Optimization of Racecar Setup in Sim Racing through Data Acquisition and Analysis

A Study By :

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THE PROLOGUE

The purpose of this thesis is to use data acquisition and analysis tools available to a motorsports vehicle dynamics engineer, namely MoTeC i2 and MATLAB in this case to analyze the performance of a racing vehicle around a racetrack and use the feedback acquired to precisely improve upon it. Given that the occasion of taking an actual racecar to a permanently closed facility for the purpose of testing its capabilities is far beyond the authors reach, the virtual world of sim racing will have to suffice. Although obviously not a sufficient counterpart to real life, one advantage of stepping through the wormhole of virtual reality is the ability to do away with the crutches of logic and explore possibilities and scenarios you could only wonder about in the real world. This will be no exception.

THE PREMISE

Inspired by the venerable Shelby Cobra to be America's next uncompromised sports car, it was only reasonable the Viper tried to show its might on the track. Based on the second generation GTS model for the benefit of the rigidity inducing hardtop, the GTS-R , built by experienced French racing team Oreca, would enter the international racing scene in 1996 and by 1998 would establish it self as a dominant force, with a brilliant show of performance in the FIA GT Series winning all but one round, including a class win at the prestigious 24H of Le Mans. The list of accolades, such as multiple more Le Mans victories, sweeps of the FIA championship and further championship success in the North American ALMS, would keep piling up, cementing the GTS-R's position in the racing pantheon. That would be the case until 2001, when Chrysler decided to end its official support for the program, and Oreca would shift their focus on their new Le Mans prototype, leaving the fate of the GTS-R to privateers. Understandably, although both teams and car would go on to show mighty persistence over the years, the stronghold it previously had over its competitors would gradually loosen up and by 2003 the Team Corvette C5-R would dominate ALMS and the Prodrive built Ferrari 550 would leave but the occasional victory to the veteran snake. This is what we shall address in this thesis, whether a better support to the car could have the tides of history changed.

THE TOOLS

The virtual world that will play host in our experiment will be GTR-2, a beloved classic in the world of sim racing. We shall drive a control run around Brno 2003, an event the 550 dominated while the GTS-R could only produce some waning results, with the best of entries qualifying almost two seconds off the pace ,and finishing only twelfth, behind four N-GT cars. Using telemetry files recorded by the game and uploaded on the MoTeC i2 program to be read and analyzed with the help of MATLAB , we will aim to produce a setup capable of claiming a time better than 1:56:695 which was the pole position in that year's race. In order to achieve our cause we will alter everything GTR-2 offers at our disposal included but not limited to gearing, aerodynamics, differential and in depth suspension tuning. We will test each change on the cars performance improving on it as we go, documenting the progress as it came to be in the process. Finally we will present the findings of the experiment and what we can conclude from it.

THE BASELINE

Starting with the default setup, we take the car out on track to see what it is able to produce and how close we can get to our target time. The input device we use is a standard Dualshock PS4 controller calibrated for softer progressive inputs. The tires with which the experiment will be conducted are the hard slick compound. An initial look at the setup reveals some very conservative configurations like high aero, a steep ramp on the locking diff, relatively forward brake bias and more things that would make the car easy to drive but not necessarily fast._Our strategy for this lap would be to brake as late as possible, slow down enough to rotate the car sufficiently and point it towards the exit, sacrificing mid corner speed to line up for a late apex and hard acceleration, since the diff could easily handle the sudden burst of power the way it was configured. After taking a couple of laps to familiarize ourselves with the track's intricacies and what would have to be done to make the most of the default setup we manage to clock in a 1:57:034, just under three and a half tenths slower than the pole time. For the reader's comprehension, below is what the full default setup looks like.

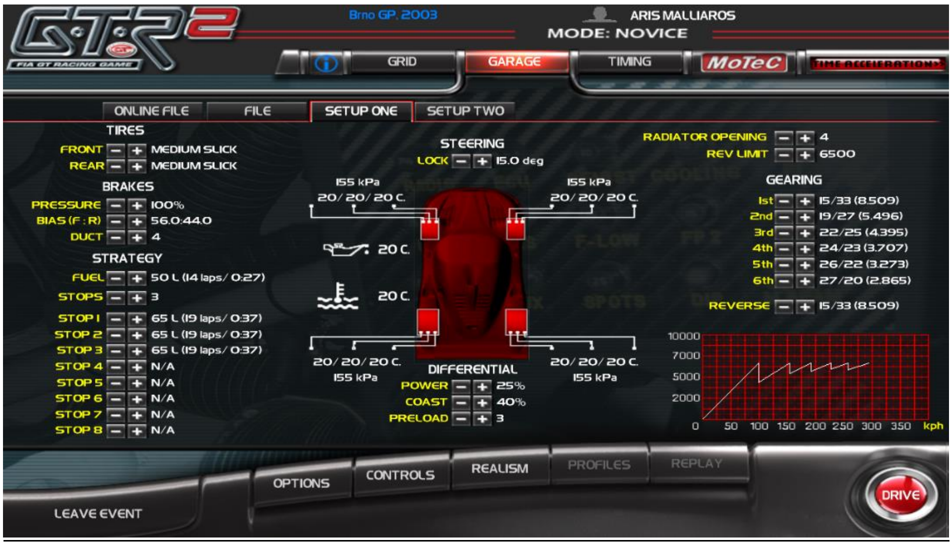

Fig. 1 First page of the default setup

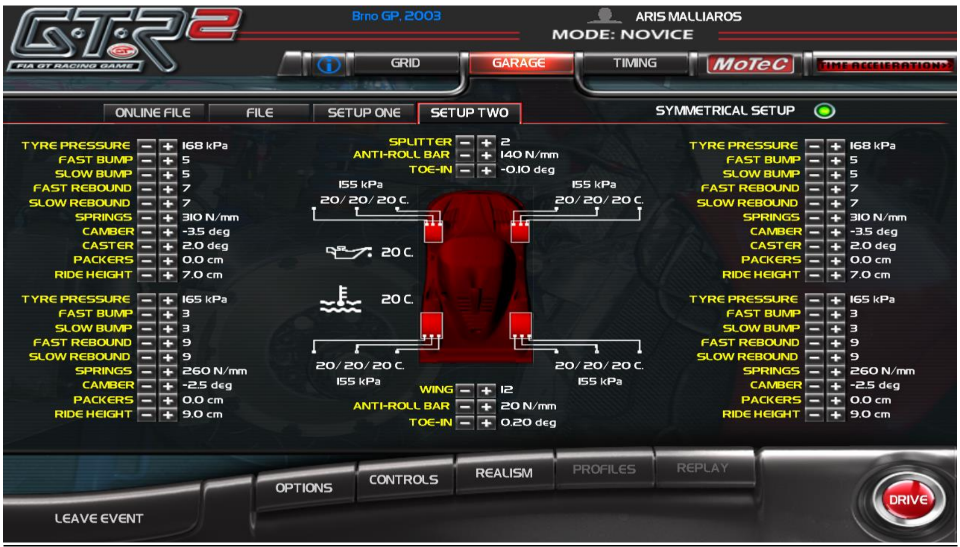

Fig. 2 Second page of the default setup

GEARING

We all know (and sometimes maybe even boast about) the horsepower of our cars. The reality is, that specific number is the peak horsepower output, only achieved at a very small range of our engine's operating window of revolutions. This means that for a car to be usable at a plethora of speeds, a device called the transmission or "gearbox" that modulates the engine speed in relation to the speed of the vehicle is used. It essentially allows the driver to be in the part of the power band he chooses for any given speed. In a racecar like the one studied here the correct selection of gear-ratios can easily be the difference between the glory of victory and the agony of defeat.

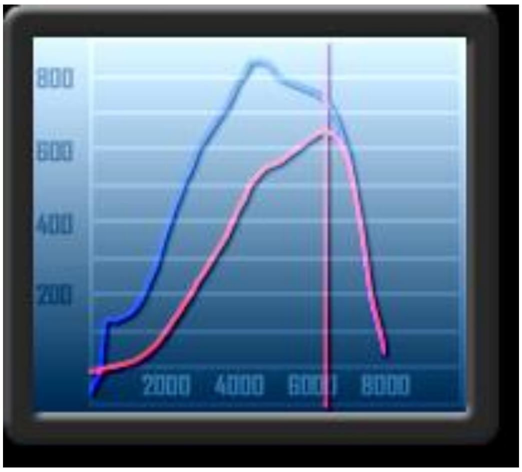

Fig. 3 The GTS-R's Power Band as presented by GTR-2

The GTS-R utilizes a standard for the time six-speed manual gearbox. Pictured below are the ratios as they came in the stock setup and their gear-speed chart

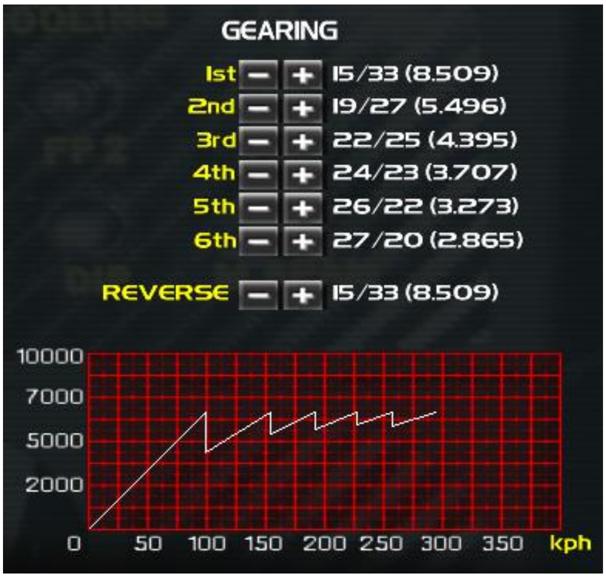

Fig. 4 Stock gears and gear-speed chart

The first thing that was immediately apparent while driving the baseline lap was that the gear ratios, perhaps expectedly were completely wrong. On corner exit a low gear would more often than not be too close to redline while the next gear would be hundreds of rpm below the favorable part of power band, losing out on acceleration. Furthermore coming into a braking zone we would miss out on a sizable part of the gear before having to slow down for the corner, and on the longest straight the car wouldn't come anywhere near its top speed for the gearing. Looking at the data log confirms our suspicion.

