Dirt Late Model Race Car Simulations with Dymola / Modelica

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Abstract

A multi-body vehicle dynamics model of a Dirt Late Model (DLM) car and application specific set of simulations were created to explore the available suspension adjustments relationship to handling characteristics. The set of simulation tools were built in Dymola, using the VeSyMA suite of libraries from Claytex. The Dymola models were specifically used to assess the effect of setup adjustments on handling and sensitivity to laptime changes. Even with input data of less than desirable accuracy, the simulation results proved both valuable and enlightening. *Keywords: Simulation, Dymola, Modelica, Racing, Dirt Late Model*

1 Background

For years, top tier race teams have used various levels of simulation tools to help improve their racing programs. From basic kinematics programs through driver-in-the-loop motion platform simulators these mathematical representations of their race cars have helped teams develop setups, design vehicles, and optimize their performance. For the past decade Dymola and Modelica have been at the core of these simulation developments.

Often, in levels of racing with budgets smaller than those in Formula 1, NASCAR, WRC, IndyCar etc. team members' desire knowledge and understanding but struggle to find high-quality simulation tools to improve their comprehension.

Dirt late models are one type of race car that fall into this category. While many of the teams have sizeable budgets, they are lower than that required to fully invest in an engineering group like those utilized in the 'big budget' forms of racing.

1.1 The Vehicles

DLM race cars are comprised of a dual a-frame coil-over front suspension cars with rack and pinion steering. The rear suspension is solid axle with two longitudinal links on each side in conjunction with a single lateral link and decoupled axle rotational control link. These types of race cars are known for their radical body attitudes, large yaw angles and large power to weight ratios. Figure 1 shows a typical on-track attitude of a DLM at speed.

Figure 1. Example of a DLM on-track / at speed.

The cars weigh 2300-2400 lbs (depending on the series) and the engines produce around 900 HP. Engines are naturally aspirated (carbureted) 2 valve per cylinder V8s anywhere between 350-500 cubic inch displacement. The gearboxes are 2 speed direct drives with a 1:1 top gear. Tires are biased ply with rollouts of 88 to 94 inches and (depending on the series) may have various tire constructions / compounds. Figure 2 shows the simulation model at dynamic equilibrium in the corner state from Figure 1.

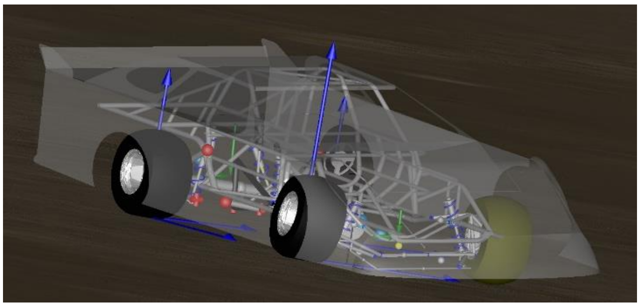


Figure 2. Simulation of a DLM on-track / at speed.

1.2 The Test Rigs

Top tier racing teams (F1, NASCAR etc.) have access to and heavily utilize pulldown rigs, Kinematics and Compliance (K&C) rigs, and 7-post 'shaker' rigs. Access to (or utilization of) these types of rigs by dirt late model teams is infrequent. Data gathered by testing on these rigs is invaluable for validation of simulation models. Without this type of data one can never be certain about the level of inaccuracies that exist in the models.

1.3 The Tracks

There are roughly 600 dirt race tracks in the U.S. They vary from ¼ mile to 1 mile in length. Banking levels vary between 5 and 35 degrees. Shapes range from circles to ovals to D shapes. The dirt itself ranges from red clay to black clay to sand and everything in-between.

Track conditions change rapidly throughout a race event. Much of the changes in condition are due to the reduction of moisture in the dirt. It is common for laptimes to slow down 3 seconds on an 18 second / lap track (16.7%) throughout a given night.

