Suspension Simulation Using MBD

Modern computer simulation tools allow the design and development of automotive suspension systems without the need for physical parts or testing. Brett Longhurst from Bremar Automotion explains the basics of suspension modelling using Multi Body Dynamics.

Computer simulation of engineering designs is becoming commonplace these days, allowing the development of components and systems 'virtually'. Finite Element Analysis (FEA) was covered in a previous technical article, and in this article, we're going to look at the simulation of mechanisms using a technique called Multi Body Dynamics (MBD) using an automotive suspension system as an example.

MBD allows the modelling of a mechanism and calculates the motion of each of its components, along with all the associated forces, velocities and accelerations of any point in the system. It also allows the designer to understand contact or interference conditions between components as the mechanism moves through its intended motion. Virtually any system can be modelled using MBD, from a windscreen winder mechanism or gear linkage, right through to suspension systems or the handling characteristics of a complete car.

The Model

In its most basic form, an MBD model consists of any number of links or bodies, which are connected by various types of joints. The links are treated as rigid bodies (ie. they don't flex or bend), can be of any shape, and will each have mass and inertia. The joints are treated as being non-compliant (ie. they are solid connections and don't have any flexibility, like a rubber bush would allow), and can be one of a variety of types from a simple revolute or pivot joint, through to a universal or ball joint.

More complex MBD models allow for flexible bodies, compliant joints and connections between links using springs, dampers or gears. Even complex logic and control systems can be modelled, meaning that almost any system that can be built, can be simulated using MBD.

Figure 1 on the following page gives a complete view of our example suspension system, while Figure 2 shows the various links & joints in more detail.

MBD Process:

1. Modelling

(assembly, inputs & outputs)

2. Solving

(computer calculation)

3. Post Processing

(results interpretation)