To fix this we shall write a MATLAB script that would read the log file after we convert it to a .mat format , and compute a more fitting set of ratios using the speed readings at braking points and corner exits, that would enable the driver to enter a braking zone right on the top of the power band, exit a corner right before the peak of it and leave nothing on the table on the long straight. Down below is a link to said script:

The gearing MATLAB would come up with is this:

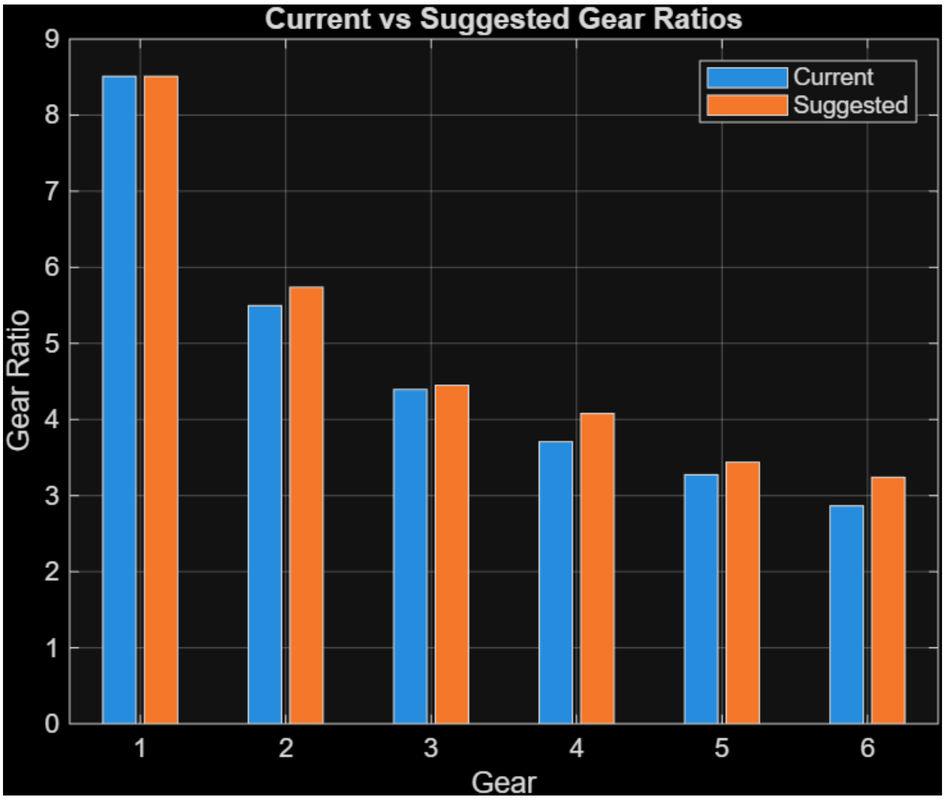

Fig. 5 MATLAB corrected gearing

We observe an increase in ratio across all gears but first which is not used during the lap. We shall also raise the rev limiter by 100 rpm to compensate for the extra top speed gained via more initial acceleration on corner exit due to the better gearing, since the gearing MATLAB computed was adjusted for the speeds of the baseline lap and not the lap the car would now be able to perform. Eventually since the changes the car will undergo will boost its performance everywhere around the lap, the gearing will be re-evaluated by the end of this examination.

After implementing the changes to the car it is now able to clock in a time of 1:56:114, a massive improvement of 0.920 seconds over the baseline lap. Looking at the log data we can confirm that the bulk of the improvement came from straight line speed improvements. A MATLAB script that plots the speed of the improved lap and overlays it onto the baseline shows the straights were speeds were higher after the revision highlighted in green:

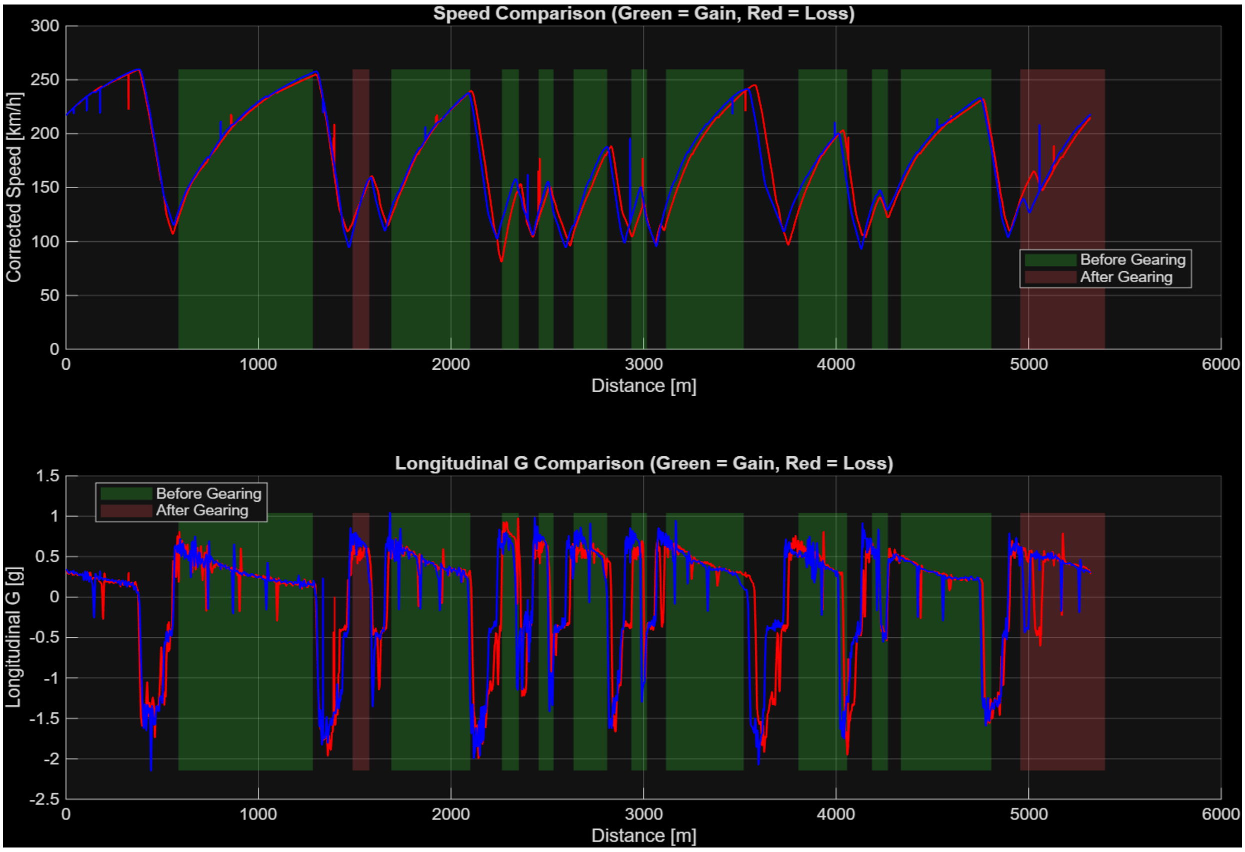

Fig. 6 Comparison of straight-line speed before and after changing the gear ratios

The areas highlighted in red, meaning the baseline lap was faster there, more than likely stem from poor driver performance rather than a bad setup.

In the perfect world that is sim racing that is a job well done. Sadly though, if we want this examination to hold some value in the real world, we have to look at some other parameters that present themselves due to this gearing change. Since we now achieved staying more consistently and longer at the top of the power band, which like vitrtually all racecars sits at the top of the rev range, both the engine and its oil will now operate at a higher themperature and the fuel consumption will also be affected for the worse.

Here is a log file showing both fastest laps overlayed on top of each other, the baseline represented by the white lines in each channel.

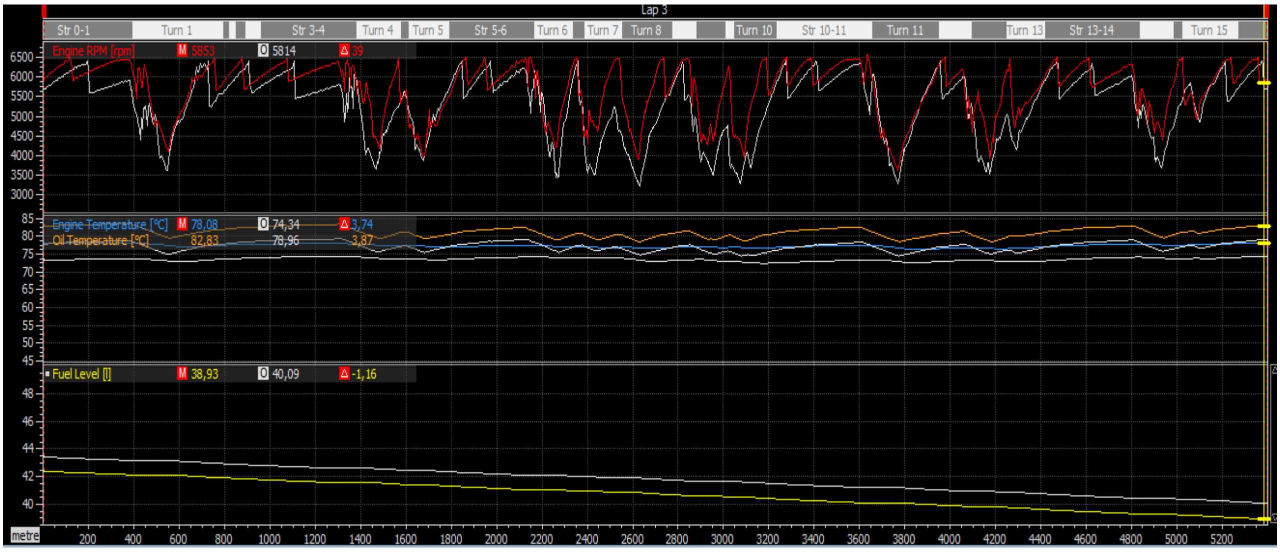

Fig. 7 Side effects of shortening the gear ratio

As is clearly visible, the engine now consistently operates at a higher rpm window which in turn causes the engine and oil temperature to rise by 3.5 to 4 °C. Another side effect is the fuel consumption which just in this one lap was greater by 0.13 liters compared to the baseline.

Obviously in the confines of this thesis, these findings serve no more than a mere observation, but as was said previously, in real life these are drawbacks that could be pivotal in the long term performance of a racecar, especially one like the GTS-R that was involved in plenty of endurance racing. As the saying goes, to finish first, first you have to finish, and a hot running thirsty engine will be of no help to that.

DIFFERENTIAL

In order to go around a corner; preferably quick, it is essential that the speed and so the power between outer and inner wheels is regulated. All cars have differentials but in a racecar application we have to look for something more particular than what is in your daily commuter. The limited slip differential makes sure it provides power in the splits necessary for both wheels to have traction and that is what we aim to configure for maximum performance output.

Below is pictured a clutch diff, similar to what could be found in GT cars in the era the GTS-R competed.

