployed before the 4th turn, as shown in Figure 22.

Table 8: Management strategy improvement.

Results	Reference time	Result Time	Improvement
1st iteration	67.742	67.327	0.415
2nd iteration	66.617	66.611	0.006
		Total Impr	0.421

The first strategy, developed on the baseline model, manages to reduce the reference time in almost 0.8 seconds. However, once it is introduced into the VD and Aero updated model, and refined after the gear ratios` introduction, a total improvement of just 0.421s [Table 8].

The final strategy results on a bigger deployment at sectors 3, 5 and 7, with also some energy deployment in sector 5, and the remaining energy in sector 15 [Figure 22], which is set to 1000 to guarantee the remaining energy is deployed there as shown in Table 9.

Table 9: MGU-K energy deployment strategy.

Sector	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Starting Point [m]	0	306	450	1235	1423	2035	2195	2588	2690	2940	3014	3668	3740	3875	3980
Deployed energy [kJ]	0	0	1000	0	1150	0	700	0	0	0	950	0	0	0	1000

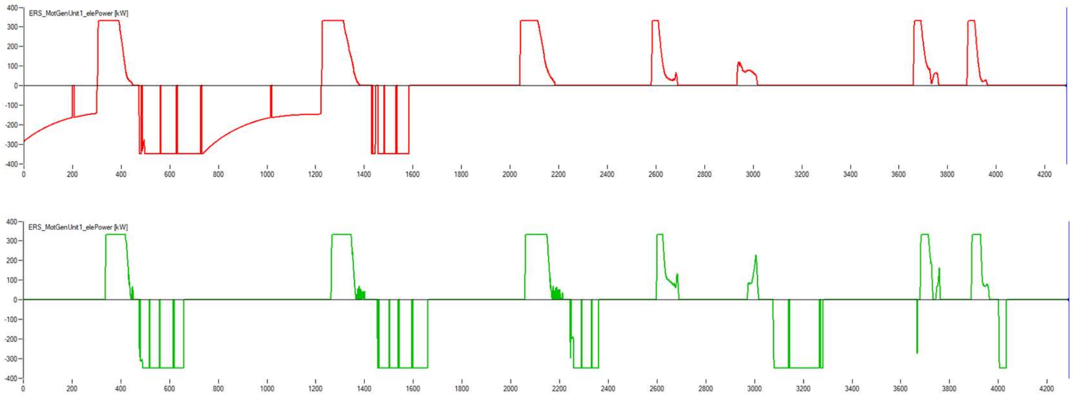

Figure 22: 2026 baseline and best energy deployment strategies.

Some concerns however, existing in this part. First of all, AVL only deploys a maximum of 4000kJ per lap, despite the limit for the MGU-K being 9000. The storage has a maximum delta of 4000kJ but can recover and deploy energy within the same lap. Which AVL doesn't replicate.

Another concern is that AVL doesn't relate the absorbed and deployed power. While it can be noticed in Figure *22* that the absorbed power is substantially less than the deployed, in further laps the deployed power keeps being 4000kJ not being any kind of depletion appreciable, which makes race simulation quite unrealistic and complicate.

5. Driver configuration

While the optimisation of the car relies heavily on the Aerodynamics, Powertrain, and Vehicle Dynamics departments, driver behaviour also plays a crucial role in lap time performance. Factors such as throttle application, braking intensity, and cornering approach can significantly influence the overall efficiency and balance of the car. In this section, two distinct driving styles are considered: an aggressive setup focused on maximising performance during qualifying, and a smoother, more consistent profile suited for race conditions. These driver profiles allow us to better understand how different inputs can affect car behaviour and overall lap time across different scenarios.

5.1. Qualifying

Table 10: Qualifying Driver's profiles. (Own work, 2025).

Acceleration [%]	Braking [%]	Cornering [%]	Time [s]
97	88	97	66.12
96	88	96	66.229
97	91	97	66.278

During the qualifying simulations, the Jobs function in VSM was used to test various combinations of driver inputs by adjusting acceleration, braking, and cornering aggression levels. As shown in the table, the best lap time achieved was 66.12 seconds, using a driving profile with 97% acceleration, 88% braking, and 97% cornering. This setup reflects a highly aggressive style, maximising the car's potential in all performance phases.

Notably, this lap time represents a 0.491 second improvement over the previous best time of 66.611 seconds, which was obtained using the optimal configuration from the three technical departments alone. This highlights the significant impact that an aggressive and well-calibrated driver profile can have on overall performance in qualifying conditions.

One key factor contributing to this result is the low fuel load of 3.5 kg, which is realistic for a qualifying scenario. This minimal fuel level allows the driver to complete a single flying lap while significantly reducing the vehicle’s weight, thus improving acceleration, braking efficiency, and overall cornering speed. The light fuel strategy, combined with the most aggressive driving profile, resulted in the lowest lap time of all simulations.

The comparison with the other two fastest configurations, which yielded slightly higher lap times, highlights the sensitivity of performance to subtle changes in driver input levels. Even a 1% reduction in acceleration or cornering can translate into measurable lap time differences, reinforcing the importance of precise driver performance.