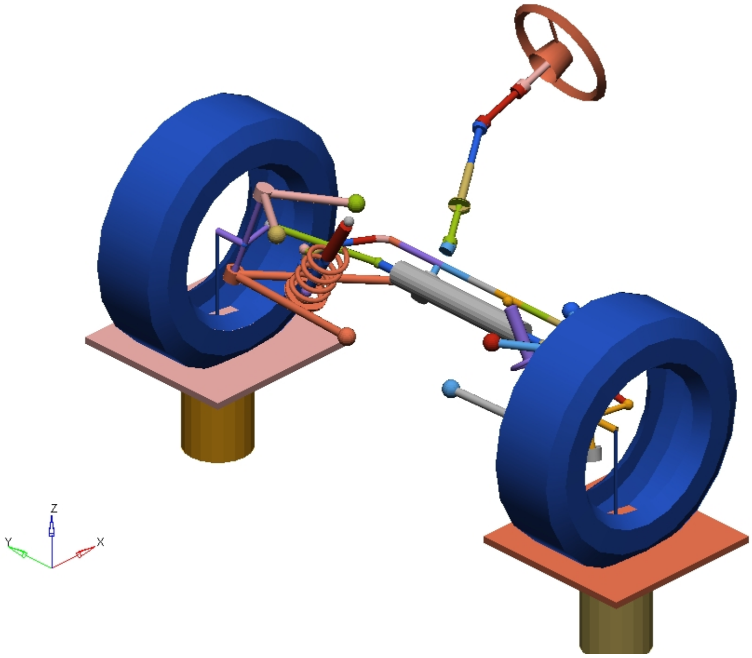


Figure 1 – Complete System

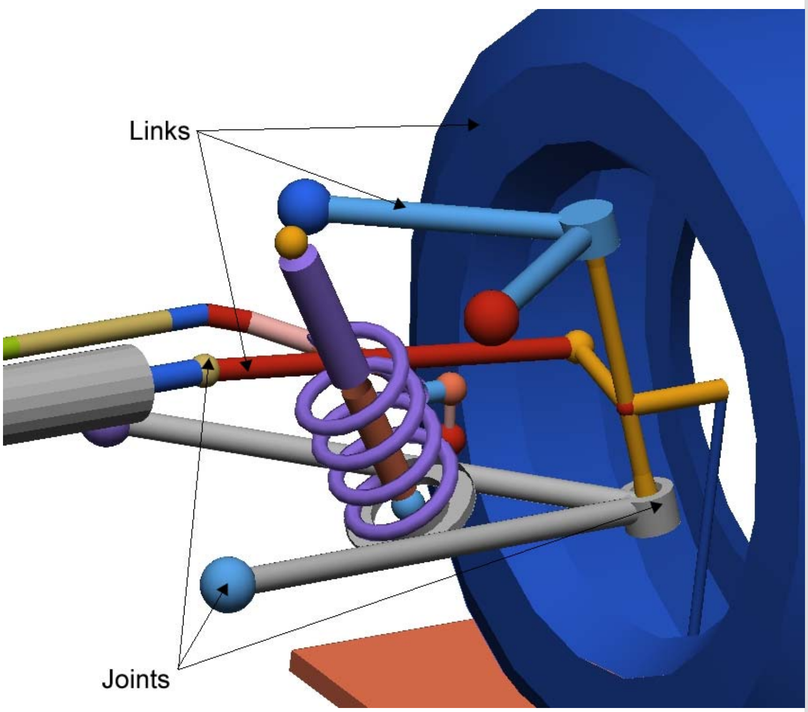


Figure 2 – Closeup System

General MBD Model:

:: rigid links (ie. no flexing)
:: solid joints connecting links
:: input forces or motions
:: requested analysis outputs

Advanced Models:

:: flexible links
:: compliant joints (eg rubber busings)
:: gears, springs, dampers

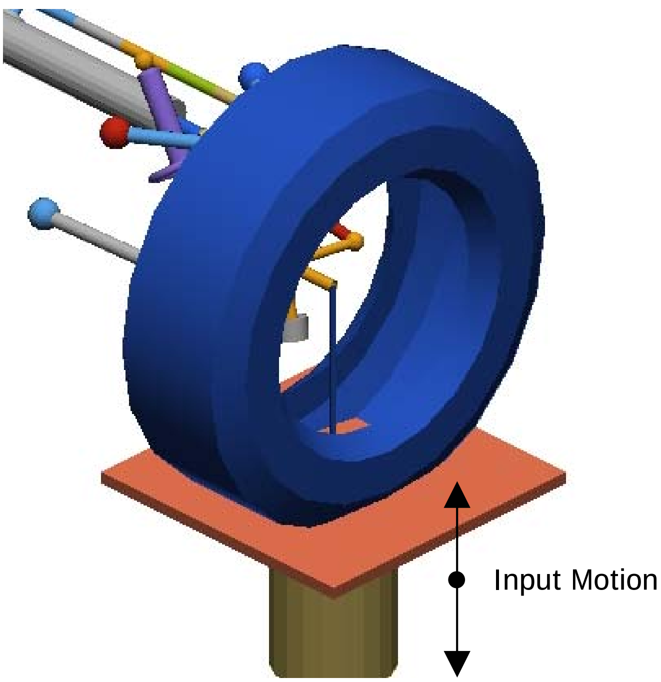
Inputs

Once the various links have been created and connected together using joints, the inputs to the mechanism can be defined. This can be done by either:

- defining a motion for a joint or link in the mechanism (either a displacement, velocity or acceleration)
- defining an external force or torque acting on the system.

Which method you use really depends on the type of analysis you're doing and what outputs you're interested in looking at.

In our suspension example, we're interested in the motion of the wheel (such as camber, castor and toe) along with forces such as wheel rates and roll stiffness as the wheel moves through its available travel. This is generally referred to as the system's "kinematics". In this example, we'll be using a defined motion to control the system rather than an external force, since we know what travel we want to move the wheel through. In this case, the input motion for each wheel will be the displacement in the vertical direction from ride height, up to full bump (jounce), down to full droop (rebound) and back to the ride height position.



