Using Racecar simulation as a weapon

When most people think about race car simulation they usually think about it as a tool you throw springs and bars at to determine the minimum lap time you can do. In reality this is barely scratching the surface because when you use a proper race car simulation package it can tell you so much about the car. When used this way a racecar simulation isn't just a tool to predict lap times and refine setups. It becomes a weapon and we are going to illustrate this by presenting a number of actual case studies.

I realise at this point a great deal of you are going to tune out of this article. If you're serious about making your racecar quick don't. The foundation stone of any branch of engineering is to quantify what you are doing. I've had the privilege of working with a number of different race teams, many of them are champions in the respective categories. The thing that gives them that winning edge is they can quantify what is going with their cars. If you're serious about winning, having a glorified spreadsheet doesn't cut the mustard. You must know how those numbers got there. You'll see the importance of this in the case studies presented in this article.

The first case study I'd like to present is when a colleague of mine was provided with two tyre compounds from a tyre supplier. The claim from the tyre supplier was there shouldn't be too much of a difference between the two compounds. The reality was one compound provided a good balance to the car. The other compound suffered from chronic understeer. This prompted a lot of head scratching.

To resolve this matter my colleague ran the ChassisSim tyre force estimation toolbox. This is the kid brother of the ChassisSim tyre force modelling toolbox and the tyre force estimation feature returns an approximation of the Traction circle radius vs load curve. While not delving into all the computer code that makes this work, what this toolbox does is it takes race data, calculates the tyre loads and using other information like steer angle it minimises the following function,

$$cf = \left| a_{y\_act} - a_{y\_sim} \right| \qquad (1)$$

Here we have,

cf = cost function – a measure of the error
a_{y_act} = The actual measured lateral acceleration
a_{y_sim} = Simulated acceleration.

Effectively what we have here is we are effectively performing a number of track replays and we change the parameters of the tyre model to minimise the error. This is the thing that makes the tyre force estimation and modelling toolboxes of ChassisSim so powerful. We are not using tyre rig data, we are using actual track data from real world conditions. It's one of the key reasons ChassisSim is able to achieve correlation like this,

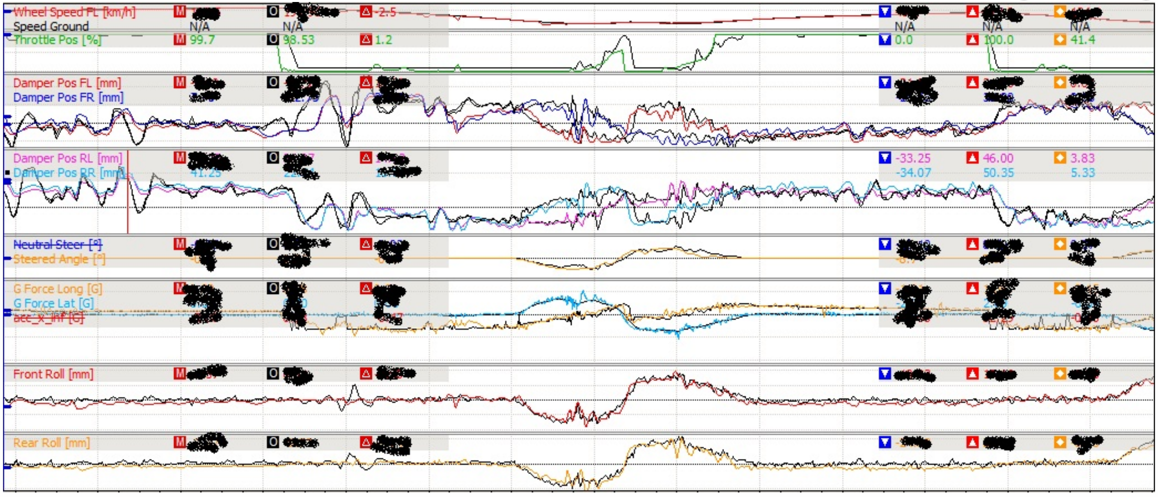


Fig-1 – StockCar correlation. Actual vs simulated.

This was a tyre model generated solely from race data using the tyre force modelling toolbox. The actual data is coloured the simulated is black. As we can see the steering angles, speeds, accelerations and damper movements are almost indistinguishable. I can't speak for other simulation packages but I think this throws into sharp relief some of the criticisms I have seen about where simulators draw their tyre models from.