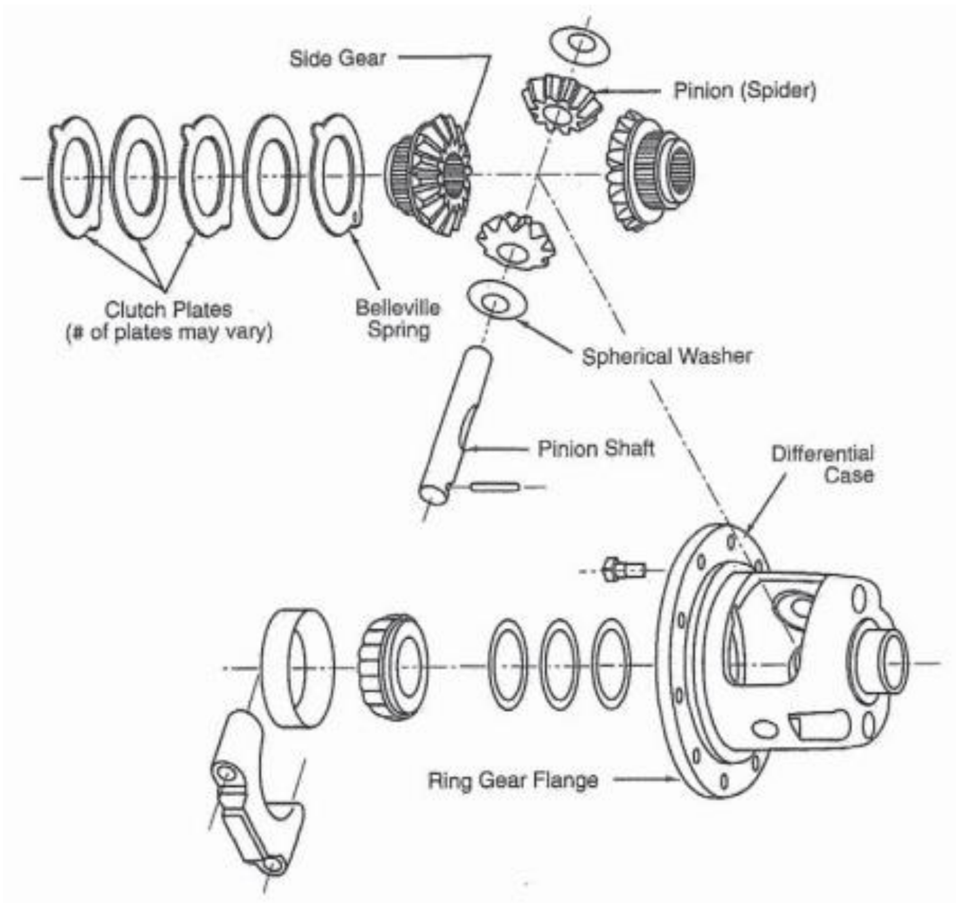

Fig. 8 Clutch plate differential

In GTR-2 ,as would be expected, the options available to us regarding the diff are the power and coast ramps, which determine what percentage of power is sent to the outermost wheel under power and coasting respectively, and preload which determines how easily the differential will lock up.

The default configuration of the diff is:

- Power at 25%
- Coast at 40%
- Preload at 3

Understandably, in order for the game to provide an easy platform as a base, these settings look very conservative and the driving feel backs it up. Very stable under braking, predictable mid corner and really good traction on exit, even with abrupt throttle application. On the downside, the car generally struggles to rotate in all states, braking, coasting and accelerating. This can be fixed by upping the percentage on the ramps and lowering the preload up to the point the car becomes too unstable under braking or starts struggling for traction. There are many ways the telemetry will back up our progress. For a start we shall determine whether we are moving in the right direction by using some more vague but absolute metrics and to complete the optimization we will dive deeper on more focused solutions.

You win by being faster so the ultimate determinant of progress in racing is speed. This is what we shall look into first. After a couple of revisions, the settings that would not only perform the best but also feel like the best compromise between speed and compliance are as follows:

- Power at 40%
- Coast at 55%
- Preload at 2

The lap we are able to perform after the changes clocks in at 1:55:324, a sizable 0:790 seconds over the prior best. Obviously the changes were favourable and to see how exactly they panned out we shall write a MATLAB script that compares the corrected speed of both laps at the apexes using the actual speeds the log collected at for a rough approximation of the gains.

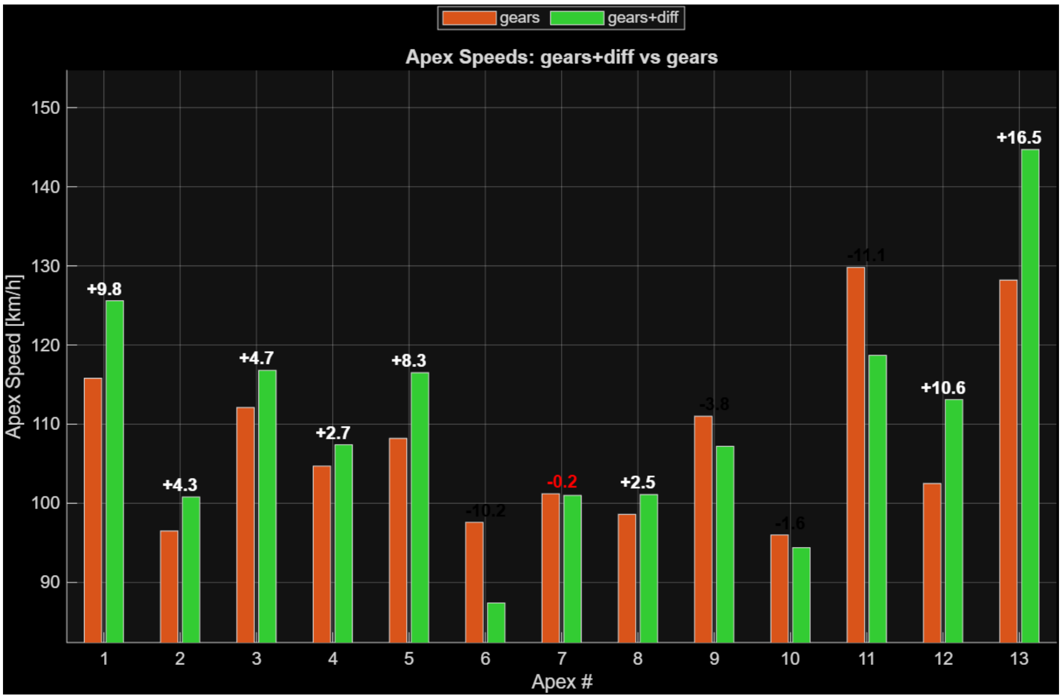

Fig. 9 Apex speed comparison between before and after tuning the differential

As we can see, the changes are mostly positive, with the apexes where the improved lap was slower stemming entirely from driver error. Here is a look into a part of the log that proves exactly that:

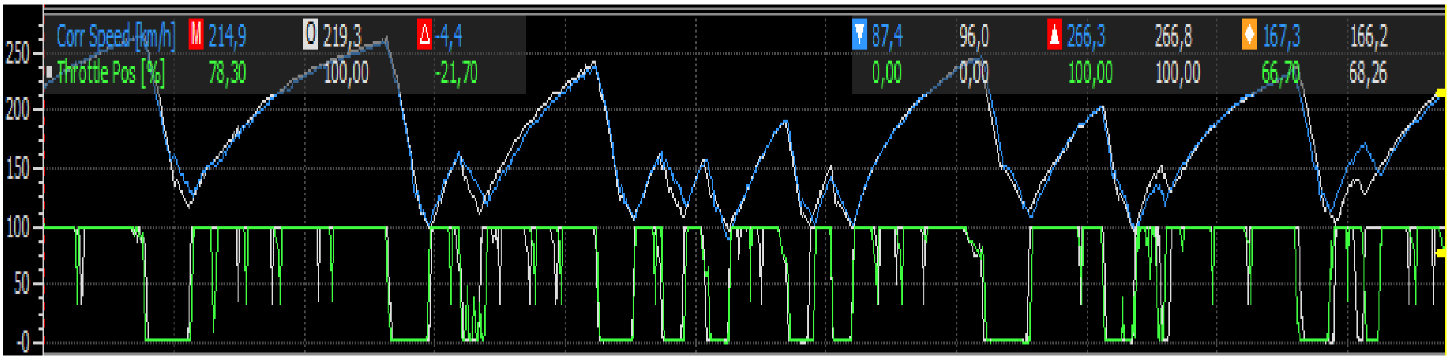

Fig. 10 Driver errors on the improved run

Overconfidence led to braking later going into apexes six and nine causing a excessive loss of speed on the apex so that the exit would not be compromised. At apexes ten and eleven, “choppy” throttle application and overall indecisiveness led to serious loss of time.

Overall though, the car felt very positive both in going through the corner and exiting it applying more throttle more confidently. It felt more controllable in a way of confidence inducing compliance rather than predictability and simplicity in its behavior like before. That said it was more than stable enough in the braking zone, still providing the consistency needed to go lap after lap chasing a good time.

Since we are now positive we are moving into the right direction, we shall employ some more focused methods to come to a definitive answer about out diff’s settings. We will keep moving the ramp percentages up until the car slows down and we are going to find the correlation between the loss of speed and the behavior of the badly set up differential.

Already going to more aggressive settings of:

- Power at 45%
- Coast at 50%
- Preload at 2

looked like a misstep, with the car not only slowing down to a 1:55 but also inheriting inferior handling. The cornering speeds did not improve and the exits became significantly slower with the rear end unable to find traction. We shall write a MATLAB script that compares rear wheel speeds during steering of more than 10 degrees to either direction. If the wheel speed during those occasions is practically identical, then the diff is locking up, the wheels are more than likely losing traction and we are losing time. Indeed, the script concurred that the slowest lap presented a locked diff for 50.84% of the time while in compared to just 32.68% for the settings that produced the quicker laptime, a definitive answer to what the diff’s exact settings should be.

AERODYNAMICS

It is fair to say that even though both now and historically aerodynamics was one of the least understood sectors of race car engineering, the importance of them though was apparent immediately. Affecting or working in conjunction with pretty much every aspect of a racecar, it's not hard to see why aerodynamics is so pivotal to performance. Straight line speed, cornering speed, fuel economy, cooling, suspension loads and so on and so forth, all can be improved upon with a good aerodynamic design.

Looking at Fig. 9 we notice something particularly interesting; nine out of the thirteen apexes are taken roughly between 100 and 130 km/h. This means that a singular fixed angle that the GTS-R's wing devices can be selected to have, will be equally as effective for most of the lap. This will make our job significantly easier.

Regarding aerodynamics, GTR-2 has three relevant settings:

- Splitter
- Rear Wing
- Cooling

Given that the cooling settings are aimed more at the sustainability of the race car, which is not the subject of this thesis, rather than raw speed, in fairness to previous runs shall not be altered.