Some tracks gain traction later in the night after they have dried completely out. This laptime gain is generally accepted to be due to the increased mu of the surface as rubber from the racing tires is deposited onto the surface.

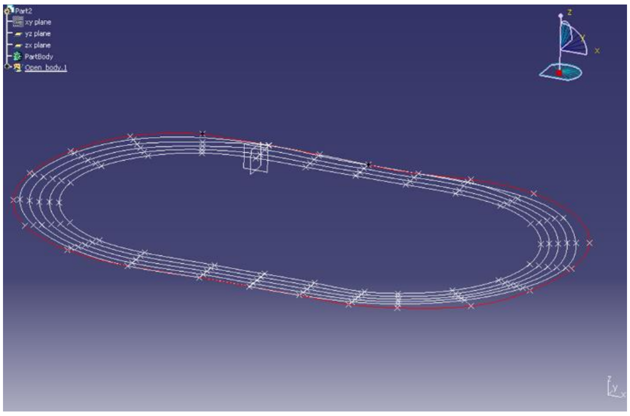


Figure 3. CAD representation of the track in West Liberty, IA.

Track geometry is an important part of any track specific simulation. In the case of West Liberty, IA a group of colleagues in college surveyed the track for simulation purposes. This information was helpful in evaluating / developing an approach that could be used for tracks where this information wasn't available.

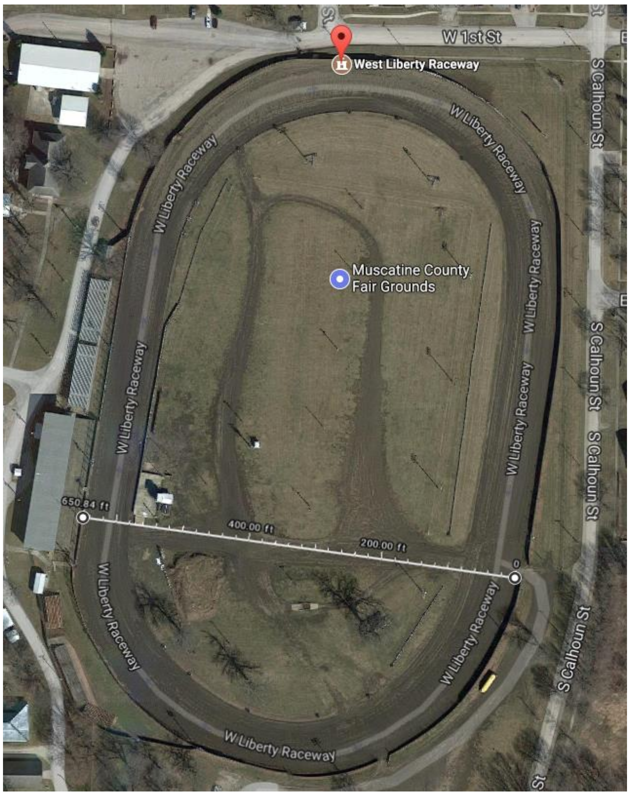


Figure 4. Example of a google maps view the track in West Liberty, IA.

1.4 The Challenges

There were numerous challenges encountered during this study.

First, vehicle configuration data is challenging to acquire. Component geometries are seldom known, and CAD models of the components are closely guarded.

Second, tire data is virtually impossible to acquire. Slip characteristics are essentially unknown. Although, vertical tire stiffness data is based on a colleague's mechanical engineering design senior project results.

Third, rig-based validation data is also challenging to acquire. Even basic first order data such as that generated on a pulldown rig is rare and once again, closely guarded.

Fourth, track geometry data (other than plan views from google maps) are largely unavailable. It was generally found that bank angles must be measured by hand for tracks that were going to be simulated.