Getting back to the comparison both compounds were run through the tyre force estimation toolbox. There was not much difference in the rear, but the front compounds were very different. The overlay is presented in Fig-2

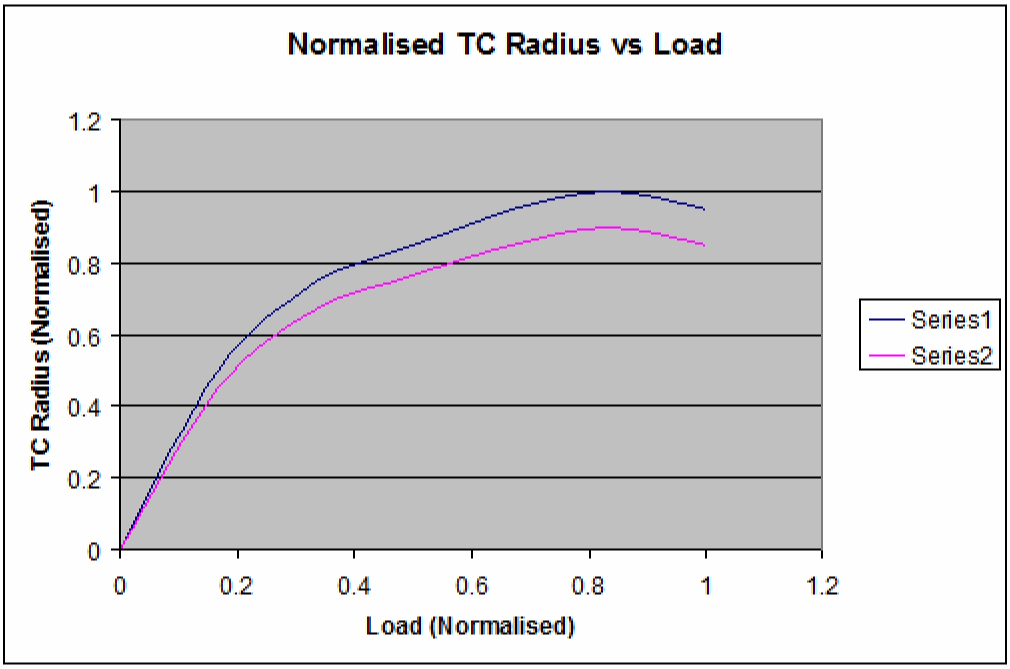


Fig-2 – Normalise plot of Traction Circle radius vs load for different tyre compounds

For confidentiality these have had to be normalised. However you can see as plain as day there is a 10% discrepancy between the baseline compound (A) and the revised compound (B). With this sort of difference it is no wonder the car suffered from severe understeer. However the lesson to be learnt from this is that we can use tools such as the ChassisSim tyre force estimation and modelling toolbox to capture this. Indeed a colleague of mine compared this to a tyre force dyno. From the correlation we see in Fig-1 and the results from Fig-2 it would be very unwise not to make good use of this.

The second case is using your simulator to pick when a motion ratio is incorrect. In most cases you actually don't need to go as far as a simulator. If you're running a monoshock or a twin spring car with linear ratios it's actually really easy. This is a good rule of thumb I follow,

- Filter the dampers
- Note the damper movement on the longest straight.
- Calculate the spring forces.
- Use this to calculate the load at the tyre.
- If you have reliable strain gauges cross referencing the loads.

By the time you get down to step 4 you'll know if something has gone wrong because you'll have an outrageous large tyre load or a very small one. Just as point of observation I will only cross referencing on strain gauges if I can put my hand on my heart and know they are reliable.

Where the simulator comes into play is if you're dealing with a car with high downforce that is using third springs with very different motion ratios to the main springs. This is a situation that a colleague of mine found himself in and this is where the simulator came to our aid. Before I discuss how we did this using ChassisSim I want to make a brief observation about doing this by hand. Technically it is possible it is just very fiddly. The procedure is the following,

- Filter the dampers
- Using the main spring motion ratios convert this to wheel movement.
- Covert back to main spring and third spring movements.
- Note the damper movement on the longest straight.
- Calculate the spring forces.
- Use this to calculate the load at the tyre.
- If you have reliable strain gauges cross referencing the loads.

That's how you would do it by hand. We will know discuss how we did this using ChassisSim.

The giveaway that we had a problem was when the aero toolbox was returning outrageous values for downforce. The aero toolbox takes race data and calculates the downforce drag and aero balance. This feature can be used to generate aeromaps from race data. In this particular case the C_LA exceeded a value of 15. When you see something like this is a clear indication something has gone very wrong and almost certainly points that something in the motion ratio wasn't right. I also knew the third springs where running very aggressive bump stops.