Splitter is the device that produces more negative lift (or downforce) on the front axle of the car, resulting in more lateral grip. Already being set to its most aggressive value of two, from the driver's perspective we don't wish to reduce our front end "bite" to any lower than it is now so this too shall not be altered.

We will instead focus at tuning our rear wing, the device that adds downforce to the rear axle of the car. Also being set at its most aggressive value of twelve, we will aim to extract some more straight line performance by lowering the angle of attack.

Fig. 11 Airflow over aerodynamic device

After experimenting with various settings, the one that manages to produce a positive outcome is the wing set at nine, with the time of 1:55:103, an improvement of 0:221 seconds which admittedly is not as significant as what we've seen so far but still a step to the right direction. Furthermore the car's behavior did not change significantly if at all.

The importance of this change in the improvement of lap time will be measured simply by comparing the speeds the car managed to get up to before entering a braking zone. For this, we shall create an Excel sheet where the user manually enters ten top speeds collected from the log file and compares them. This is what was found:

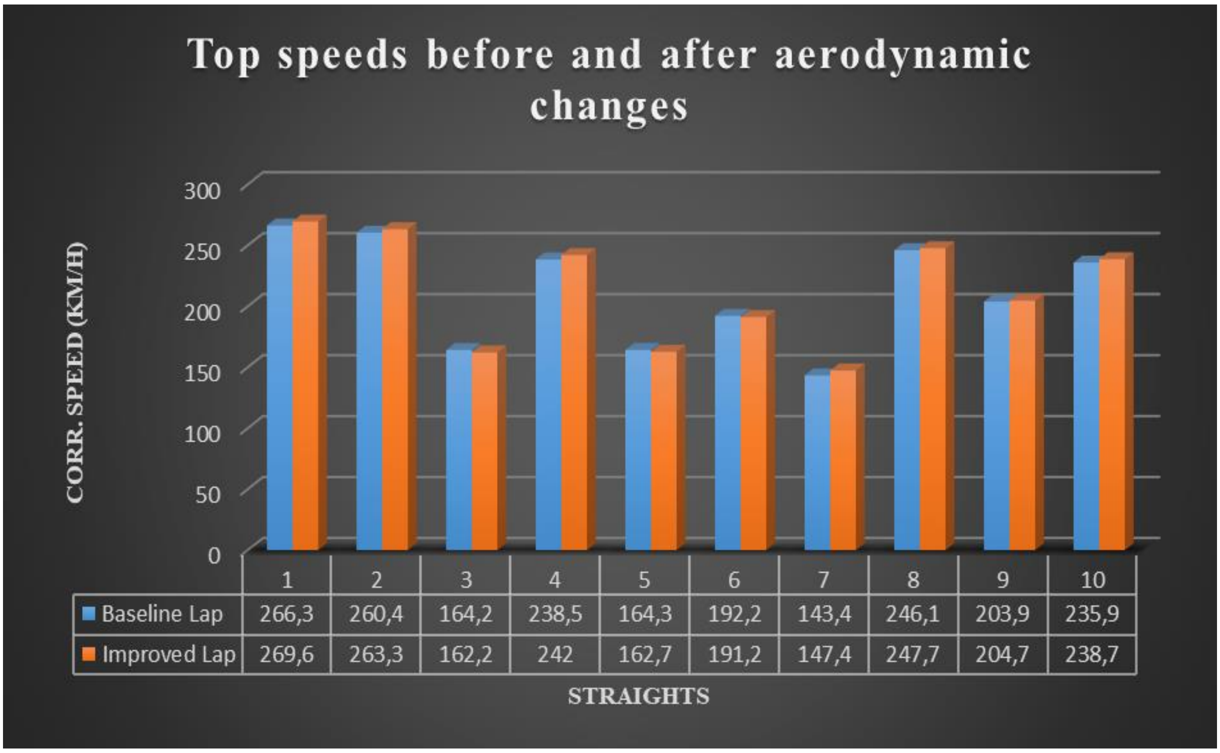

Fig. 12 Top speed comparison before and after the aerodynamic changes

Based on this we can absolutely attribute the gain of lap time to the aerodynamic changes we deployed. Just like other comparison the few occasions where it looks like speed was lost is due to driver error, in the same way as before, but in this case more apparent than ever since the optimization brought small change and lack of driver performance could more easily be interpreted as a mistake in the setup.

BRAKES

In racing, most overtaking opportunities are found in the braking zones. Between two race cars battling, the one more daring to push the envelope further will be victorious, provided of course he can stop in time. This is why the braking system's optimal performance is so vital both for pure lap time and wheel-to-wheel racing.

Below are pictured the caliper and rotor of a LMGTE-AM car:

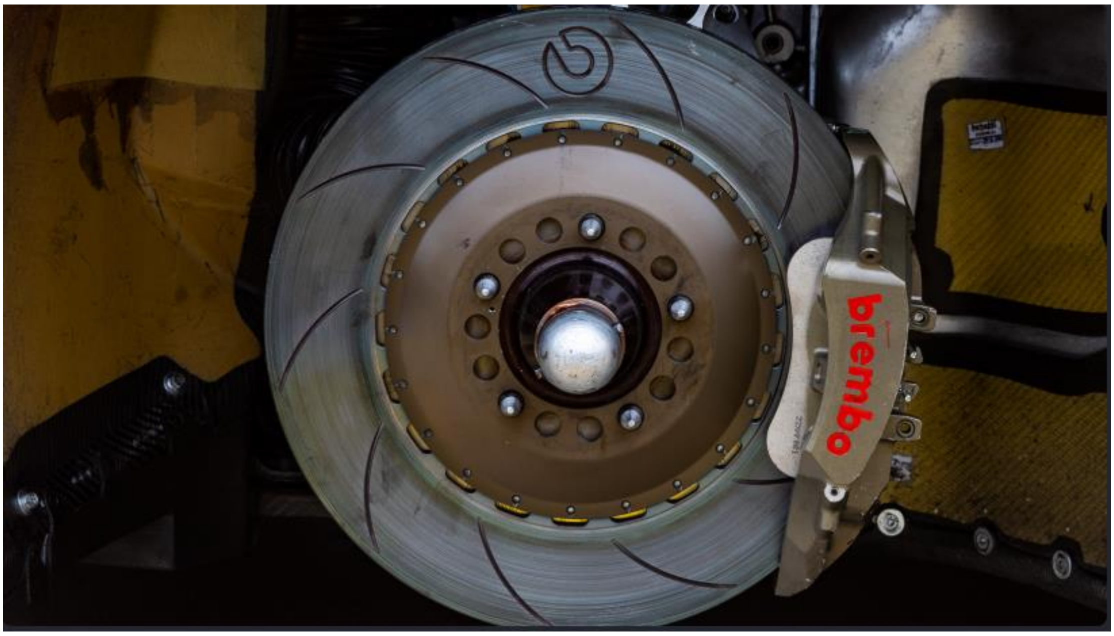

Fig. 13 Braking system

In GTR-2, the available options regarding the braking system is brake pressure and front/rear bias. Since we use a controller as the input device we shall not be bothered by the pressure settings, seeing as they won't affect anything.

Instead, we shall focus our attention on the brake bias. What the brake bias does is it distributes the pressure between the front and rear brakes. More pressure at the front means more stability at the cost of less rotation on corner entry and vice versa more pressure at the rear means sacrificing stability for the purposes of rotating the car coming into the corner.

The default setting for the GTS-R is 56:44 front to rear which is fairly standard for a GT car with a conservative setup. But of course we shall make the car faster an since it still is more than stable enough on braking we shall sacrifice some of that stability for better rotation. After many laps of trial and error the best combination of a sustainable yet fast setup is a bias of 52:48 front to rear that ultimately is able to produce a lap time of 1:54:045, more than a second over the previous setup, so we can already say the changes were certainly positive but we will investigate how they contributed anyway.

Looking at lateral and longitudinal acceleration, two things become apparent; in a braking zone, the car :

- Generates lateral acceleration sooner and has a much smoother log curve, meaning rotation started earlier and the load shifts sides more naturally, providing more confidence for the driver.
- Generates more gradual and smooth longitudinal traces, meaning the brake balance is more optimized and we did not miss out on stability as we feared we would, backed by the driver input.

Looking at the steering wheel angle and gyro yaw angle channels we can see steering initiated earlier, facilitating for better rotation and the gyro yaw angle has a much smoother trace, meaning the car was more stable while cornering, indicating at the smoother transitioning mentioned before.

Here are some characteristic screenshots of the longitudinal, lateral acceleration and gyro yaw logs in turn three indicating at the above:

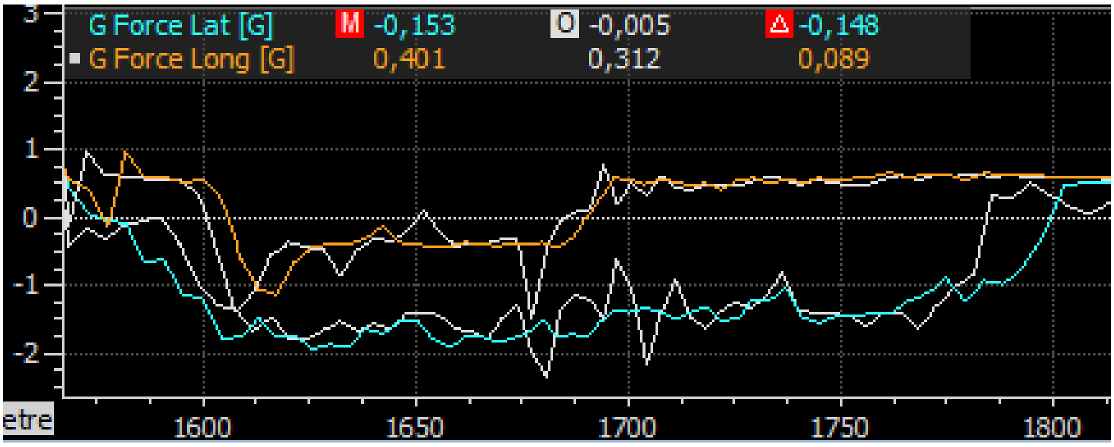

Fig. 14 Lateral and Longitudinal acceleration in turn 3

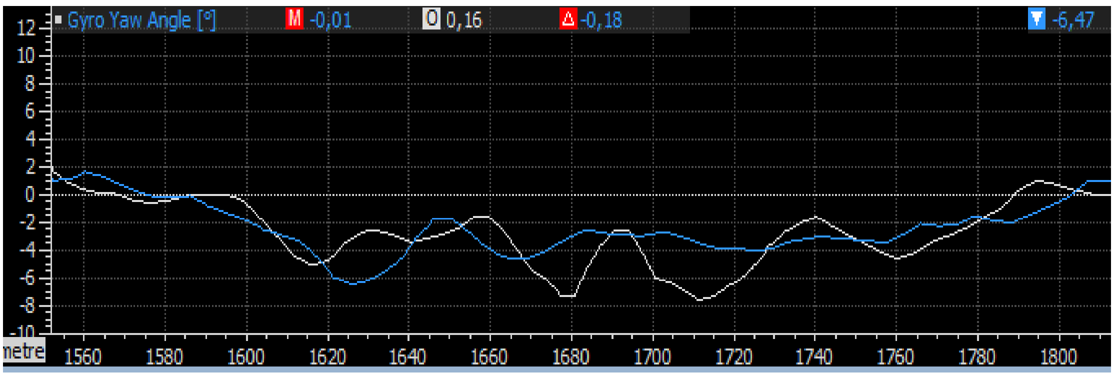

Fig. 15 Gyro yaw angle in turn 3

SUSPENSION

Last but certainly not least, is suspension. The suspension is responsible for controlling the motion of the body as it traverses uneven road surfaces and manages the shifting loads applied to it. This will be our most complex modification of the setup as it consists of more configurable parts than the previously studied aspects of the car. It makes sense that we have a logical sequence of parts configured depending on the role of each one. That sequence shall be as follows:

- Springs & Anti-Roll Bars
- Tire Pressure
- Ride Height
- Slow Damping
- Fast Damping

- Springs & Anti-Roll Bars

Since springs and anti-roll bars are the two devices responsible for controlling most of the car's movement, they shall be looked into first. Their roles not to be confused, springs determine the total amount of weight transfer, since weight transfer depends on Center of Gravity, height and spring stiffness, and anti-roll bar**s** determine how that transfer is shared between front and rear.

Fig. 16 Typical front anti-roll bar

Looking at the default springs and ARB settings inGTR-2, we are presented with a conundrum. The rear spring is at its minimum allowable stiffness. Nevertheless, this shall not deter us since our plan is to actually stiffen the rear end. The previous modifications on the differential and brakes have made the car more responsive and capable during turn in but it came with a cost. Though still controllable, the car is now much more highly strung and unforgiving. We shall aim to improve on this without losing out on performance output and a good way to do that is to make the rear relatively stiffer than the front to make the car more predictable during the transient state, by allowing the rear end to rotate more freely. Theoretically, a softer front end should also provide more mechanical grip at the cost of some response.

These are the default settings:

- Front springs: 310 N/mm
- Rear springs: 260 N/mm
- Front anti roll bars: 140 N/mm
- Rear anti roll bars: 20 N/mm

These settings are a typically conservative setup for a front-engined car.

After testing one altered parameter at a time, we come to the conclusion that these are the most suitable options:

- Front springs: 300 N/mm
- Rear springs: 310 N/mm
- Front anti roll bars: 90 N/mm
- Rear anti roll bars: 50 N/mm

The overall result of these changes is an improved time of 1:53:819, a gain of almost a quarter of a second over the previous best time. Looking at the data log, we see a clear pattern: loss of apex speed but net gain on exit. Below is the Variance channel proving that.

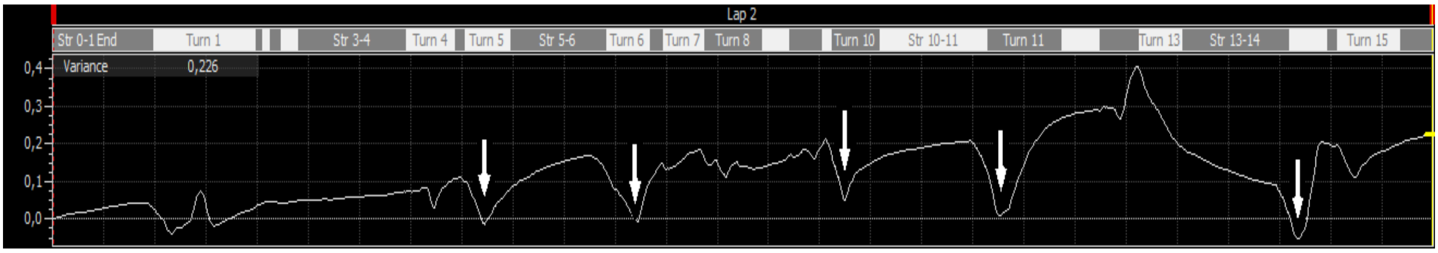

Fig. 17 Variance channel

Pointed with the white arrows are the apexes, clearly losing time there that was then immediately gained. In fact, the improved lap was 0.4 seconds ahead at turn 13, before an overenthusiastic application of throttle drifted the car wide enough for the outside rear wheel to clip the grass, hence the time loss. We also can look at the acceleration channels to see how the traces are generally more gradual and smooth, hinting at improved stability.

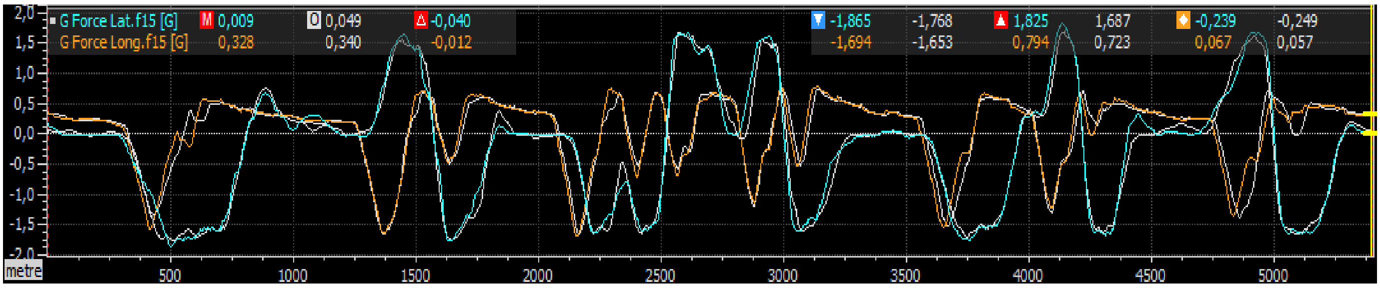

Fig. 18 Filtered G traces

Tire Pressure

Tire grip determines how much force can be transferred before sliding occurs, making them the foundation of handling, stability, and performance. Their behavior depends on factors like load, pressure, temperature, and slip angle, all of which influence the size and shape of the contact patch. Even small changes in these parameters can drastically alter balance and responsiveness, which is why understanding tire dynamics is essential for optimizing any racecar setup.

Now that the loads on each corner are closer to being finalized, lets look at tire pressures. Tire pressures significantly impact the handling characteristics of a tire and therefore of the car as well, on top of being a key factor in the temperature they hold and the way they deform and wear.

Not necessarily looking for an improvement of speed, setting the correct tire pressure is mostly aimed at “taming” the car’s behavior in a similar fashion the spring and arb settings did since as mentioned before in the search of speed the car is now more temperamental than ever before. These are the default tire pressure settings:

Front: 168 kPa

Rear: 165 kPa

Since we have softened the front anti-roll bar, we will slightly increase the front tire pressures to compensate for the additional compliance and to sharpen the initial steering response by reducing sidewall deflection. At the rear, we will lower the pressures slightly to increase the contact patch and promote greater rotational stability, as the added sidewall flex will make the rear end more progressive and forgiving at the limit.

After some deliberation the pressures with the optimal result are as follows:

Front: 170 kPa

Rear: 161 kPa

Ultimately, the lap time we manage to extract from these settings is 1:53:962, just over a tenth slower from our best time. But as stated previously, this was more of an exercise in drivability rather than pure speed. Our target was achieved, with the car now instilling much more confidence without any significant tradeoff. The front end is still as responsive and the rear feels more planted mid corner. Looking at the tire data nothing particularly troublesome appears regarding performance. The second lap is actually about 0.2 seconds faster for the first half of the lap, there the temperatures and pressures look higher than the first lap compared to the second half where they are pretty similar. Sadly, this info can be no more than speculative since we don't really have any information on the performance envelope of the tire compound. Here are screenshots of the data log concerning both tires and more general information.

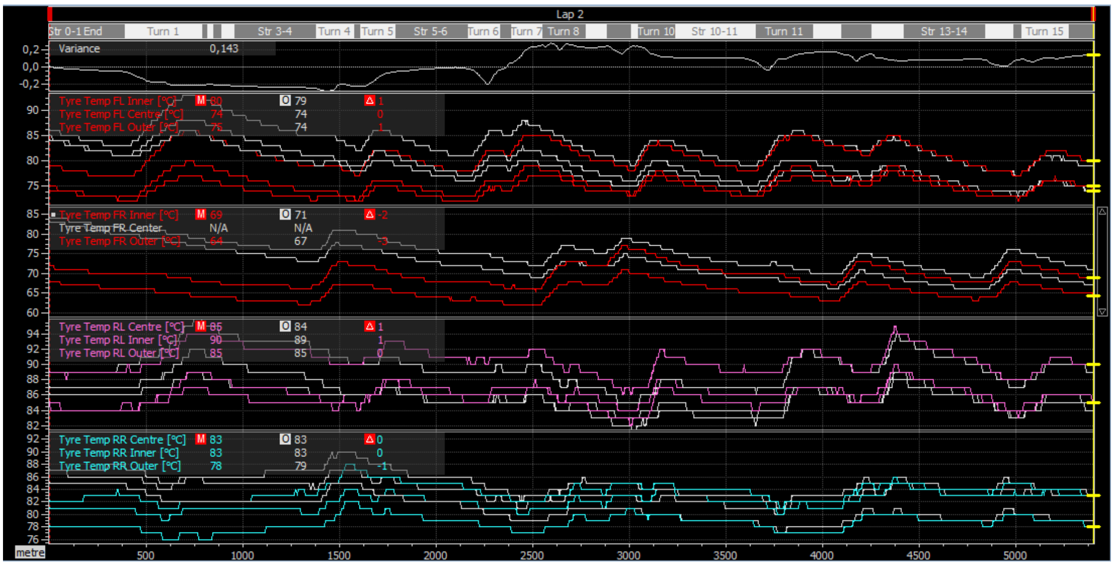

Fig. 19 Tyre data

Fig. 20 General data

- Ride Height

A car's ride height effects a lot of things: lower height can increase downforce and lower the CoG to decrease body roll, but too much will make the air underneath stall and could cause the suspension to bottom out, rendering it ineffective. In the adjustment of ride height rake should also be considered. Rake is the ratio between front and rear ride height and is called positive when the rear is higher than the front. Positive rake accelerates the air underneath the body which creates downforce, but too much of it will result in front end dive, diffuser stall and overloaded front tires.

