Mechanical, Automotive, & Materials Engineering
401 Sunset Avenue
Windsor, Ontario, Canada N9B 3P4
519 253 3000 (2616)
www.uwindsor.ca/mame

Formula 463

Arjun Posarajah - 104980541

Thomas Recchia - 104969537

MECH-4463

Vehicle Dynamics

April 11, 2022

Contents

List of Figures

List of Tables

Introduction

Formula 4463 is an annual competition in the Vehicle Dynamics MECH 4463 course. The challenge this year is to complete the fastest lap time around the track shown in figure 1.1.

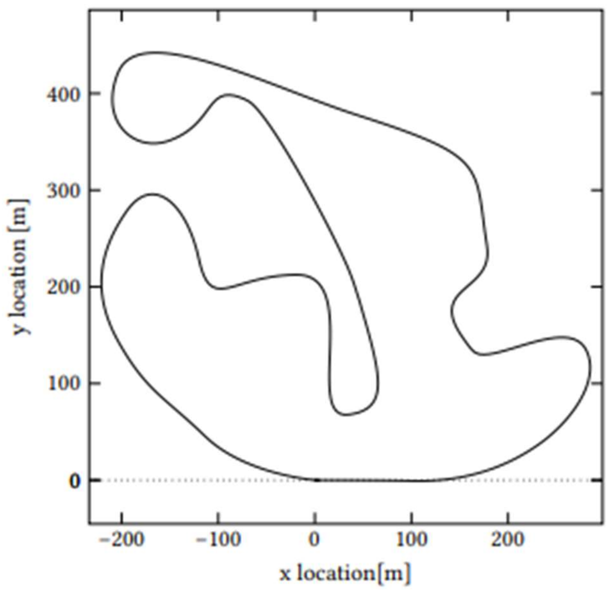

Figure 1.1: Track Map

The vehicle in question is a virtual simulation created inside the EoM software package. A variety of parameters can be edited to increase the virtual car's performance such as the suspension geometry, suspension component stiffness, gear ratios, driver input, etc. This report will focus on the changes made to the stock vehicle file. The reasoning behind each change to the Dennit Racing car will be thoroughly discussed and explained. The Dennit Racing machine was able to achieve a time of 119.00s with a position of 11th place. This report outlines the how and why of the performance of the vehicle relative to its competitors.

Transmission Ratios

The goal of a racing transmission is to keep the engine at or around peak power output over the course of a lap. For the F463 challenge, two engines were available to choose from. The engine the transmission is coupled with is Engine 1, which is the engine with a higher RPM range than its other counterpart, shown in Figure 2.1.

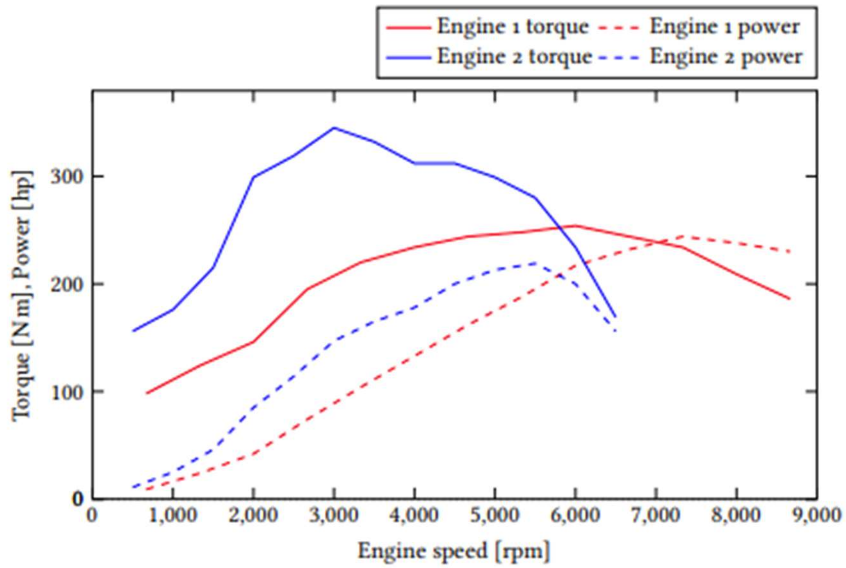

Figure 2.1: Engine Choices

The ideal location for the revolutions to be at for this engine is between 6000 and 8500 RPM. This range will give the best power output for the vehicle, which will help with top speed and acceleration. To meet these requirements a gear box with many relatively short gears is used in conjunction with a high final drive to allow for good acceleration, without being impossible to control. The gear ratios and final drive are shown below in table 2.1.

Gear #	1st	2nd	3rd	4th	5th	Final Drive
Ratio	4.11	3.16	2.61	1.89	1.34	5.5

Table 2.1: Gear Ratios

These ratios maximize acceleration for the highest possible top speed this car can handle, which is around 135 km/h. This is also reflected in the Traction force vs. Speed graph shown in figure 2.2. This gearing shows some short shifting which is applicable in this scenario due to the torque curve of this motor. This gearing helps to maintain the best possible RPM over the course of the lap, shown in figure 2.3. This ensures that the vehicle is always producing an acceptable amount of power on exit of the corners and on straights.