5.2. Race

For the race simulation, fuel load was calculated based on the calculated consumption of 1.25 kg per lap at full power seen in Drive Race. Given that a full Formula 1 race at the Red Bull Ring consists of 71 laps, this results in a total race distance of 306.452 km (71 laps × 4.318 km per lap), in line with FIA regulations that require races to cover at least 305 km. Based on this, the optimal starting fuel load was set to 88.75 kg, ensuring the car can complete the full race distance without refuelling while accounting for potential variations in energy deployment. This fuel estimation provides a realistic baseline for assessing driver behaviour and car performance in long run conditions.

Table 11: Race Driver's profiles.

Acceleration [%]	Braking [%]	Cornering [%]	Time [s]
95	86	96	68.367
94	88	96	68.493
94	91	95	68.547

As seen in Table 7, the lap times are generally slower compared to those achieved with the qualifying driving style. This is largely due to the increased fuel load at the start of the race, which has a significant impact on car dynamics. The added weight increases inertia during braking, reduces acceleration and braking efficiency, and decreases overall responsiveness. As a result, the driver must adapt to these conditions by adopting a smoother driving style, which helps maintain stability and reduce tyre degradation over a race distance.

In addition, another representative parameter that helps visualise the difference in driving styles and the consequences of the added fuel weight is the tyre energy dissipation. Looking at figure 23, is evident that the energy dissipated along the lap varies significantly between both scenarios. While the qualifying tyre would dissipate less energy due to a lower weight, the aggressiveness of the driving style to minimise lap time, triggers a greater tyre degradation. In parallel, due to the added fuel weight, even though the set-up is less aggressive thereby tending to degrade less at the end of the lap, the tyre

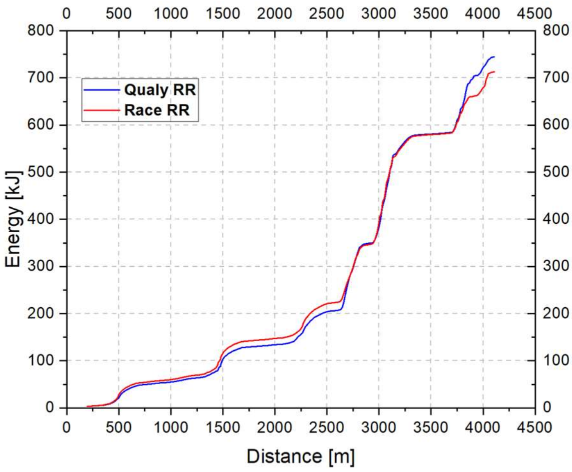

Figure 23: Energy dissipated at the rear tyres for qualifying and race.

will still dissipate more energy in determined points of the circuit, mainly in high braking points, to account for this added weight. (Milliken and Milliken, 1995)

6. Conclusions

This study has demonstrated the effectiveness of a structured and multidisciplinary approach to Formula 1 car optimisation in anticipation of the 2026 FIA technical regulations. By integrating aerodynamics, powertrain, and vehicle dynamics development into the AVL RACETECH VSM software, and by crossing and iterating values, the team has successfully adapted a 2024 spec baseline model to meet new regulatory requirements and achieved significant performance gains at the Red Bull Ring.

In this way, starting from the 2026 baseline, with a time of 69.909 seconds, changes in parameters from the different departments have been essential to develop the car until reaching the final time of 66.611 seconds. This improvement has been achieved with optimising only geometry and mechanical elements of the car. Nevertheless, later has been demonstrated that the driver's driving style has also a significant impact in the lap time. With a more aggressive set-up focused on qualifying and with minimum fuel, with the optimisation of the driver, a time of 66.12 seconds was able to be reached. For reference, this value is still far from the lap time record at the Red Bull Ring, which is 62.939 seconds, but the improvements and optimisation performed compared to the baseline are still significant.

All in all, the project not only has achieved regulatory compliance and performance improvements but also provided valuable insights into the complex interactions governing modern F1 car performance. Therefore, the methodologies and results presented here offer a robust foundation for further research and development as Formula 1 transitions to its next generation of technical regulations.

7. Group reflection

Throughout the project, the team collaborated to optimise a 2026-spec Formula 1 vehicle using AVL's VSM lap time simulation tool. Each department, Aerodynamics, Powertrain, and Vehicle Dynamics began working from a shared baseline model. Iterative improvements were introduced in aerodynamics and vehicle dynamics first, followed by powertrain integration due to its greater complexity.

Team communication was effective, with departments regularly sharing updates, reporting issues, and keeping the project aligned. However, in the early stages, we faced challenges with file version control, which occasionally caused confusion. In future work, setting up a clear file-naming and version management system would help streamline collaboration. Additionally, earlier integration of all departments, especially powertrain, could allow for more cohesive optimisation.

From a personal learning perspective, the team adapted well to the VSM environment over time. The software's structured interface helped us quickly understand where and how to apply changes for each department. While we are still learning, we became more confident using the tool to test design adjustments and analyse performance. This experience also enhanced our understanding of how simulation supports decision-making and improved our teamwork, especially in terms of communication, task distribution, and keeping a shared objective in mind.

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