To resolve this issue we put in some baseline aero numbers that made sense and looked at the comparison of pitch and roll to real data. What we did here was to run a simulation with curvature only with no bumps. The baseline comparison is shown below.

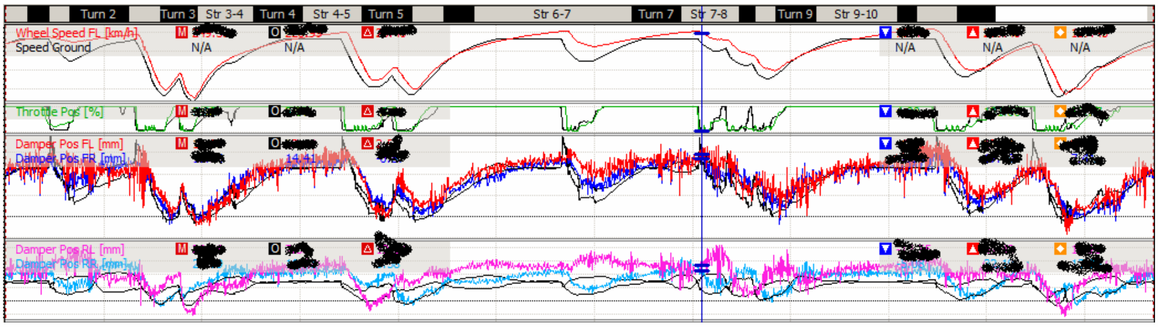


Fig-3 – A comparison of actual to simulated data with the baseline motion ratios.

The actual data is coloured, the simulated data is black. Again due to confidentiality the scales and values are all blacked out (this is also the case for Fig-4). As we can see the front dampers aren't too bad. However the rear damper traces are not compressing enough on the straights. The giveaway here is in the corners. As we can see the simulated vs actual roll isn't too bad. They are not on top of each other but this isn't what we are looking for at this point. This indicates clearly that the main spring ratios are not the problem. What we need to address is the rear third spring motion ratio. As a rough rule of thumb if there is a big discrepancy in the dampers the first thing you look at is motion ratios.

So taking an informed guess we inverted the motion ratios and this resolved the problem. The revised comparison is shown in Fig-4.