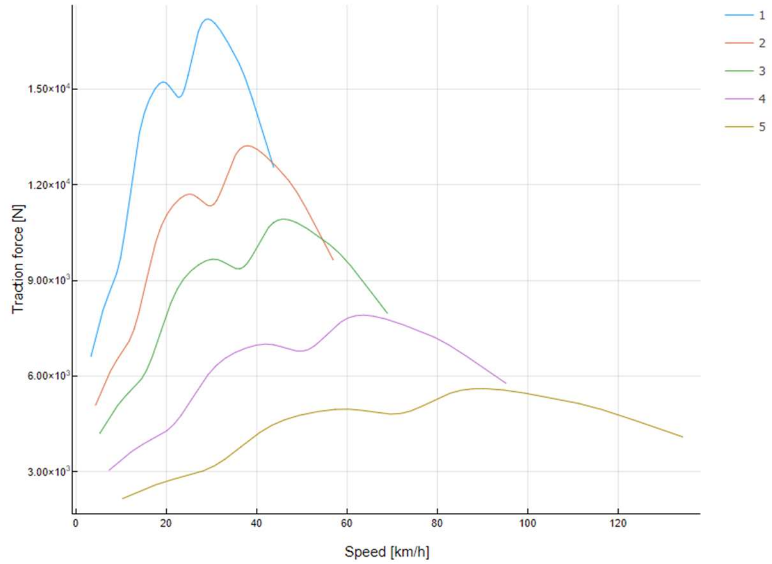

Figure 2.2: Traction Force vs. Time

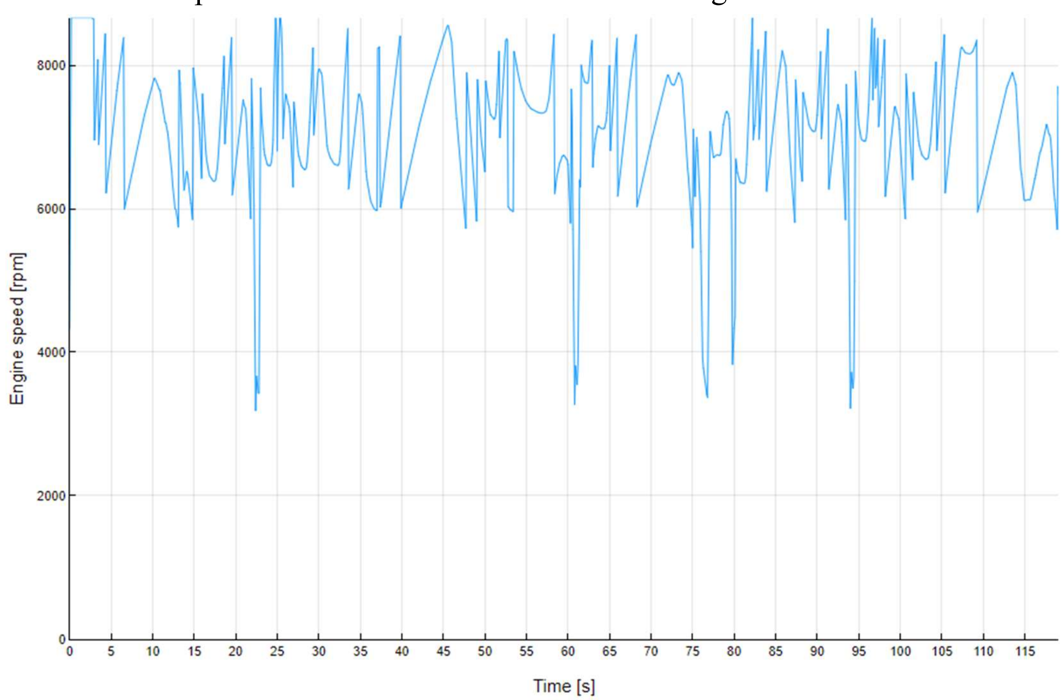

Figure 2.3: Engine Speed vs. Time

As shown, the RPM only drops during extremely low speed corners, but accelerates to an appropriate engine speed very quickly due to the short gearing. It is also crucial to maximize the use of the entire gearbox to ensure that no engine power is wasted. Figure 2.4 shows that all five gears are utilized, while figure 2.3 shows that at no point is the RPM at redline on straightaways.