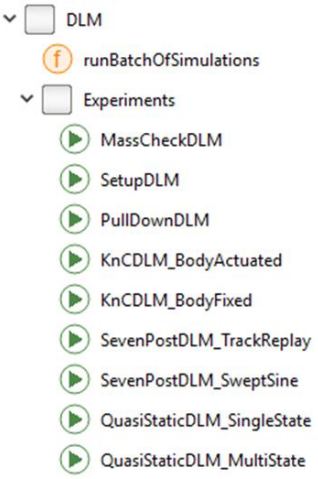
Fifth, on-track data is challenging to acquire. Often, mechanical measurements, photos, and video are the best options.

1.5 The Goal

The desired outcome for DLM racing is to design a vehicle configuration that has linear and minimal change in handing behavior relative to track conditions and fuel load variation over the duration of an event.

2 The Simulations

A vehicle model based on the VeSyMA - Motorsports library NASCAR vehicle was created and customized to match the suspension configuration of a DLM race car. The changes that were made included rack and pinion steering, and a custom rear suspension. The vehicle conforms to the open source VehicleInterfaces library standard. Figure 5 contains a Dymola view of the completed vehicle model.



- DLM
  - runBatchOfSimulations
  - Experiments
    - MassCheckDLM
    - SetupDLM
    - PullDownDLM
    - KnCDLM_BodyActuated
    - KnCDLM_BodyFixed
    - SevenPostDLM_TrackReplay
    - SevenPostDLM_SweptSine
    - QuasiStaticDLM_SingleState
    - QuasiStaticDLM_MultiState

Figure 6. Experiments created in the DLM project.