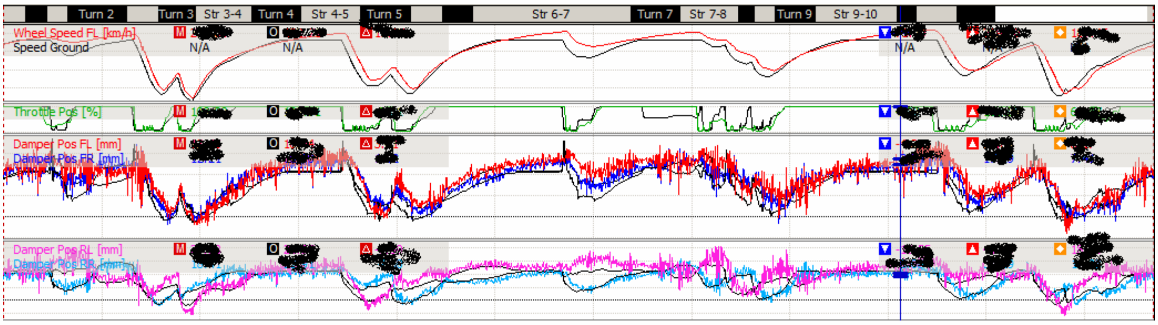


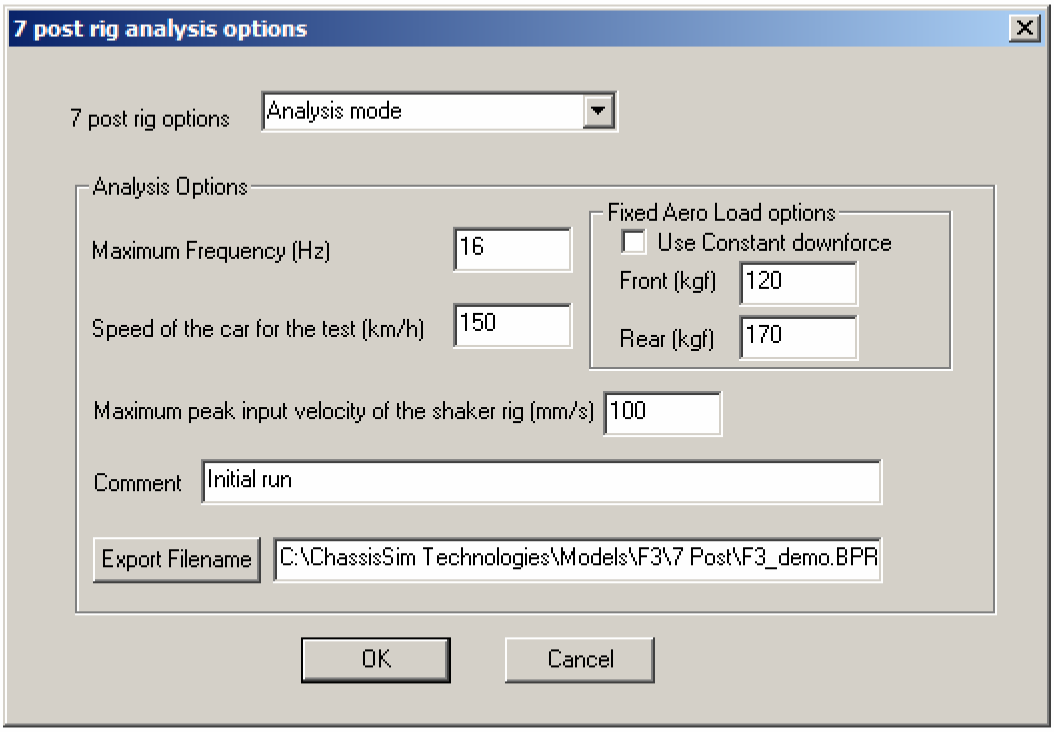
Fig-4 – Revised simulated comparison

As can be seen in pitch, the rear in particular is significantly better. At this point in the analysis we are not looking for picture perfect correlation. We just need to be within a couple of mm. This is what we have achieved in this comparison. Once where we at that point the numbers where re-run through the aero toolbox and they where far more representative.

While this example might border on the trivial it shows that your simulator can be used to quantify very quickly if there is an error in your car measurement. If truth be told one of the major benefits of using race car simulation is that it is the ultimate motorsports calculator that will quickly quantify if there have been any errors in measuring up the car. What we have just seen here is a perfect case in point.

The last case study I want to talk about is the use of the ChassisSim shaker rig toolbox. I realised it wasn't that long a go I wrote a dedicated article about this. That being said this toolbox is now starting to get significant traction right across the ChassisSim community. What we are about to discuss has been used in categories as diverse as touring cars, High downforce open wheelers, FIA GT and stockcars/touring cars. Consequently I would be mad not to include it in this discussion.

First things first let's discuss setting up and running the ChassisSim shaker rig toolbox. This is outlined in Fig-5,



7 post rig options: Analysis mode

Maximum Frequency (Hz): 16

Speed of the car for the test (km/h): 150

☐ Use Constant downforce

Front (kgf): 120

Rear (kgf): 170

Maximum peak input velocity of the shaker rig (mm/s): 100

Comment: Initial run

C:\ChassisSim Technologies\Models\F3\7 Post\F3_demo.BPR

Fig-5 – Setting up a frequency run

The comments and filenames are pretty self explanatory. Just put in something relevant to the setup and store the log file for test where you are going to remember it. However the controls you need to pay attention are the speed of the test and the peak input velocity of the road input.

You choose the speed of the test to choose the corners you want to simulate. If you want to simulate a low speed corner choose say 100 km/h, or if you are looking at a high speed corner you choose say 150 – 170 km/h. You'll also notice you have an option to set the downforce at a fixed value. This is ok for validation work, but personally I prefer to leave this off. The reason is the ride height map will impact on the frequency response of the car and in high speed corners this will make its presence felt.

In terms of the peak input velocity you choose a value that represents the peak input velocity that is representative of the road input. There are a number of ways you can do this. For a rough rule of thumb, 50 mm/s approximates a relatively smooth surface, 100mm/s is middle of the road, and 150mm/s represents a pretty bumpy circuit. Another way you can do it is look at the data. Look at the peak damper velocity and divide the results by say about 3. It's a rough measure but it will get you by. If in doubt start the test at 100mm/s.