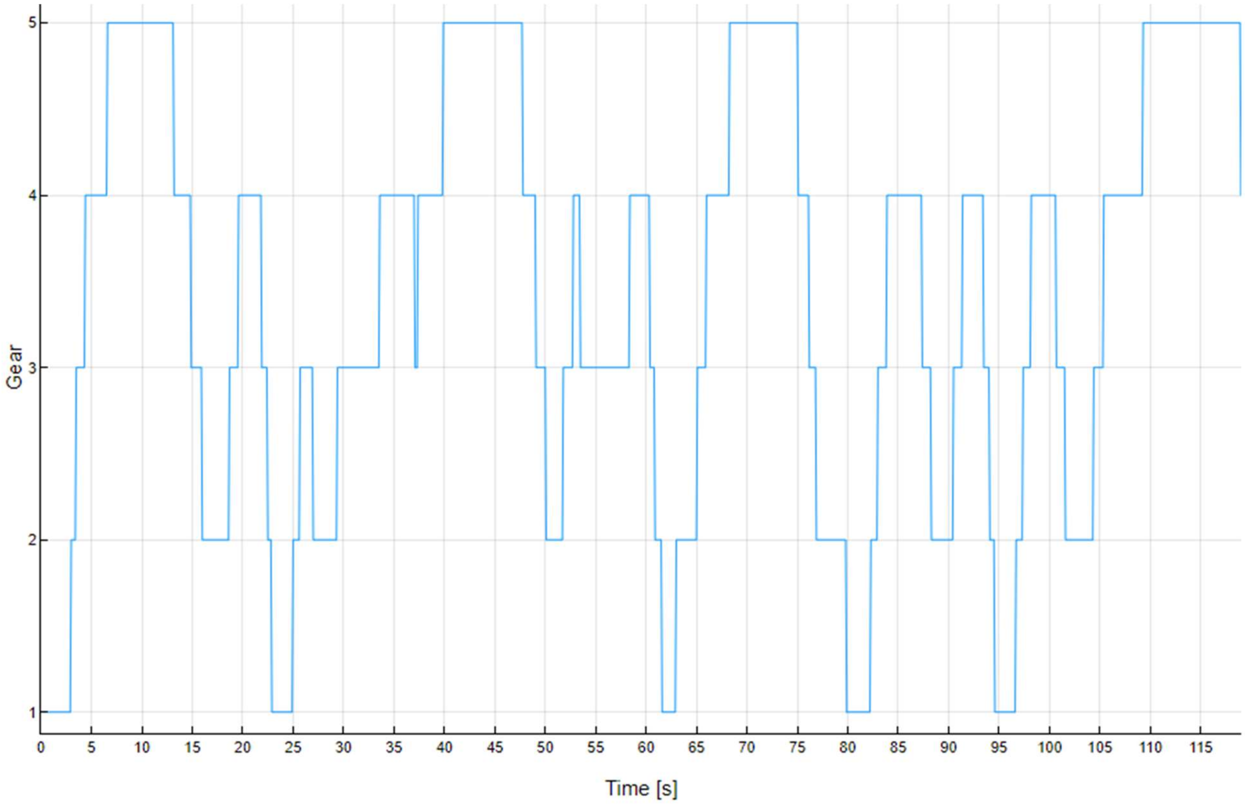

Figure 2.4: Gear vs. Time

In only one case, near the 25 second mark, the RPM approaches redline, this however occurs in second gear indicating that it was a driver decision based on an upcoming corner. This gearbox facilitates the driver to have a high maximum acceleration of 0.705 g. If the gearbox had shorter gears, it is likely the driver would spin and not complete the circuit. The combination of these graphs and driver input are some of, if not the most substantial variable when it comes to lap time.

Spring and Damping Rates

The purpose of the spring and damping rates is to make the vehicle handling better around corners and to reduce oscillation that were induced by acute turns. By controlling such values and taking consideration of the motion ratio effects due to the stiffness being measure at the spring and not the wheel these were the results received. The suspension stiffness is 26000N/m and 30000N/m for the front and rear respectively. The suspension damping is 5000Ns/m and 5400Ns/m for the front and rear respectively. The antiroll bar stiffness is 550Nm/rad and 400Nm/rad for the front and rear respectively.

Eigenvalues of minimal system

No.	σ±ωi [1/s]	ω_n [Hz]	ζ	τ [s]	λ [s]
1	-403.3	0.0	NaN	0.00248	Inf
2	-400.3	0.0	NaN	0.002498	Inf
3	-308.0	0.0	NaN	0.003247	Inf
4	-306.1	0.0	NaN	0.003267	Inf
5	-32.24-55.01im	10.15	0.5056	0.03102	0.1142
6	-32.24+55.01im	10.15	0.5056	0.03102	0.1142
7	-31.67-48.06im	9.16	0.5503	0.03157	0.1307
8	-31.67+48.06im	9.16	0.5503	0.03157	0.1307
9	-27.97-53.34im	9.586	0.4644	0.03575	0.1178
10	-27.97+53.34im	9.586	0.4644	0.03575	0.1178
11	-27.47-56.21im	9.957	0.4391	0.0364	0.1118
12	-27.47+56.21im	9.957	0.4391	0.0364	0.1118
13	-17.65	0.0	NaN	0.05664	Inf
14	-11.74	0.0	NaN	0.08519	Inf
15	-10.98	0.0	NaN	0.09108	Inf
16	-6.737	0.0	NaN	0.1484	Inf
17	-2.49-3.991im	0.7486	0.5294	0.4016	1.574
18	-2.49+3.991im	0.7486	0.5294	0.4016	1.574
19	-1.535e-5	0.0	NaN	65150.0	Inf
20	-2.147e-7	0.0	NaN	4.657e6	Inf
21	0.0	0.0	NaN	Inf	Inf
22	0.0	0.0	NaN	Inf	Inf
23	0.0	0.0	NaN	Inf	Inf
24	0.0	0.0	NaN	-1.269e8	Inf
25	2.068e-7	0.0	NaN	-4.835e6	Inf
26	1.535e-5	0.0	NaN	-65150.0	Inf
27	0.9104+4.651im	0.7543	-0.1921	-1.098	1.351
28	0.9104-4.651im	0.7543	-0.1921	-1.098	1.351