The default setting for the GTS-R is:

- Front ride height: 7cm
- Rear ride height: 9cm

After some testing the settings that could produce the best lap time are as such:

- Front ride height: 6cm
- Rear ride height: 6.5cm

The improved lap time is 1:53:589, more than two tenths faster than previously. The car now sits lower and with less rake and the results are predictable. It now controls its weight shifting better thanks to reduced body roll, offering a more linear and predictable driving experience. Furthermore even though the car was lowered, the suspension did not bottom out and the reduction in rake provided some much needed traction out of the corners, once again providing a more manageable behavior.

We shall write a MATLAB script that computes the difference between right and left ride height for the instances of lateral acceleration exceeding the value of ±1 and plots the results of both laps overlayed.

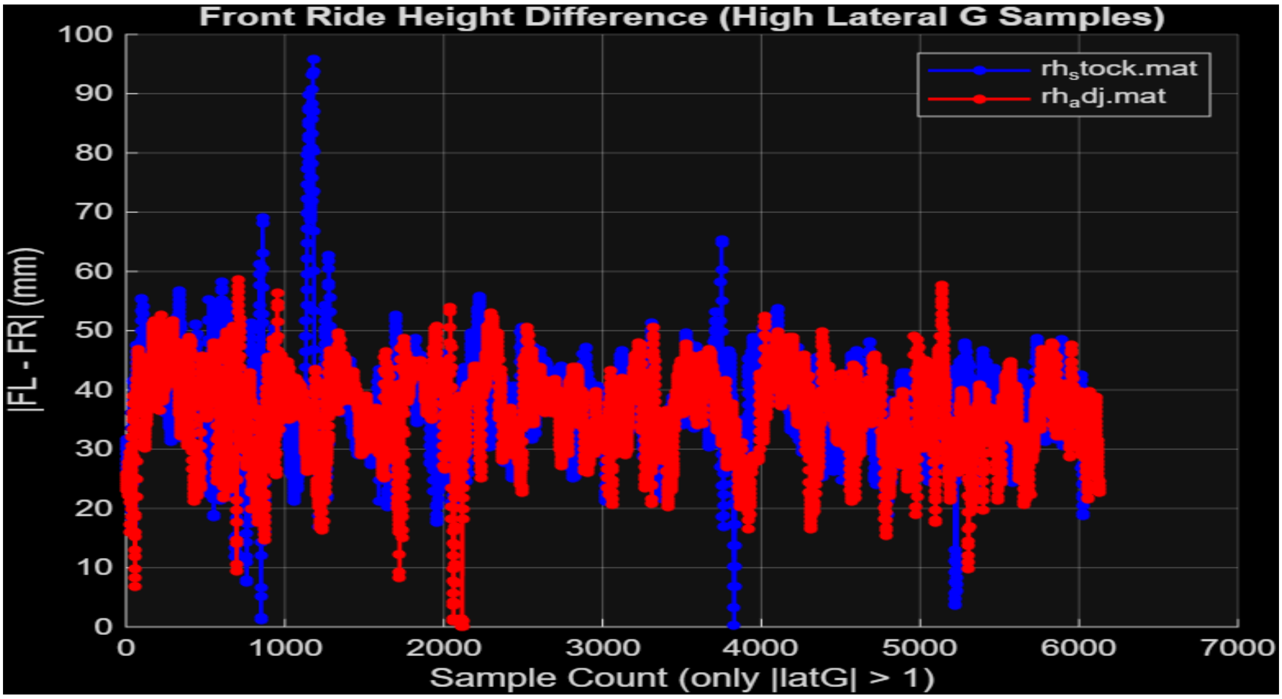

Fig. 21 Front Ride Height Difference

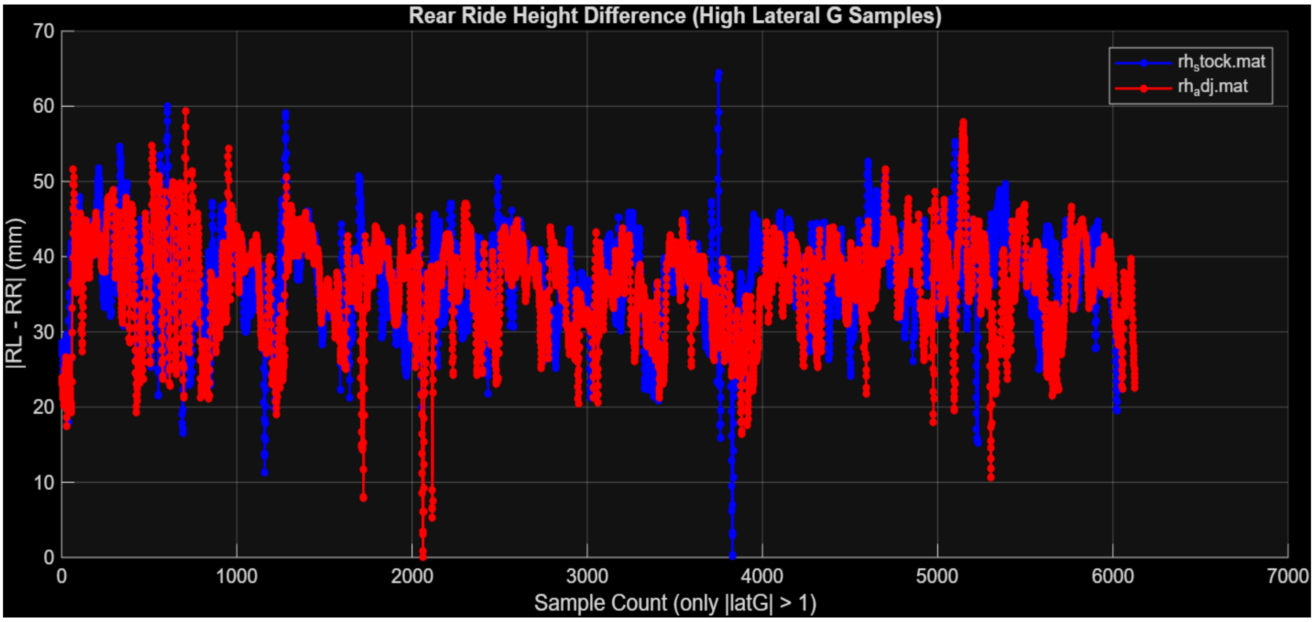

Fig. 22 Rear Ride Height Difference

As, we suspected, under heavy lateral acceleration the body roll is greatly reduced, even at te front were we can recount softening both the springs and the anti roll bars.

Furthermore, looking at the damper position channel we can see no plateau forming at the bottom, meaning the car did not bottom out.

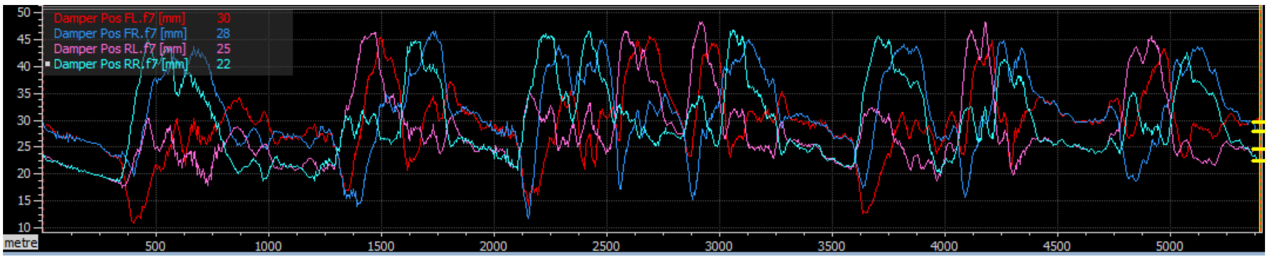

Fig. 23 Damper positions

We can also see just by looking at the variance channel, how reduction in rake reduced apex speed, but increase in traction and improved braking by shifting more weight rearwards more than negated the difference.

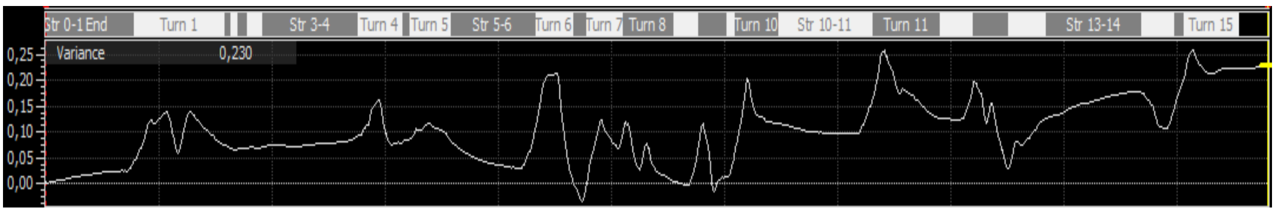

Fig. 24 Variance

- Slow Damping

Dampers are used to slow down the movement of the suspension. There are two distinct aspects when it comes to damper tuning: fast and slow damping. We shall start with slow bumping which has to do with the events that makes the damper move slowly, thus the name. These events revolve around chassis control; body roll, pitch, heave etc. The reason we start with the slow damping is it that it effects the main handling characteristics of the car, whereas the fast damping aspect affects behavior over bumps and kerbs mostly. Both aspects treat the compression and extension of the damper, also known as bump and rebound, differently and as such bump and rebound can be configured separately provided the damper has that possibility.

Fig. 25 Damper

In GTR-2, the default slow damping settings are:

- Front Compression: 5
- Front Rebound: 7
- Rear Compression: 3
- Rear Rebound: 9

Since the slow damper behavior is directly affected proportionally by the spring rates, in other words is the springs are softer so should be the dampers and vice versa, we now what direction to move to. Both compression and damping need to be softened at the front and stiffened at the rear. After testing, the best result is achieved with these settings:

- Front Compression: 3
- Front Rebound: 5
- Rear Compression: 5
- Rear Rebound: 11

We manage to improve the lap to 1:53:332, more than a quarter of a second faster than the previous best .Once again, the behavior of the car improves without any cornering ability lost. To determine whether it was the changes that we brought that improved the lap time we shall use channels such as damper velocity, histogram and FFT.

Looking at a screenshot of the damper velocity channel for the first sector of the lap, we can clearly see how the dampers are generally not reaching the velocities they did before, hinting at a more stable behavior and the tires are contacting the road more consistently, meaning this is possibly a correct change.