In terms of what this toolbox is it will return a plot of Output Amplitude on input Amplitude. The output of the toolbox is shown in Fig-6,

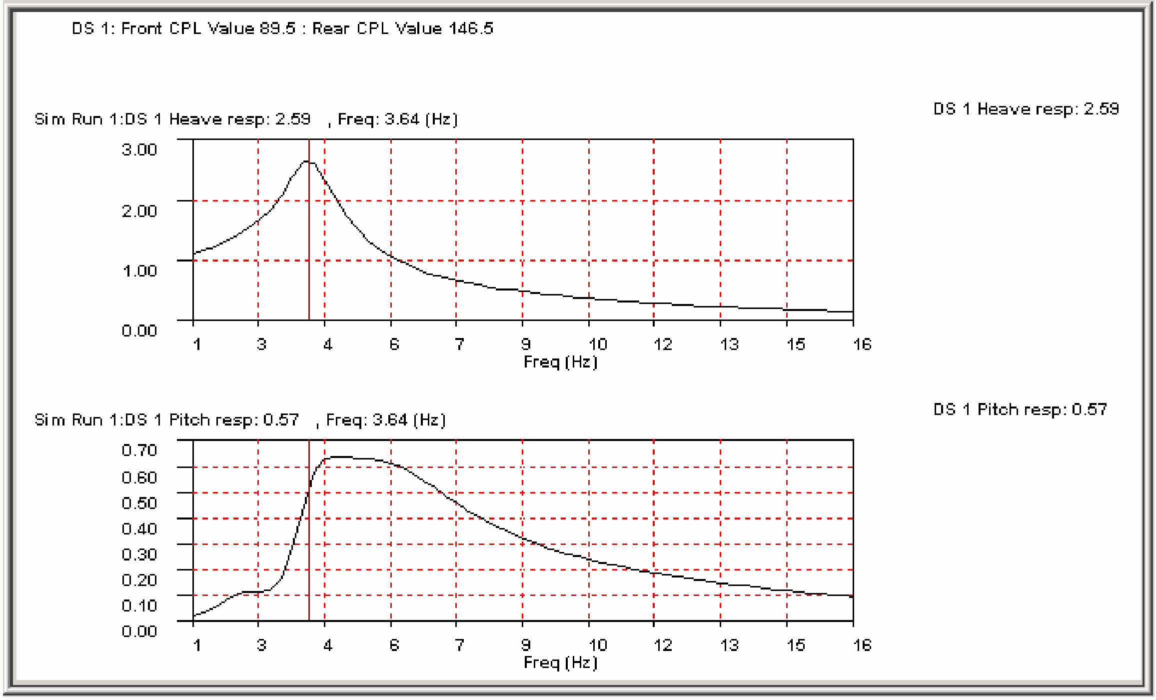


Fig-6 – Output of the shaker rig toolbox.

You'll see that the Contact Patch Load variation (CPL) is shown in the top of the graph. This is averaged over the whole frequency run and the units are kg. This is the delta load variation from the static load for the conditions specified for the test. The plots below are the ratio of output vs input amplitudes. Here we have shown heave and pitch for a heave input to the car.

However the real power of this toolbox is tying the CPL figures with the frequency response. This technique was actually pioneered by a colleague of mine Pat Cahill when he was engineering a GT car at Bathurst in 2011. The technique is actually breathtakingly simple. The first part of the process is that you play with springs and large damper adjustments to minimize CPL. What will happen is when you get into the zone the CPL will hit a minimum and actually won't vary too much. Once you hit this you start playing with minor spring and damper changes to get the shape of the frequency response that you want. It's actually that simple. This technique has been used very successfully in cars with C_LA numbers from 1.2 – 2.7. The result of this has been a marked improvement in mechanical grip without compromising driver feel.

The key to all the examples we have spoken about is don't go silly with the simulator and always closely look at the results. Remember at the end of the day a simulation package at its core really is just a glorified calculator. Yes it's a powerful, but just bare in mind that the real power of this is the end user making good use of the results. A case in point was an apprentice of mine was looking at some downforce sweeps for a low downforce circuit. ChassisSim pointed him towards low downforce and forward aero balance. The numbers it pointed weren't particularly outrageous but they where a tad aggressive. At this point I reminded him of this principle. The simulator gives you a direction, but you always temper it with experience. This is why we started the car with more downforce and less aero balance. As the drivers got up to speed we ultimately headed that way. The moral of the tale is the simulator is just one of many inputs you'll use to make your decision.

In closing I think you can start to appreciate that a racecar simulation package isn't just a tool to predict lap times and refine setups. When used properly and appropriately it can quantify what the tyres are doing, help you nail down motion ratios, and genuinely understand the frequency response of the car. If truth be told we have just scratched the surface of what we can do with simulation. However just remember always look at the results carefully and use it as one of many inputs you will use. If you use a simulation package in this manner it will be a weapon you can't do with out.