Table 3.1: Minimal System Eigenvalues

Rotation centres of first body for all modes

No.	Eigenvalue	x	y	z	u_x	u_y	u_z
1	-403.3	-0.00552	0.0	5.944	0.0	-1.0	0.0
2	-400.3	0.00862	0.0	2.835e-5	-0.003288	0.0	1.0
3	-308.0	-0.008165	0.0	5.878	0.0	-1.0	0.0
4	-306.1	0.007298	0.0	1.971e-5	-0.002701	0.0	1.0
5	-32.24-55.01im	-0.0003849+6.838e-5im	0.0	0.01255+0.06433im	1.0	0.0	0.0001008+0.005964im
6	-32.24+55.01im	-0.0003849-6.838e-5im	0.0	0.01255-0.06433im	1.0	0.0	0.0001008-0.005964im
7	-31.67-48.06im	-0.5257-0.01164im	0.0	-0.01939+0.0006837im	0.0	1.0	0.0
8	-31.67+48.06im	-0.5257+0.01164im	0.0	-0.01939-0.0006837im	0.0	1.0	0.0
9	-27.97-53.34im	0.8227+0.5639im	0.0	-0.01932+0.0007379im	0.0	1.0	0.0
10	-27.97+53.34im	0.8227-0.5639im	0.0	-0.01932-0.0007379im	0.0	1.0	0.0
11	-27.47-56.21im	-0.0004026+7.403e-5im	0.0	0.007427+0.06695im	1.0	0.0	-0.0004335+0.006061im
12	-27.47+56.21im	-0.0004026-7.403e-5im	0.0	0.007427-0.06695im	1.0	0.0	-0.0004335-0.006061im
13	-17.65	-0.09012	0.0	0.6095	0.9892	0.0	0.1463
14	-11.74	-1.686	0.0	-0.01922	0.0	-1.0	0.0
15	-10.98	0.06934	0.0	0.3401	0.9798	0.0	-0.1998
16	-6.737	-4.523	0.0	-0.01916	0.0	-1.0	0.0
17	-2.49-3.991im	-0.004546+0.01043im	0.0	-0.4288+0.3856im	0.9998	0.0	-0.01795-0.008177im
18	-2.49+3.991im	-0.004546-0.01043im	0.0	-0.4288-0.3856im	0.9998	0.0	-0.01795+0.008177im
19	-1.535e-5	132100.0	-57210.0	393300.0	0.948	-3.419e-7	-0.3184
20	-2.147e-7	9.442e6	629.7	2.811e7	0.948	4.648e-7	-0.3184
21	0.0	3.377e10	-3.663e9	1.142e11	0.9589	0.009167	-0.2833
22	0.0	-9.884e10	-1.007e10	-2.652e11	-0.9349	-0.05398	0.3505
23	0.0	-5.66e10	-6.556e9	-1.465e11	-0.9327	-0.00504	0.3605
24	0.0	-2.576e8	-204000.0	-7.663e8	-0.9479	1.242e-5	0.3186
25	2.068e-7	-9.805e6	-1167.0	-2.919e7	-0.948	4.78e-7	0.3184
26	1.535e-5	-132100.0	57220.0	-393300.0	-0.948	-3.458e-7	0.3184
27	0.9104+4.651im	-0.06978-3.54im	0.0	-0.01907-5.563e-5im	0.0	-0.0197+0.9998im	0.0
28	0.9104-4.651im	-0.06978+3.54im	0.0	-0.01907+5.563e-5im	0.0	-0.0197-0.9998im	0.0

Table 3.2: Rotation Centers of First Body for all modes

When reviewing table 3.1, there are 4 high frequency modes at 10.15 Hz, 9.16 Hz, 9.586 Hz, and 9.957 Hz. There are 2 low frequency modes at 0.7486 Hz and 0.7543 Hz. With a medium frequency range, the suspension and damper would suppress the frequency. The Suspension would handle the middle frequency while the chassis will absorb the low frequency as seen from the two ranges of natural frequency exhibited. Tires will play a very small part in terms of absorbing the frequency that is being applied. In table 3.2, it is seen when analyzing the rotation center of the vehicle that the car does experience all three motions of roll, pitch, and yaw. With the most dominant motion being body roll, this was under study when optimizing the stiffness and damping values by overall increasing the stiffness value until the car was under performing due to over stiffness. Then the next parameter that would help with roll motion is the by increasing the anti-roll bar stiffness. The whole purpose of anti-roll bar being to reduce body roll would allow for the car's handling to improve through redistributing cornering loads between the front and rear wheels. The second highest rotational force experienced on the car was the yaw rate, this will be explained in further depth below. The least experienced force is the pitch force which was significantly reduced through the benchmarking of decreasing roll motion. When reviewing the XD competition simulation, the vehicle even after the turn is experiencing a lot of rolls with a continuation of the oscillatory motion. This was decreased significantly through benchmarking the damping values until an underperformance.