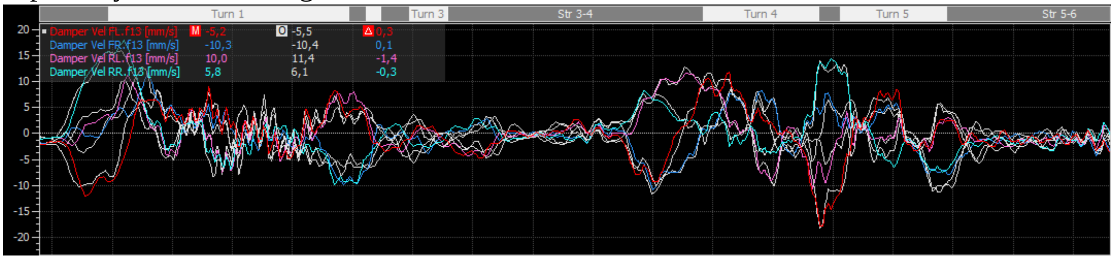

Fig. 26 Damper velocities

Looking at the FFT, we notice how the oscillations at the front end around the area that represents the chassis movements (0 to 0.5 Hz) have been largely smoothed out. This suggests that the front was underdamped, so making the dampers softer was definitely the correct decision. On the contrary, at the rear where we stiffened the dampers we do not notice any prominent peaks meaning we did not go too far.

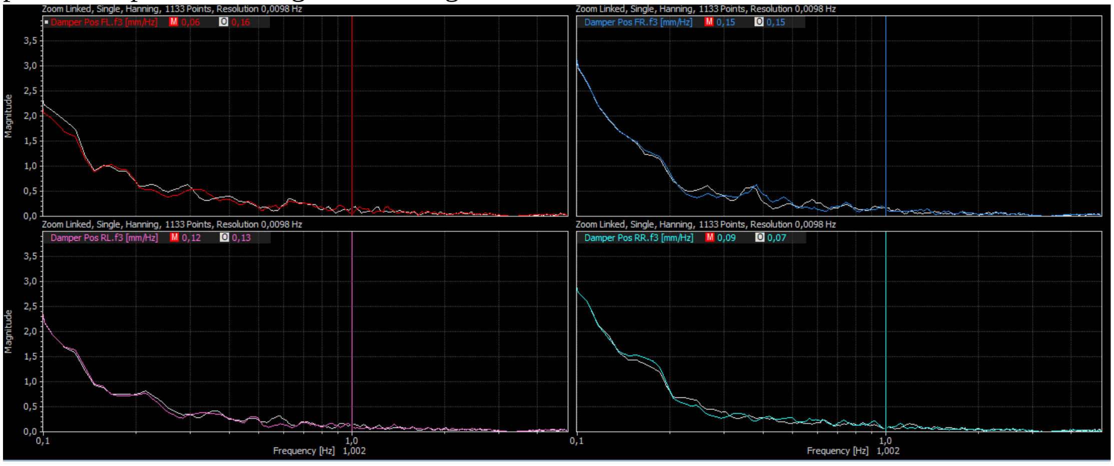

Fig. 27 Damper FFT

Finally looking at the histogram, we notice how we have eliminated the areas where speeds reached around 25mm/s, meaning less sudden events and more consistent tire contact.

Fig. 28 Damper histograms

- Fast damping

Fast damping as the name implies concerns the higher frequencies of the damper i.e. during weight transfer (1-3 Hz) and driving over bumps and kerbs (3-5 Hz). Since Brno is a track with a generally smooth surface (with the exception of some parts on the first sector) and has very forgiving kerbs which we can easily drive over without any complications, we shall stiffen the fast damping, this should also help with improving the car's control.

The default settings for fast damping in GTR-2 are as follows:

- Front Compression: 5
- Front Rebound: 7
- Rear Compression: 3
- Rear Rebound: 9

After testing, the best result is achieved with these settings:

- Front Compression: 8
- Front Rebound: 10
- Rear Compression: 7
- Rear Rebound: 13

The car now feels more precise and manages to absorb bumps better. As a result the lap time is improved to 1:52:942 almost four tenths faster than the previous best. To see whether our changes actually contributed to the improvement, just like the slow damping we shall look into the FFT's and the histograms of the dampers.

Looking at the 1-5 Hz region of the FFT's we can clearly notice how the traces have smoothed out, indicating better body control and bump absorption in the respective frequency regions mentioned before.

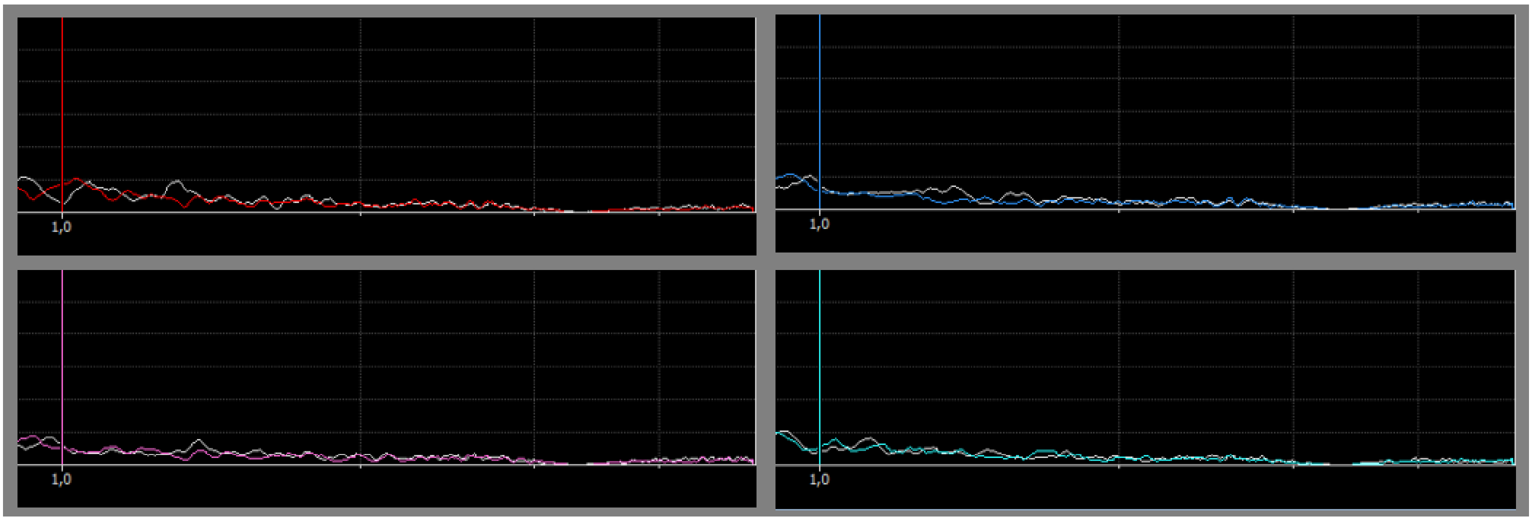

Fig. 29 Damper FFT's zoomed in for the 1-5 Hz region.

Looking at the histogram, we eliminated the faster speeds of 25mm/s, meaning the car is more compliant over the bumps and kerbs as well as during weight transfer.

Fig. 30 Damper Histogram.

This concludes our research into suspension. Through data analysis we succeeded in making the car both more manageable to drive and faster. Collectively we managed to shave off 1:103 seconds from the best time we did prior to the suspension revisions, a massive improvement.

ALIGNMENT

Alignment is the geometry of the wheels relative to the car. The goal of tuning the alignment is to give the car desirable handling characteristics, mainly in accordance with the driver rather than the track. In this thesis we will study two aspects of alignment tuning, that is camber and toe. Camber is the angle of the face of the wheel relative to the vertical axis and toe is the equivalent for the horizontal axis. The perfect camber angle will ensure more and more consistent contact of the tires with the road along with better temperature distribution. Toe fine-tunes turn-in sharpness, stability, and traction.

Starting with camber, since a known suspension geometry provides a correlation between roll rate and camber, we can use Figs. 21 & 22 to get an idea of the direction we need to move towards.

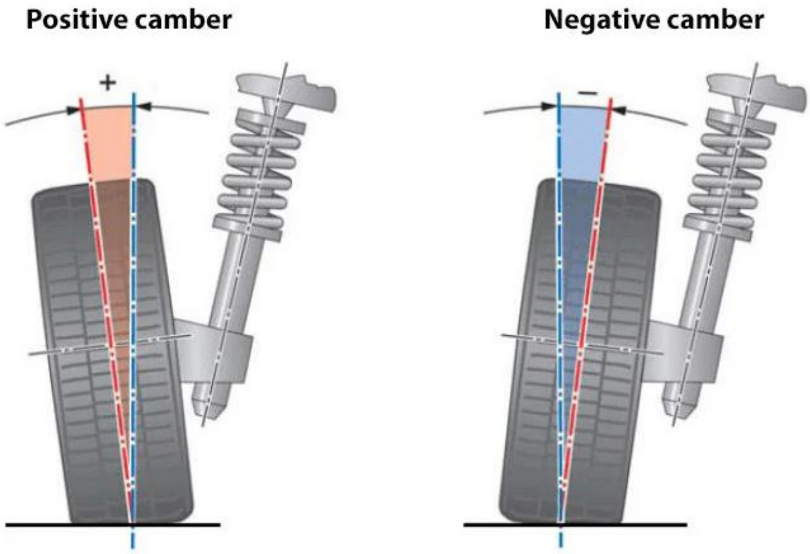

Fig. 31 Camber

Both figures display how the roll rate has been lowered so in theory we need to lower the angle of the camber in order to get the best results.

In GTR-2 , the default camber settings are:

- Front : -3.5^{o}
- Rear : -2.5^{o}

After testing, the optimal settigs are these:

- Front : -3.2^{o}
- Rear : -1.8^{o}

Predictably, the car now feels more predictable and stable thanks to a more consistent tire contact patch. The time we are able to extract out of the setup is 1:52:627, more than three tenths faster than the previous best.

To see whether the changes we implemented are to credit for the lap time improvement, we shall look into the tire temperature channel.