Outputs

The final step before running the simulation is to define the outputs you're interested in looking at. Again, there are various ways to do this and you can output any parameter you like. Displacement, velocity, acceleration and force at any joint can be output, or indeed any point of interest on the mechanism. One of the main advantages of MBD simulation over physical testing is that it allows a much better understanding of the motions and forces within the system. The sensors required to obtain this information from a physical test would be expensive, and in most cases impossible to actually install. You can also use math functions to define outputs that no sensor could even measure.

As mentioned earlier, outputs for our suspension example would include camber, castor and toe of each wheel. These outputs would be defined as being the rotational displacement of the wheel/hub/upright assembly about each of the longitudinal, lateral and vertical vehicle axes respectively.

Possible Inputs/Outputs:

:: force
:: torque
:: displacement
:: velocity
:: acceleration
:: user defined functions

We may also be interested in wheel rates and roll stiffness. These parameters can be calculated if we know the amount of force at the tyre contact patch. Whilst we're using a defined motion to move each wheel rather than an external force, the analysis is able to tell us how much force is required to move the wheel through the defined travel. This can be considered equivalent to the force at the tyre contact patch, and through use of some math functions, can easily be converted into outputs for wheel rate and roll stiffness.

Solving

So to recap, the assembled model consists of a number of links or bodies, connected by various types of joints. An input has been defined for our analysis, which in this case is the displacement of each wheel moving through its available travel. And the outputs that we're interested in, being camber, castor, toe, wheel rate and roll stiffness have all been defined.

Now the model is submitted to the MBD solver, which does all the calculations based on the model and inputs you've given, and returns the outputs you've requested. The solver will output an animation of the mechanism motion to allow visualisation of the motion, along with any outputs you've requested as raw data which can then be plotted on a graph.

Results & Post Processing

Now you've got the results, it's time to present the output data in a useful form and interpret the results – a task known as post processing.

First of all, we're interested in how much bump steer our system has. This is effectively the amount of change in toe as the wheel travels up and down. Along with the baseline run, two additional setups were evaluated. The first of these was to see the effect of spacing the outer steering tie rod joint up by 10mm, the second shows the effect of moving the joint down 10mm.

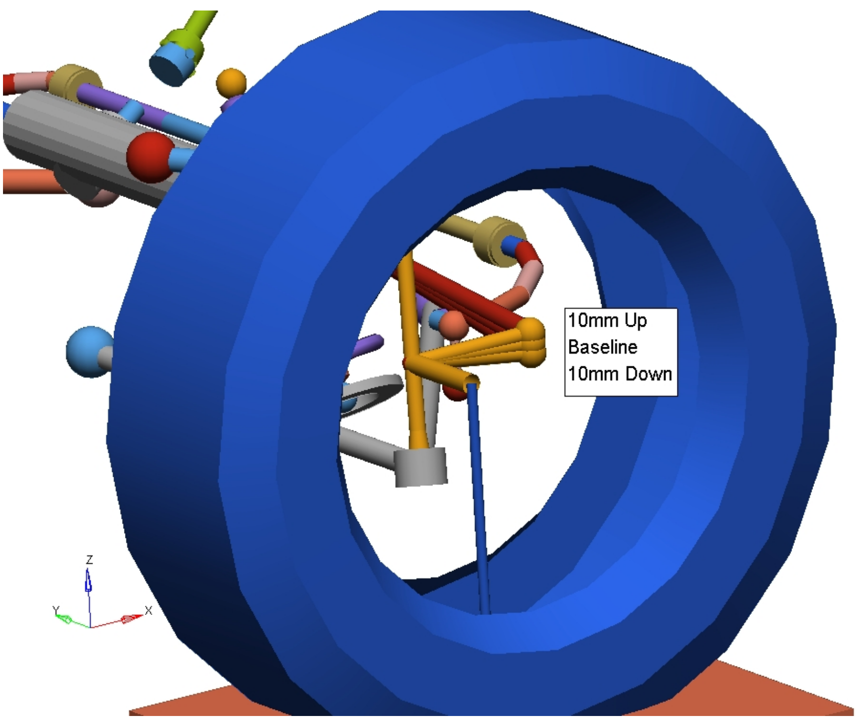


Figure 3 – Varying Outer Tie Rod Joint Height

bremar automotion

Kinematic Analysis:

:: motion & forces calculated

:: quasi static analysis

:: mass & inertia not taken into account

Dynamic Analysis:

:: motion & forces calculated

:: transient analysis

:: forces due to mass & inertia are calculated

Figure 4 shows a plot of toe angle versus vertical movement of the left wheel for each of the three setups.

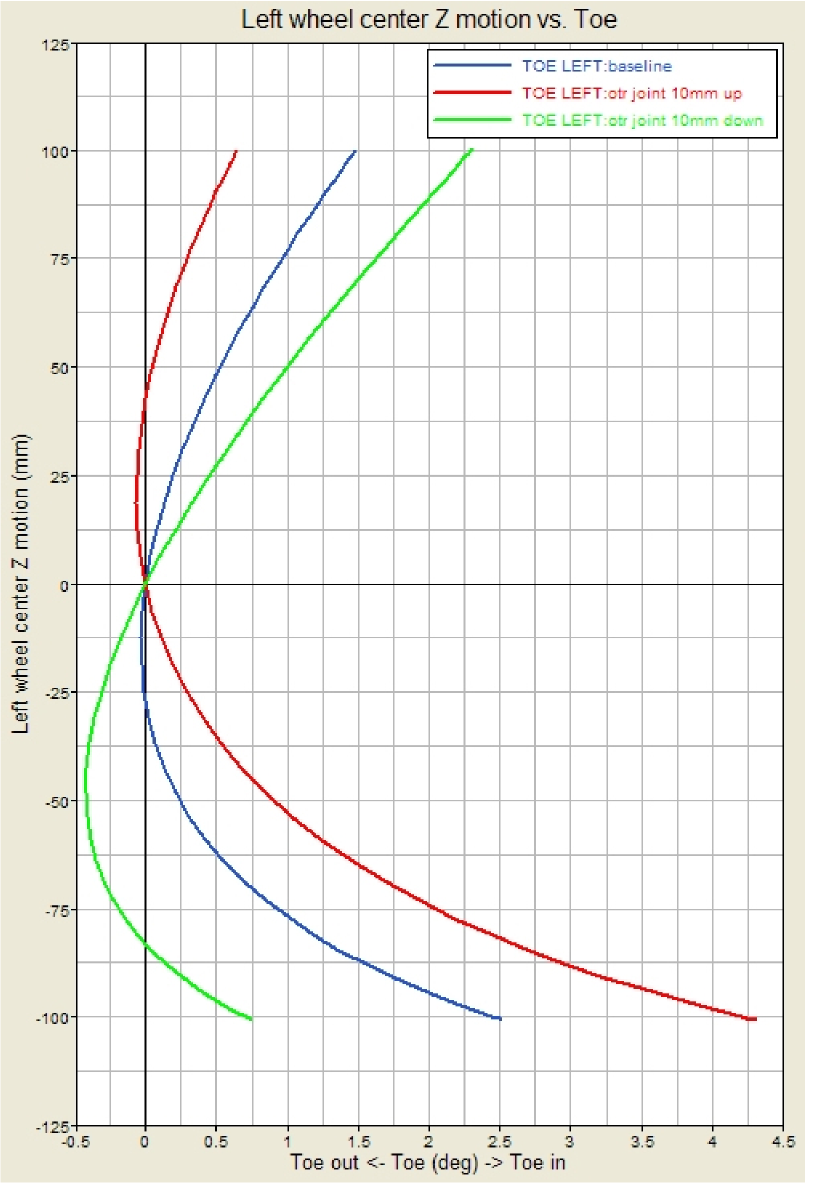


Figure 4 – Toe Curves

You can see that the static toe for each setup has been set to zero because when the wheel travel is zero, toe is also zero for each of the curves. Looking closer at the curves, the following observations can be made:

Baseline (blue)

-immediately starts to toe in as the wheel moves upwards (bump or jounce)

-continues to toe in to a maximum of 1.5deg at 100mm jounce

-remains constant as the wheel moves down (droop or rebound) until around 30mm, where it again starts to toe in

-reaches a maximum of 2.5deg toe in at 100mm droop

MBD Analysis Outputs:

:: animations of mechanism motion

:: raw data to be used in plots

Move outer tie rod joint 10mm up (red)

-remains constant until around 50mm bump, where it starts to toe in

-reaches a maximum of 0.7deg at 100mm bump

-immediately starts to toe in as the wheel goes into droop

-reaches a maximum of 4.3deg toe in at 100mm droop

Move outer tie rod joint 10mm down (green)

-immediately toes in as the wheel goes into bump, at a faster rate than either of the other setups

-reaches a maximum of 2.3deg at 100mm bump

-immediately starts to toe out as the wheel goes into droop

-reaches a maximum of 0.5deg toe out at 50mm droop

-begins to toe in to reach 0.75deg toe in at 100mm droop

Which setting is best depends on what you're trying to achieve, but by using MBD, you have a much better understanding of the effects each change is going to make.

The other output we'll look at in detail is the roll stiffness resulting from the roll bar system. For us to evaluate the stiffness contributed by the roll bar, the stiffness of the coil springs is set to zero (which is done by simply changing a value on the screen – a lot simpler than removing springs to do the same test physically!). This means any resistance to the vertical wheel movement will come directly from the roll bar.

Along with the baseline run, a second setup was evaluated where the attachment point between the roll bar drop link and the lower control arm was moved outboard by 5mm.

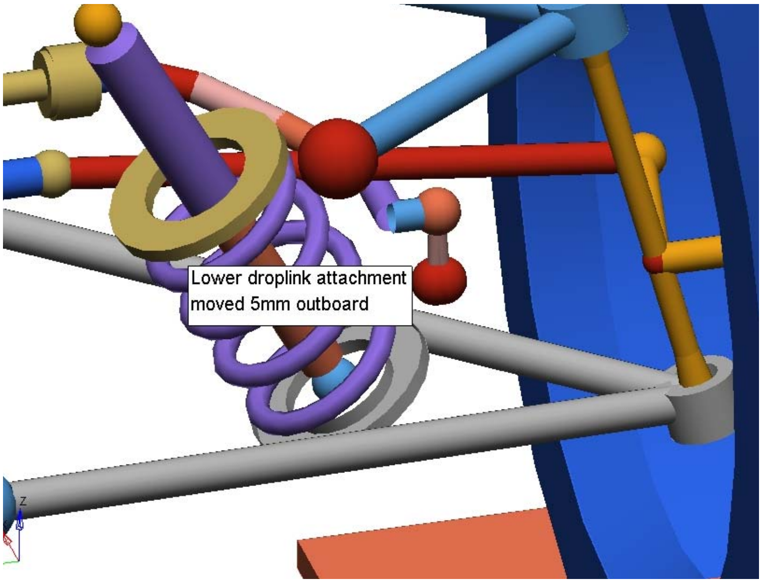


Figure 5 – Varying Droplink Mount

MBD vs Physical Testing:

:: better visualisation of motion & interactions using MBD

:: changes to geometry, forces, stiffness etc. can be made at the click of a button using MBD

:: MBD can calculate outputs that would be physically impossible to measure in a test

Figure 6 shows a plot of vertical force versus wheel travel for the left wheel. This is the amount of force required to move the wheel through its travel, remembering that the only thing resisting this movement in this analysis is the roll bar.