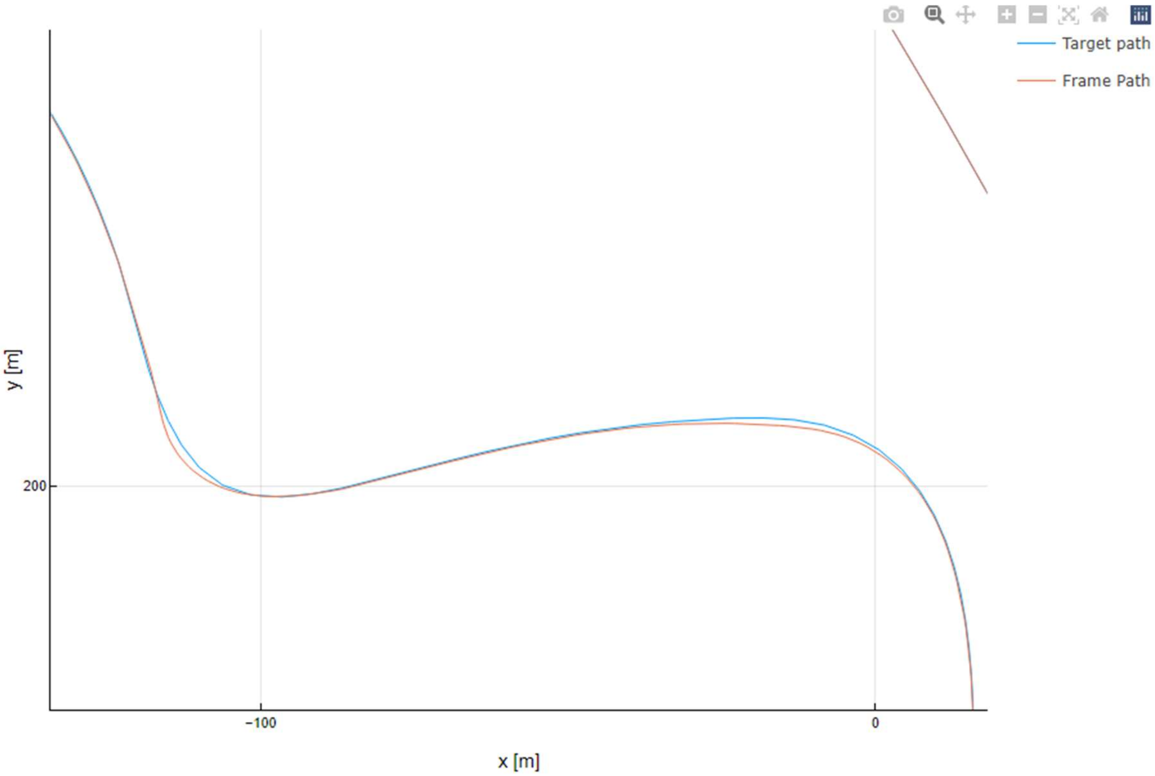

Figure 3.1: Path of the Vehicle Section

As seen in figure 3.1, it is not possible to pinpoint whether the vehicle only understeers or oversteers with the first turn being from the right in the figure the car experiencing oversteer cutting in the corner while in the following turn the vehicle is understeering taking the longest path of the turn.

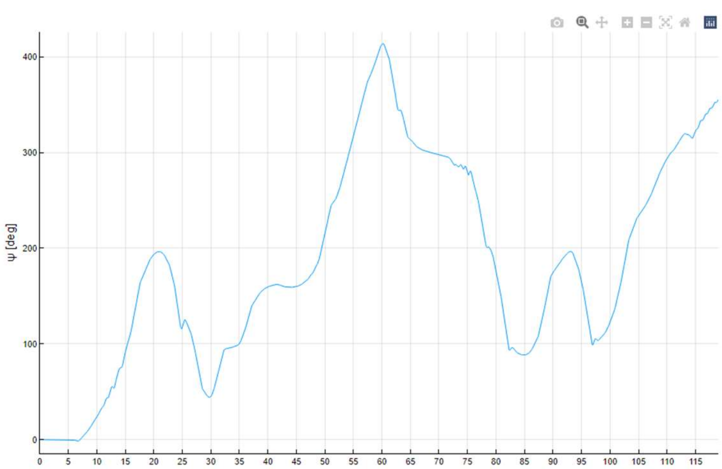

Figure 3.2: Yaw vs Time

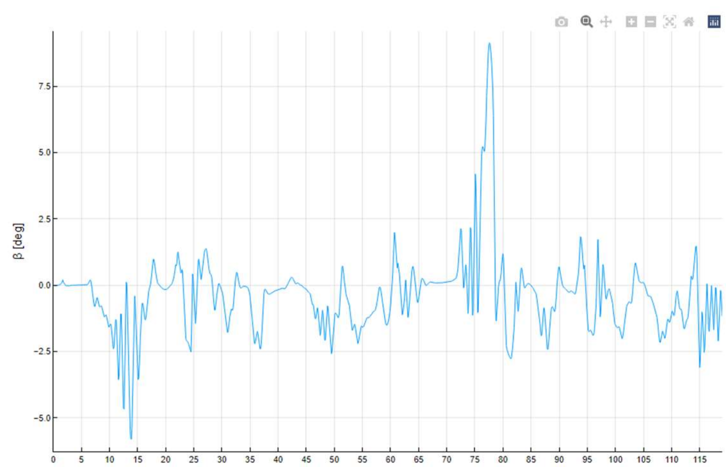

Figure 3.3: Body Slip vs Time

When reviewing figure 3.2 for the yaw vs time, the degree of severity increases with the more dramatic turns as the yaw of the vehicle will adjust and turn with the steering input. With figure 3.3, the body slip of the vehicle correlates with the steering input as well with the bigger turn the body will increase, as this data is used during the benchmarking of the vehicle.