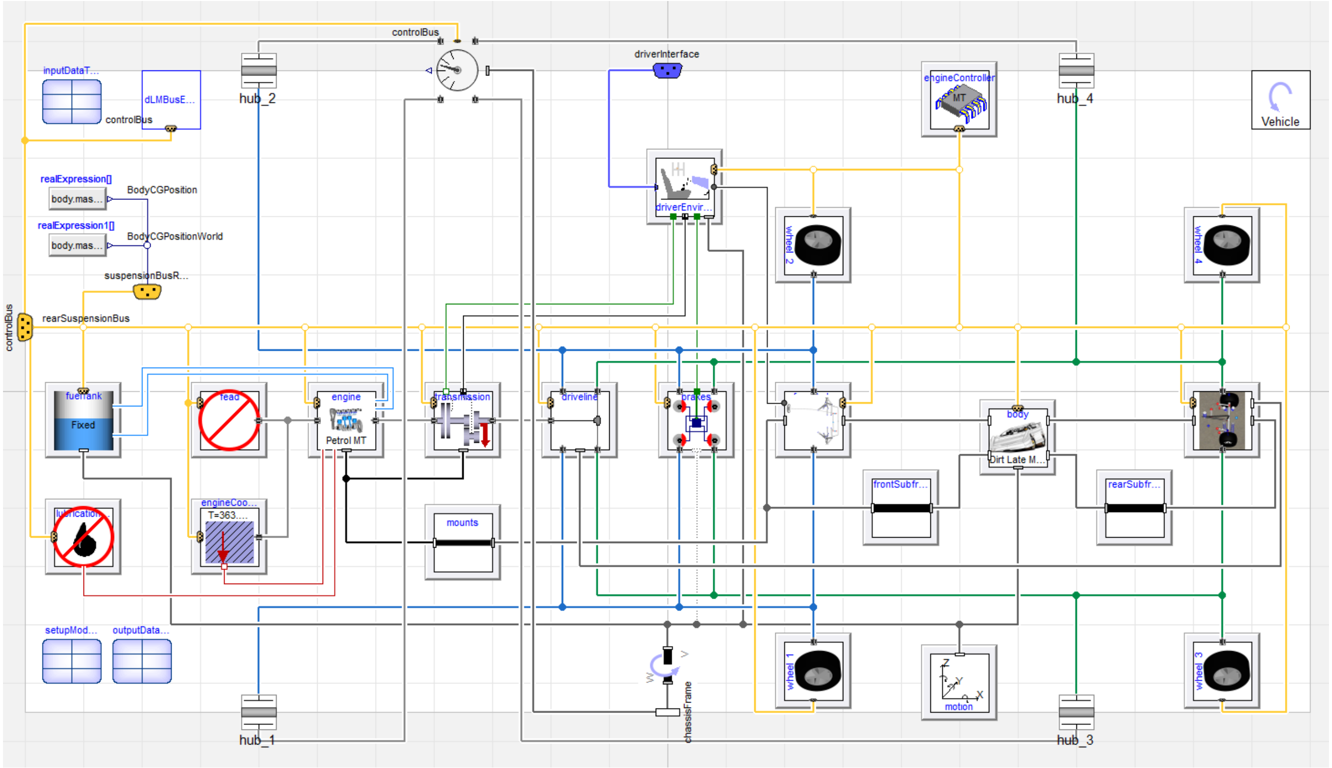


Figure 5. The DLM vehicle model based on the open source VehicleInterfaces standard.

This vehicle model was then used in various simulation experiments. Figure 6 contains the various experiments that were created using the DLM vehicle model.

2.1 Mass Check

Mass check simulations are the first level of checkout used to validate a vehicle model. The simulation is simply a vehicle released and allowed to settle on the suspension and tires. The total wheel loads are added up and checked to be sure that the mass of the vehicle equals what is expected based on the inputs.

2.2 Setup Model

Setup models are used to simulate the setup process of a race car. Closed loop adjustments are made to the vehicle to achieve various targets such as ride heights, suspension alignment, and weight distribution. During this simulation PID controllers make shim adjustments to match prescribed values for each target. The final timestep results from this simulation are then used as input parameters to each subsequent experiment. These input parameters ensure the vehicle is starting in the configuration specified by the user. It is common to feed these input parameters back into the Mass Check simulation to check that the vehicle remains static for the entirety of the simulation. This verifies that all setup adjustment values and starting conditions are being properly passed into the subsequent simulations.

2.3 Pulldown Rig

Pulldown rigs are used to test the low frequency force versus displacement performance of the suspension. In addition to this the camber versus wheel travel and steer versus wheel travel characteristics can also be evaluated. Generally, dampers are removed for this type of testing. The body is usually held fixed and the tires are actuated vertically while recording the resulting wheel vertical load and displacement are recorded. The two actuators on an axle are either actuated in phase or out of phase to determine heave or roll performance respectively. Figure 7 contains an image of the DLM vehicle on a virtual pulldown rig.

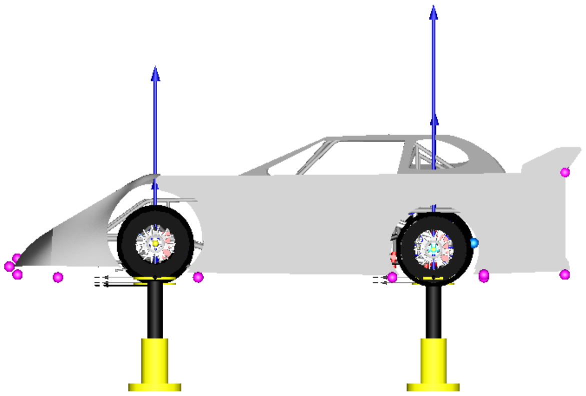


Figure 7. Image of the DLM on a virtual pulldown rig.

2.4 Kinematics and Compliance

K&C rigs are extensions of pulldown rigs that are generally more accurate and allow loading / analysis of additional degrees of freedom. Low frequency testing is again the target of this type of rig. The additional degrees of freedom are lateral, longitudinal, and aligning torque which can be applied to each tire or hub. Generally, dampers are removed for this type of testing.

This type of testing allows the users to study anti force characteristics of the suspensions, the frictional characteristics of the joints under load, as well as several types of compliance. For example, camber compliance can be evaluated by applying a lateral load to a tire and recording the camber change. In the same results set the anti-force characteristic can be determined. There are generally two types of rigs, body actuated, and body fixed. For this reason, two K&C simulations were created.