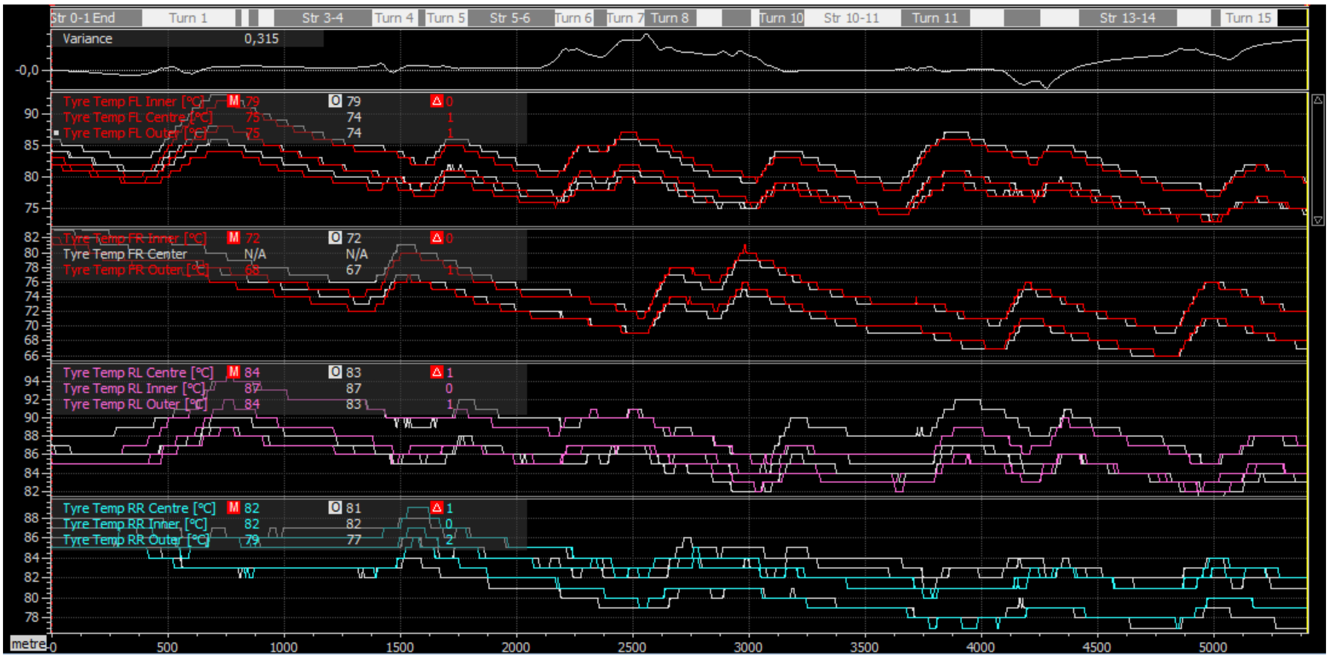

Fig. 32 Tire temperatures

We shall write a MATLAB script that compares the tire temperature differences for each corner between the two laps, distinguishing the high and low load cases with the threshold of ±1g of either lateral or longitudinal acceleration. This is what is reported with Log1 being the baseline:

=== Comparison of inner-mid and outer-mid averages ===

--- FL ---

High load | Log1: inner-mid = 5.54, outer-mid = 0.93 | Log2: inner-mid = 5.59, outer-mid = 1.45
Low load | Log1: inner-mid = 5.20, outer-mid = 0.94 | Log2: inner-mid = 5.03, outer-mid = 1.29

--- FR ---

High load | Log1: inner-mid = 3.27, outer-mid = -0.42 | Log2: inner-mid = 3.05, outer-mid = -0.38
Low load | Log1: inner-mid = 2.80, outer-mid = -0.48 | Log2: inner-mid = 2.54, outer-mid = -0.35

--- RL ---

High load | Log1: inner-mid = 3.49, outer-mid = -0.73 | Log2: inner-mid = 2.92, outer-mid = -0.26
Low load | Log1: inner-mid = 3.73, outer-mid = -0.38 | Log2: inner-mid = 3.16, outer-mid = 0.13

--- RR ---

High load | Log1: inner-mid = 1.33, outer-mid = -2.89 | Log2: inner-mid = 0.89, outer-mid = -2.30
Low load | Log1: inner-mid = 1.05, outer-mid = -3.12 | Log2: inner-mid = 0.66, outer-mid = -2.31

As is clear the tires display smaller temperature differences throughout the length of the tire's contact patch, indicating in a more optimal camber setting.

Link to MATLAB script:

Finally, toe is more of an adjustment adhering to the preference of the driver rather than pure performance through its fine tuning. This is why in this segment we will look into improving consistency and longevity rather than one lap pace. We shall drive five laps with the previous setup and then five more with the toe settings that suit us the best to compare findings.

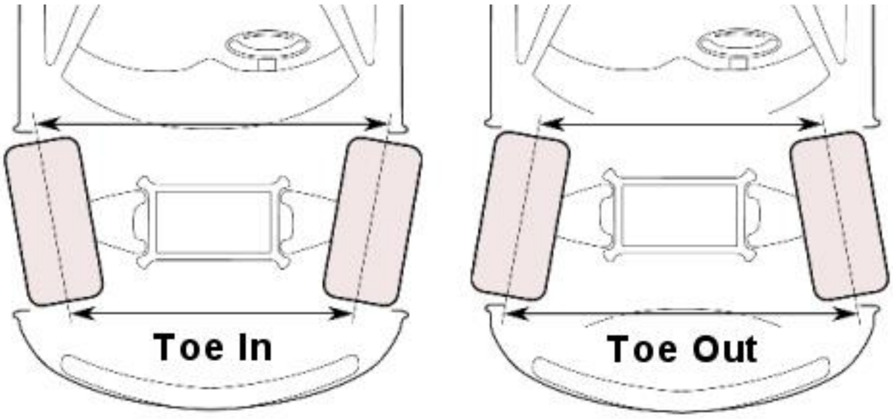

Fig. 33 Toe

On the default toe-in settings of:

- Front : -0.10 degrees
- Rear : 0.20 degrees

We managed to complete 5 laps at a time of 9:29:508 minutes with the fastest lap being 1:53:599 and an average lap time of 1:53:824.

The changes we shall deem as favorable are:

- Front : -0.10 degrees
- Rear : 0.20 degrees

We managed to complete 5 laps at a time of 9:27:958 minutes with the fastest lap being 1:53:039 and an average lap time of 1:53:486.

We conclude that the changes in toe made the car more suitable to our driving style, leading to a better performance over a longer period of time.

REVISIONS

Given how the changes we brought have been so drastic overall, it is very logical to look back at some of the first ones we made and see if they are still as effective as intended. Indeed, the first thing that then appeared immediately to be wrong, does so again. The remarkable gains in corner exits mean the gearing is once again incorrect. Not needing to run the MATLAB script we put together, all we have to do is lengthen sixth gear, which was topping out on the start finish straight. The revision nets us 4.1 km/h more before the car starts braking and an improvement of time that concludes the testing at 1:52:603.

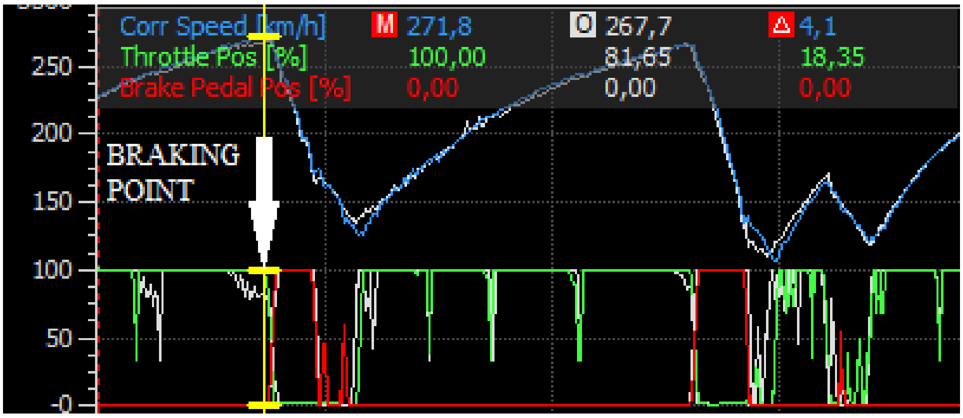

Fig. 35 Braking point

Lastly, one thing that needs to be revised is actually the baseline lap. In the quest of improving the setup it is natural to have gained more experience both for car and track so it would be unfair to say that all the gains have come from the setup improvement alone. For this we revisit the track with the default setup and we manage to clock in a 1:54:596, almost a second and a half over the initial base line lap. We can conclude then that the setup revisions contributed to 1:993 seconds of improved lap time. Below are some general telemetry channels showing the linear gain of time between base and final throughout the lap.

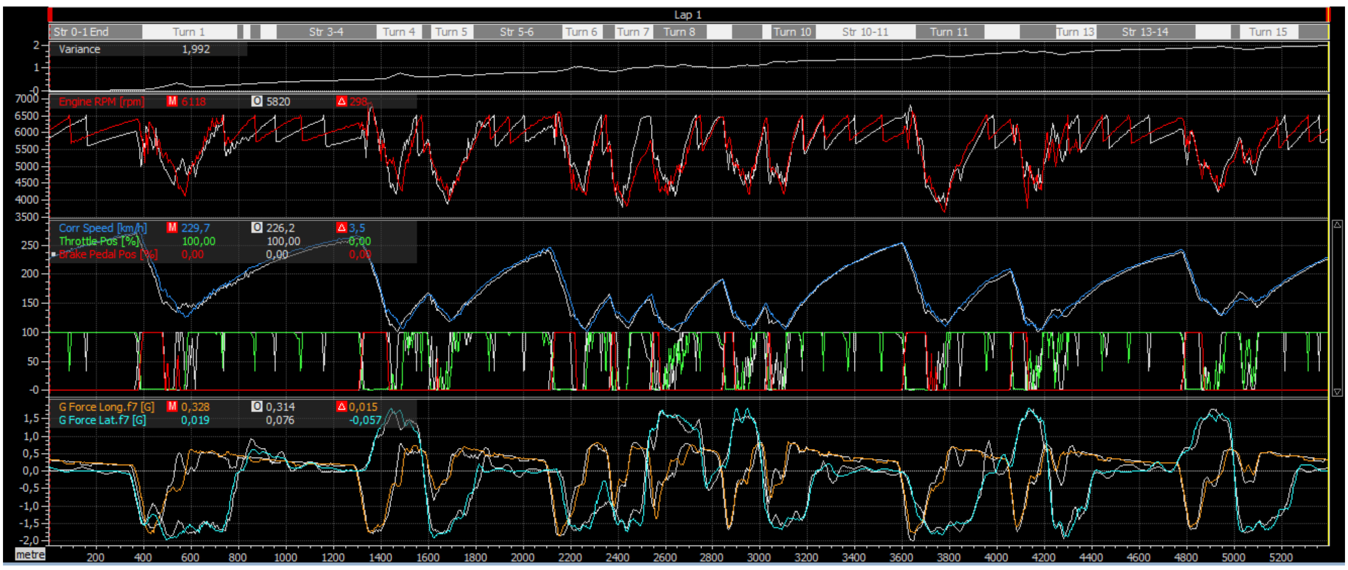

Fig. 34 General telemetry channels

CLOSING REMARKS

In conclusion, we did manage to beat our target time by quite a bit, even though our car was on the hardest tire compound and was carrying 50 liters of fuel. This more than likely means that the model in GTR-2 is slightly incorrect, but our exercise still proved how important telemetry and data analysis is in the modern environment of motorsport where every fraction of time could be crucial. Although not giving the full picture, they provide an objective insight that cannot be provided just by the driver's feedback. Using MoTeC i2 Pro and MATLAB, we were able to not only understand the nuances of how the car performs but also distinguish the path needed to be taken in order to move forwards.

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