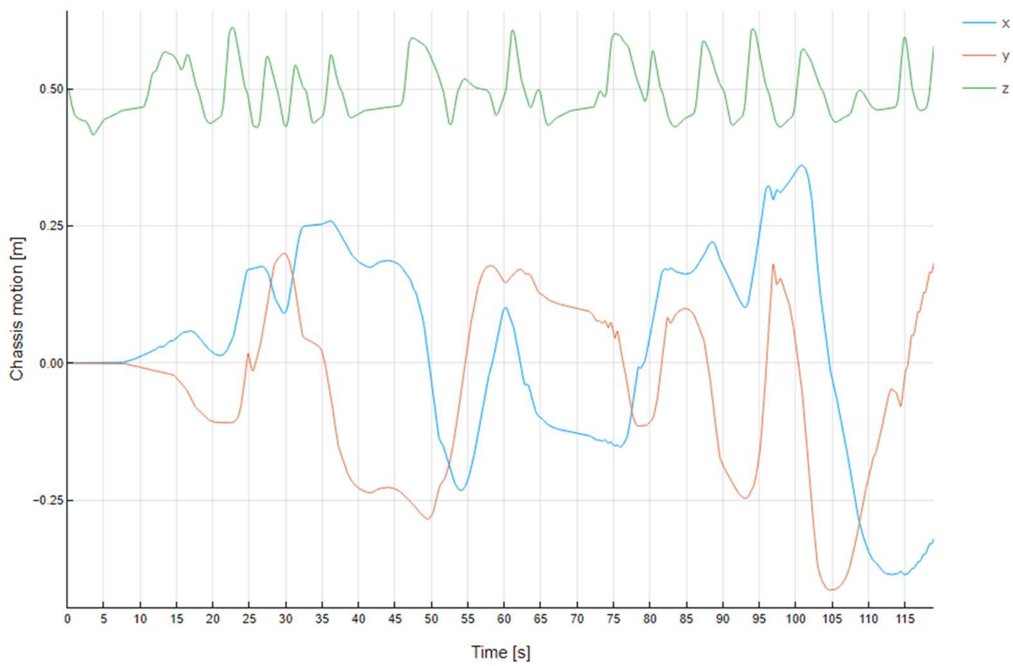

Figure 3.4: Chassis Motion vs Time

In figure 3.4, the chassis motion of the vehicle was analyzed to understand the how much the body would move along various axes. This would further the understanding received in table 3.2 with how the rotation of the vehicle would work and the effects of the benchmarking.

After altering the stiffness, damping and anti-roll bar the driver was able to push the car even further allowing for a more significant lap time. The biggest factor when benchmarking was being able to increase the damping which allowed the driver to push even more, and this is due to the reduced oscillation the driver would experience after the turn which would allow for the driver to accelerate unhindered by the motion of the vehicle earlier. The motion ratio effect was also reviewed with the amount of force transfer to the vehicle chassis reduces with increase in the motion, this was more researched when designing the suspension geometry.

Suspension Kinematics

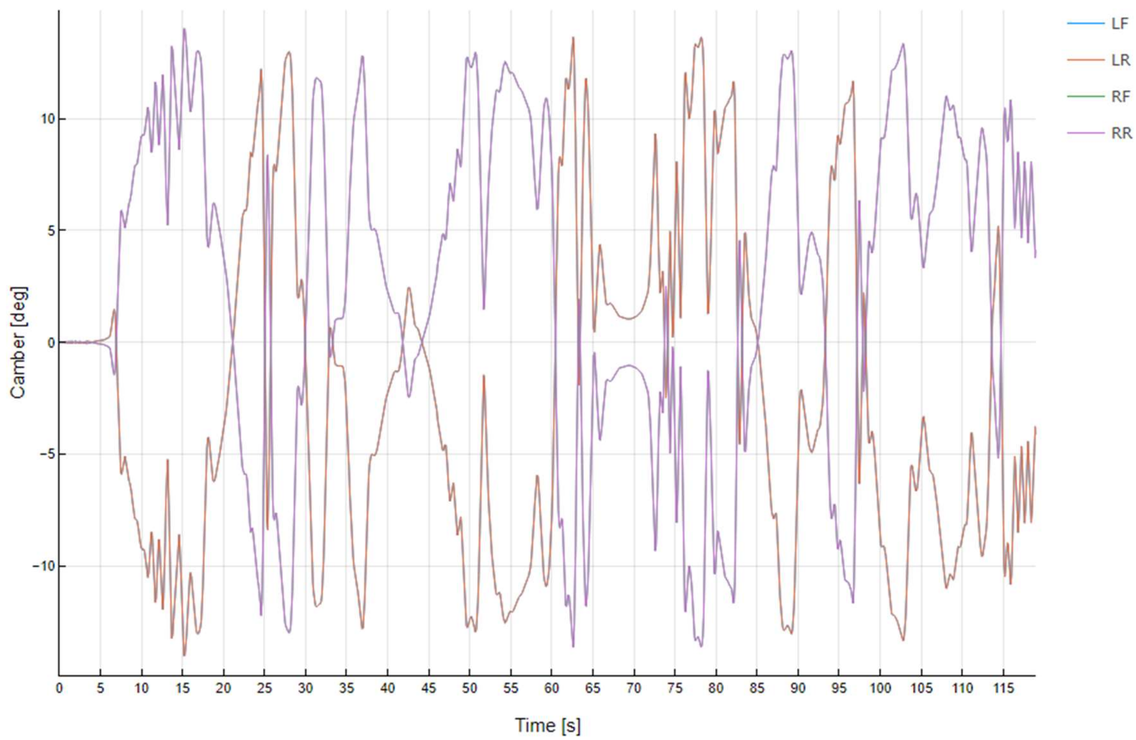

Figure 4.1: Camber vs Time

In figure 4.1, it is evident the natural camber that occurs when cornering as the left and right side of the vehicle acts as opposites to counterbalance the lateral shifting of weight. This is easily seen when the first left turn occurs, it creates a negative camber on the left tires creating better traction while creating a positive camber on the right-side tires to counter act the weight transfer which provides a more stable turning experience which will help reduce cornering times.