2.4.1 Body Actuated

As the name suggests, the vehicle body is actuated in this type of test and or simulation. The yaw, pitch, and roll of the chassis can easily be changed to either a different static position or varied throughout the test.

2.4.2 Body Fixed

Body fixed K&C simulations generally handle vehicle roll via rolling the wheel pads while the body remains stationary. From a simulation perspective one model could be constructed to handle all cases, but for this project a separate model was created to mimic this type of rig.

2.5 7 Post

Seven-post test rigs often called ‘shaker rigs’ are used to conduct high frequency testing and are generally used to reduce normal load disturbances on the tires. The four ‘posts’ actuating the tires are like those on a pulldown rig but are capable of achieving much higher speeds and frequencies. Three (or more) additional actuators are connected to the chassis and are used to actuate the body to replicate aerodynamic / inertial loadings of the vehicle. Figure 8 contains an image of the DLM on the virtual 7-Post rig.

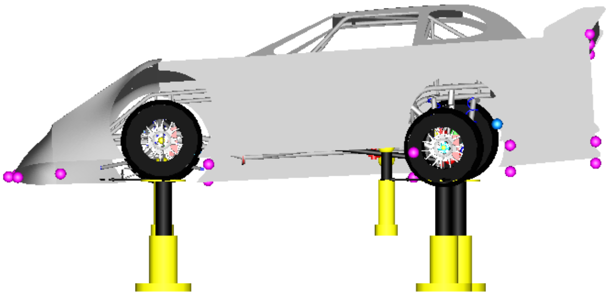


Figure 8. Image of the DLM on a virtual 7-Post rig.

Simulation of this type of event allows the user to correlate the vertical dynamics of their vehicle model to the real world. Two types of testing are commonly conducted on race cars; track replays and swept sine inputs.

2.5.1 Track Replay

Track replay testing is done to study vertical load performance around a circuit. The drive files for this type of test can be generated in several ways. They are often reverse engineered from data recorded during physical testing, but can also be generated directly from driving simulator laps etc.

2.5.2 Swept Sine

Swept sine 7-Post testing is often used to study the modal behavior of a race vehicle. Evaluation of the various body and suspension modes can be conducted with this type of test. The vehicle setup on this behavior can then be evaluated to optimize the setup for a desired behavior. Resonances are evident in the individual wheel load time histories in the top plot of Figure 9.

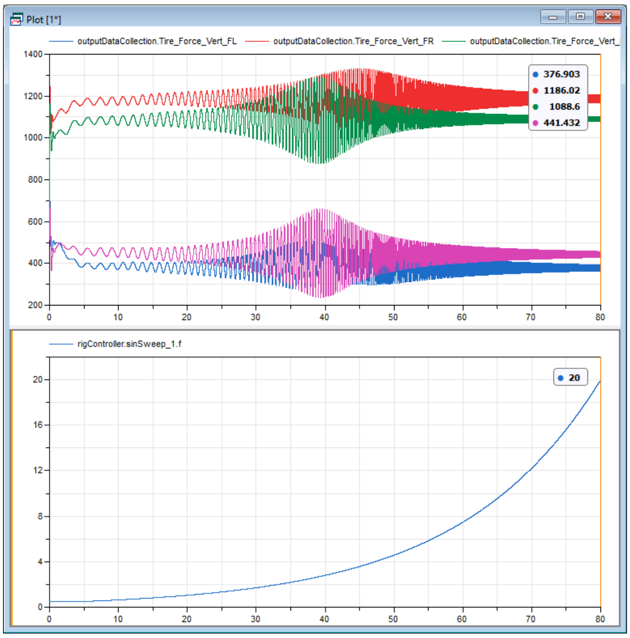


Figure 9. Sub-plots of wheel load time histories and input frequency for the top and bottom respectively.

A variety of post processing techniques can be used to analyze the various channels in this type of test or simulation to determine many different vehicle characteristics. Correlation work on the vertical dynamics of a simulation versus physical vehicle can be both challenging and enlightening.