The geometry of the suspension was not heavily modified. A few changes were made to the length of the springs. For the upper end the spring was lengthened to affectively increase stiffness when cornering without heavily impacting the straight-line performance when braking. This elongated spring is shown in Figure 4.2.

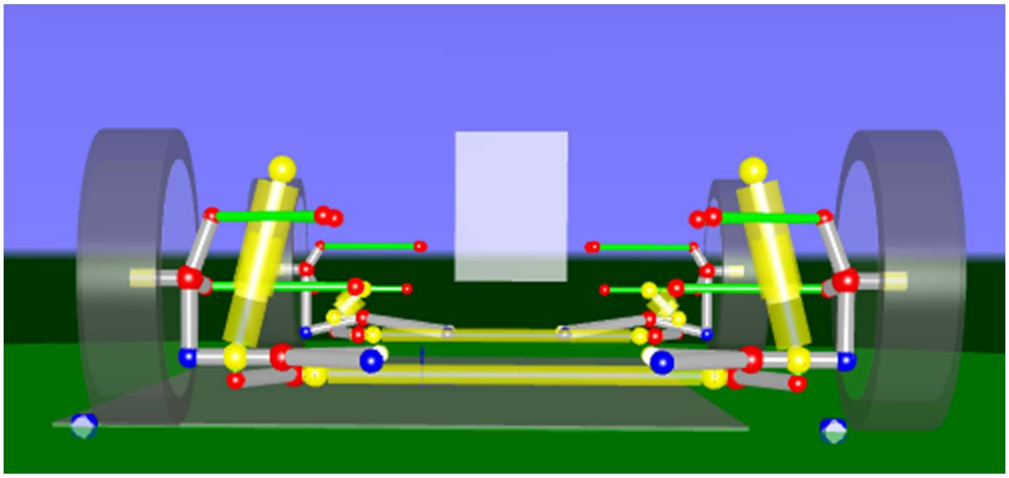

Figure 4.2: Front Suspension

For the rear suspension, the opposite approach was taken. This spring was shortened to simulate a less stiff spring through tangent stiffness. This allows the spring to simulate the less stiff spring when cornering which allows for an understeer behavior, which contributes to better control on corner entry and exit for the powered wheels. The geometry is shown below in Figure 4.3.

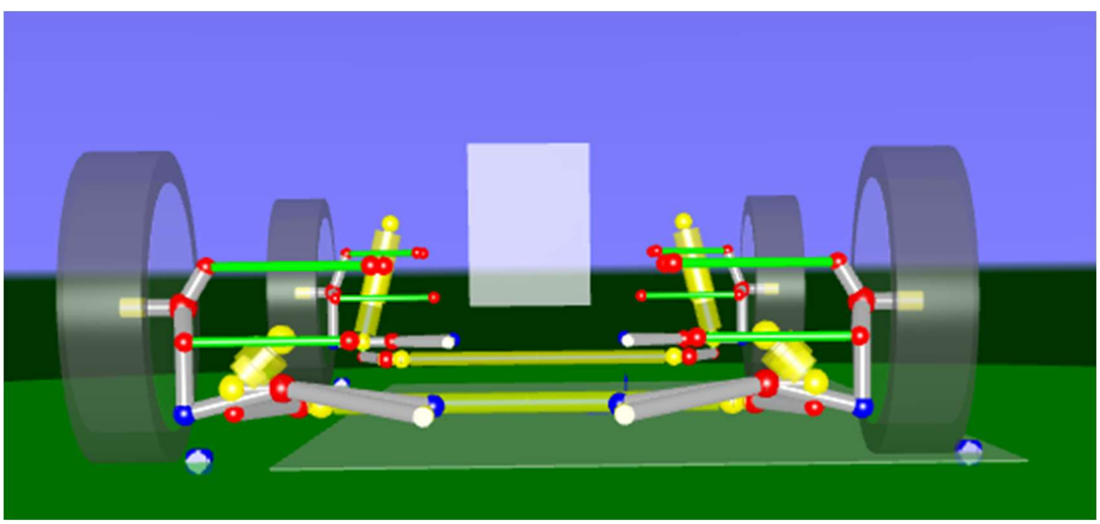

Figure 4.3: Rear Suspension

When reviewing upon the modes of the 3d suspension, with mode 5 and 6 the front tires are experiencing pitch motion with offset oscillation of both tires as left and right are at peak and min respectively together with the very minor movement in the rear suspension. With mode 7 and 8, the front tires are experiencing bounce motion with very minor feedback forces in the rear suspension. For mode 9 and 10, the rear is experiencing bounce motion with the front suspension having feedback, but more interestingly the rear oscillation amplitude decreases significantly after the first bounce compared to mode 7 and 8. Similarly to mode 5 and 6, modes 11 and 12 also have the same finding as mode 9 and 10. Mode 13 and 15 experience body roll motion with a jerk motion laterally showing the effects of the shock absorbers and antiroll bar. With mode 14 and 16 it shows the chassis bounce movement effects on the suspension and understanding how to decrease the second bounce amplitude that occurs. Mode 17 and 18 is another roll motion simulation in the opposite direction. Mode 27 and 28 show the yaw and bounce of the most extreme case creating the chassis to vigorously rise and fall, but with further understanding and increasing damping this was made better.