Once correlation of all the rig tests has been completed and updates to the model have been implemented to achieve a level of correlation that is deemed acceptable, on-track correlation can begin.

2.6 Quasi Static

Quasi Static (QS) simulations are often the first level of track-based simulations that are used by professional level motorsports teams. The vehicle is placed into a single state where the path curvature (lateral and vertical) is known, as well as the vehicle speed. From these inputs, the applied lateral acceleration, vertical acceleration, yaw rate are calculated and applied to the vehicle. There are various way to set up this type of problem. The QS simulation that was built for the DLM project drove the 6 degrees of freedom of the chassis to equilibrium using integrator blocks which were fed the residual constraint forces corresponding to each chassis degree of freedom. Each of the additional simulation state variables were left alone and solved as a dynamic system. Over time the vehicle model settles to quasi-static equilibrium. At this quasi-static equilibrium state, vehicle ride heights, camber angles, wheel loads steer angles, throttle/brake positions etc. can be compared to recorded track data. Figure 10 shows the experiment level layout of the ‘Single State’ DLM quasi-static simulation.

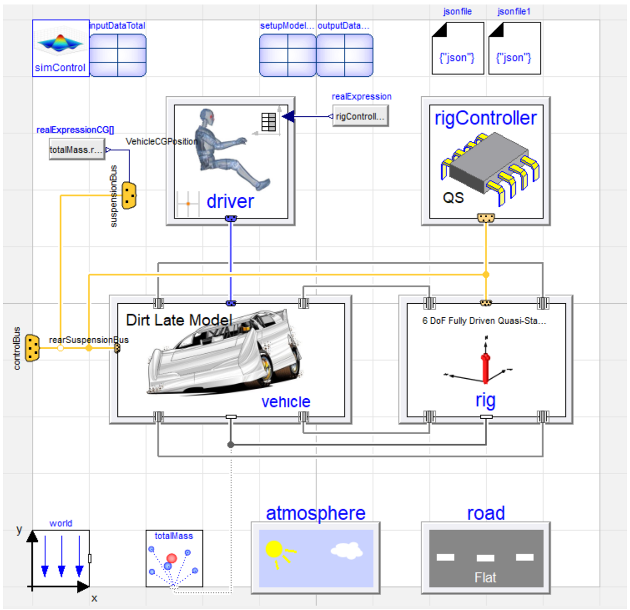


Figure 10. Experiment level view of the Single State QS model.

2.6.1 Single State

The single state simulation converges the QS simulation for a single point on the track. For many cases this is all that is needed for a ride height or tire load prediction.

2.6.2 Multi State

The multi state simulation gives the user the option to sequentially solve a variable number of states. This was the simulation that was used most heavily on the DLM project. States for corner entry, mid corner, and corner exit were solved sequentially so comparisons on vehicle performance across these three states could be analyzed.

3 The Results

Several first order inputs had to be assumed on this project. These assumptions include aerodynamic performance of the vehicle, tire lateral and longitudinal slip characteristics, and vehicle center of gravity height.

Several other first order inputs were determined through less than optimal methods. For example, the track curvature was estimated based on Google Maps measurements. Bank angles were based on values published on the web (or hand measurements at some of the race tracks). Component measurements were made with a tape measure and other methods (chassis measurements were made with a plumb bob with chalk on the shop floor).

Some of the inputs are considered good. For example, tire vertical stiffness characteristics are based on actual test data. Spring force versus displacement curves are accurate and based on dynamometer data. Damper force velocity inputs are based on dynamometer data.

Even with these less than optimal inputs, the 'on track' simulations behaved as expected across the ranges tested. The estimated ride heights were within reason, and the resulting body attitudes were believable. Studies of common setup changes were simulated, and the results changed in ways that are consistent with what happens in real life. It was enlightening to be able to investigate all the intricacies that occur when making these changes. For example, how much additional load goes into the left rear droop limiter when the panhard bar is dropped one inch on the rear axle housing. Digressive and progressive spring curves were explored for use in certain circumstances. Some changes had much impact, some had little. It was valuable to see which setup parameters had impact and where (on track) they had the most impact.