Centre of Mass and Braking Performance

In racing power is often attributed to top speed. However, braking is also essential in putting in a good lap time as the ability to decelerate the car can add time as much as the ability to accelerate. Lockups occur in racing due to being too aggressive with brake pedal application for the braking balance the vehicle is set to. This vehicle is equipped with a front brake fraction of 0.631. This means 63.1% of the braking is handled by the front wheels. In an ideal scenario no locking of the brakes will occur. However, with the aggressive acceleration and therefore high targeted cornering speeds of the driver at 0.705 g, lockups were nearly impossible to fully avoid. There is a solution to locking, which requires a lower targeted acceleration, but this negatively affected lap time by a significant margin. Therefore, minimizing the impact of lockups became the goal. The front weight fraction of the Dennit Racing car is 0.45, meaning 55% of the weight is in the rear of the vehicle. This significantly impacts our braking balance as the rearward weight needs to be balanced with the front heavy braking. To minimize the impact lockups, have on the vehicle the Wheel Speed vs. Time graph, shown in figure 5.1, was thoroughly checked after any alteration of parameters. To minimize the impact on lap time, and keep the vehicle in control, the rear lockups need to be minimized to extremely low speed scenarios as this can lead to spinning and loss of control when it occurs at high speed.

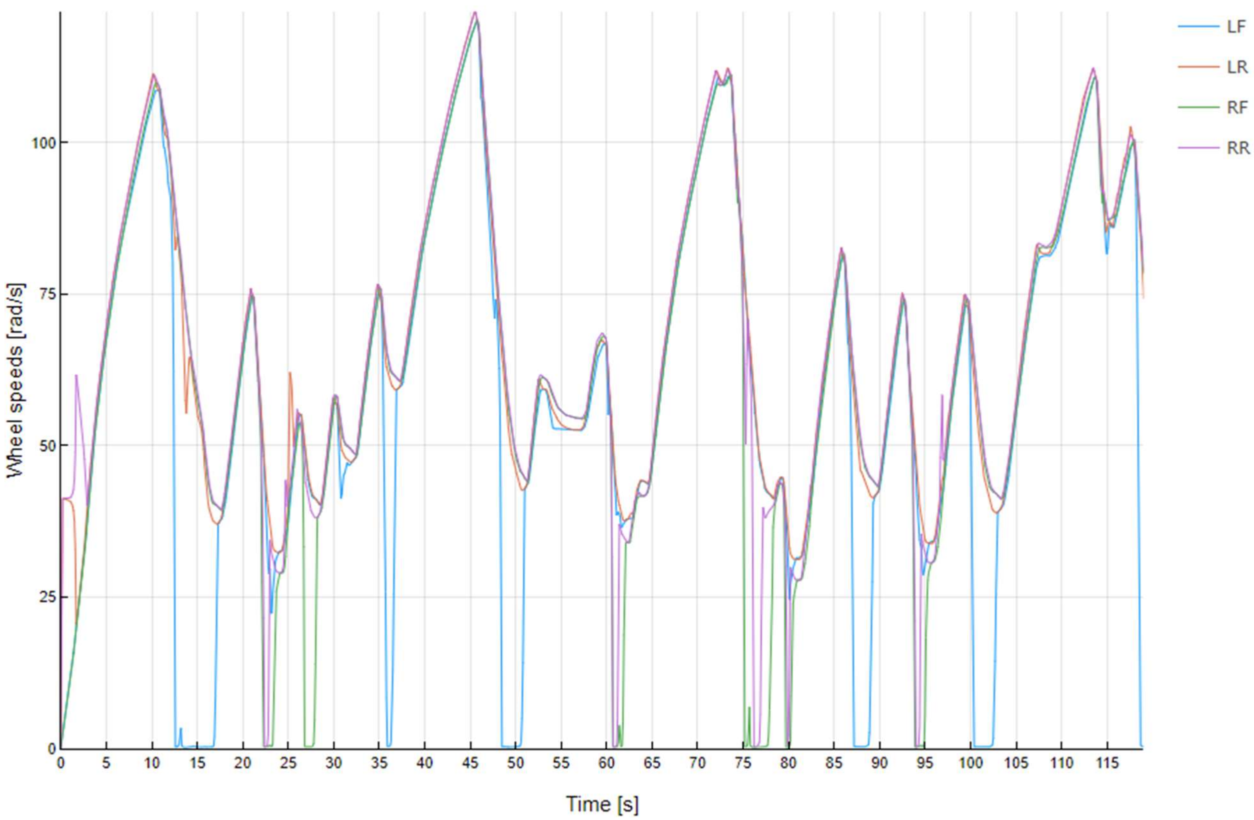

Figure 5.1: Wheel Speed vs. Time

As shown, the rear wheels only lock up in low-speed corners, and for brief periods of time. This situation is controllable for the driver at the given required acceleration. The front wheels lock up briefly in the high-speed corners as well, but the benefits of these lockups out weight the costs when it comes to overall lap time. The front brake fraction of 63.1% helps offset the weight transfer under braking to take braking load off the rear wheels with the higher weight percentage of 55%. Overall, this braking profile is relatively controllable considering the high amounts of expected acceleration from the driver.