The level of usefulness of the simulations themselves was impressively high. This was not entirely expected considering the relative lack of input data for so many parts of the vehicle as well as the lack of rig data available for correlation. This reminded the author of the 2017 North America Modelica Users Group keynote presentation. Figure 11 contains a plot from that presentation which relates usefulness and accuracy.

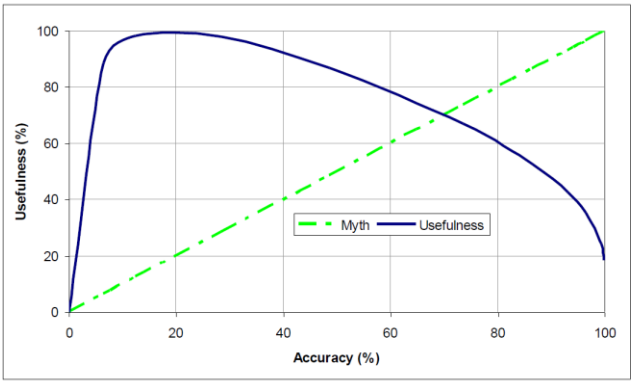


Figure 11. The Myth of Accuracy (Blundell & Harty, 2004).

The most valuable information came from the fast lap versus slow lap state comparisons. The slow lap states were determined by reducing input vehicle speed based on laptime increase gleaned from historical data. In conjunction with the effective mu of the track surface was reduced to achieve similar levels of tire saturation. The magnitude of handling differences in the simulation highlighted the perceived hypersensitivity to laptime. Table 1 contains the steady state steering wheel angles for a fast and slow lap in all three corner states.

Table 1. QS equilibrium steer angles (negative is turning right) for three vehicle states for fast and slow laptime.

	Entry	Middle	Exit
Fast Lap	-26.0	-50.1	-119.1
Slow Lap	-35.4	-31.0	-64.5

Steering angles are the simplest channels to compare for this type of analysis and were selected over a tire slip-based handling metric because the LF tire under some conditions has zero vertical load which causes step changes in most common handling metrics. An additional channel of interest (cross weight) is contained in Table 2.

Table 2. QS equilibrium cross weight (%) for three vehicle states for fast and slow laptime.

	Entry	Middle	Exit
Fast Lap	63.9	60.2	58.4
Slow Lap	54.3	54.4	56.9

The predicted handling differences along with other metrics helped to explain the subjective feedback of the driver over the course of the event. Handling hyper-sensitivity to laptime had troubled the team for months. Some potential causes of this behavior were studied in the simulation. Center of gravity height was one suspected culprit but was found to be relatively insensitive. Left rear spring rate was studied and found to have a substantial impact. Further investigation led to the discovery that the rear axle droop limiting device was active during some parts of the corner and not during others. The slower laptimes magnified this effect as the device was seldom engaged under these conditions. This suspension non-linear force engagement was the largest contributor to the hyper-sensitive handling changes with respect to laptime.

Further studies involving simulation and analysis have led to substantial vehicle configuration changes being implemented over the off-season and elevated expectations for the upcoming season.

There are many opportunities to improve the accuracy of this simulation. The first order gains will be made by simply eliminating some of the rough estimations of input data. The team is on a quest to eliminate some of these assumed first order inputs. Test rig time and a data acquisition system for track testing have been purchased to help generate correlation data. The team have witnessed the value of simulation, even when questionable input data were used.

Acknowledgements

The simulation input data and general guidance on dirt late model vehicle performance were provided by Matt Furman.

References

Michael Blundell, Damian Harty. The Multibody Systems Approach to Vehicle Dynamics. Elsevier Science. 2004, 2014.