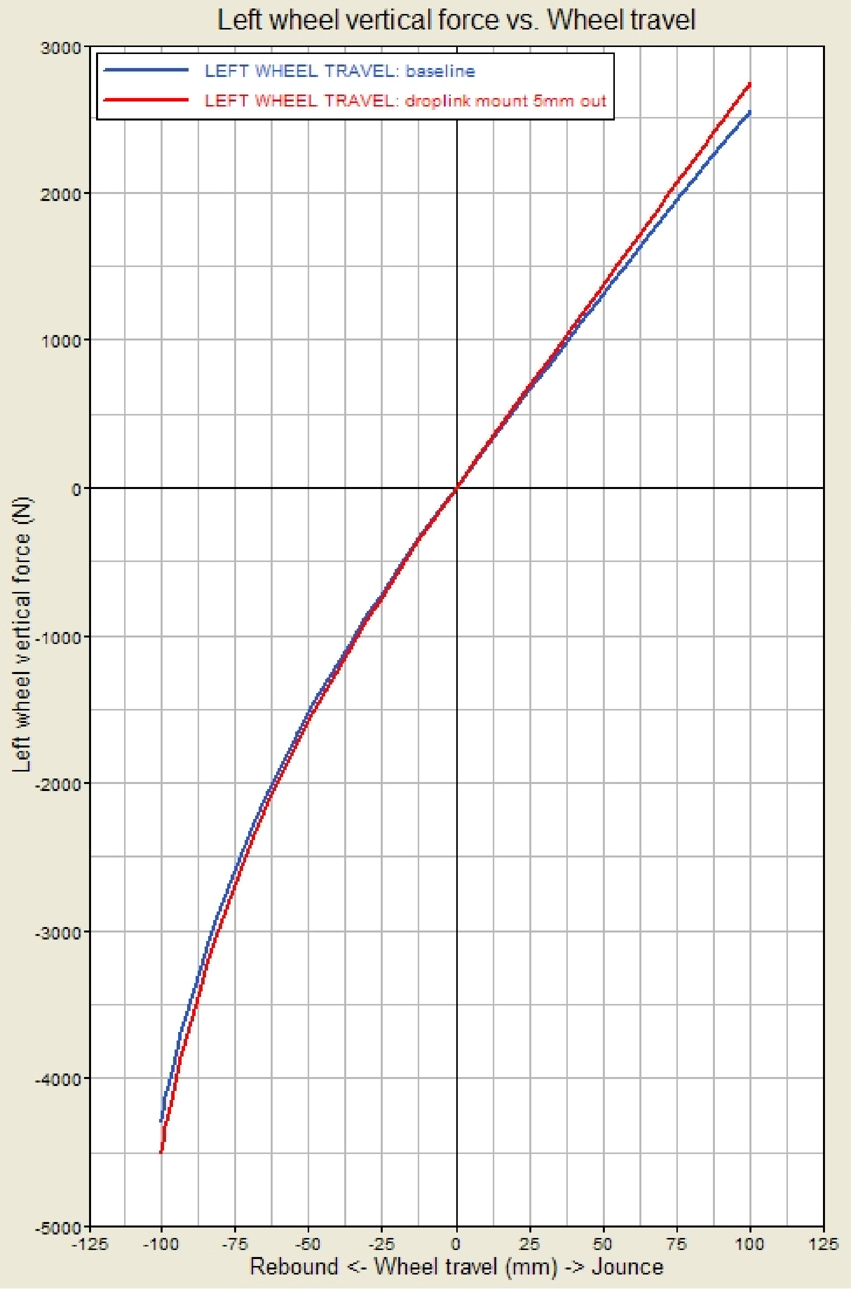


Figure 6 – Vertical Force

The two curves look quite similar, with the baseline setup showing slightly less roll stiffness as the wheel goes into bump (jounce). This occurs due to the droplink laying over during the wheel's travel.

Another way to compare the roll stiffness is to differentiate the force curves and have a look at the rate of force required per millimetre of wheel travel:

Advanced Analysis:

:: calculate stress & strain within flexible links

:: determine contact conditions between links

:: automated optimisation of model parameters & outputs

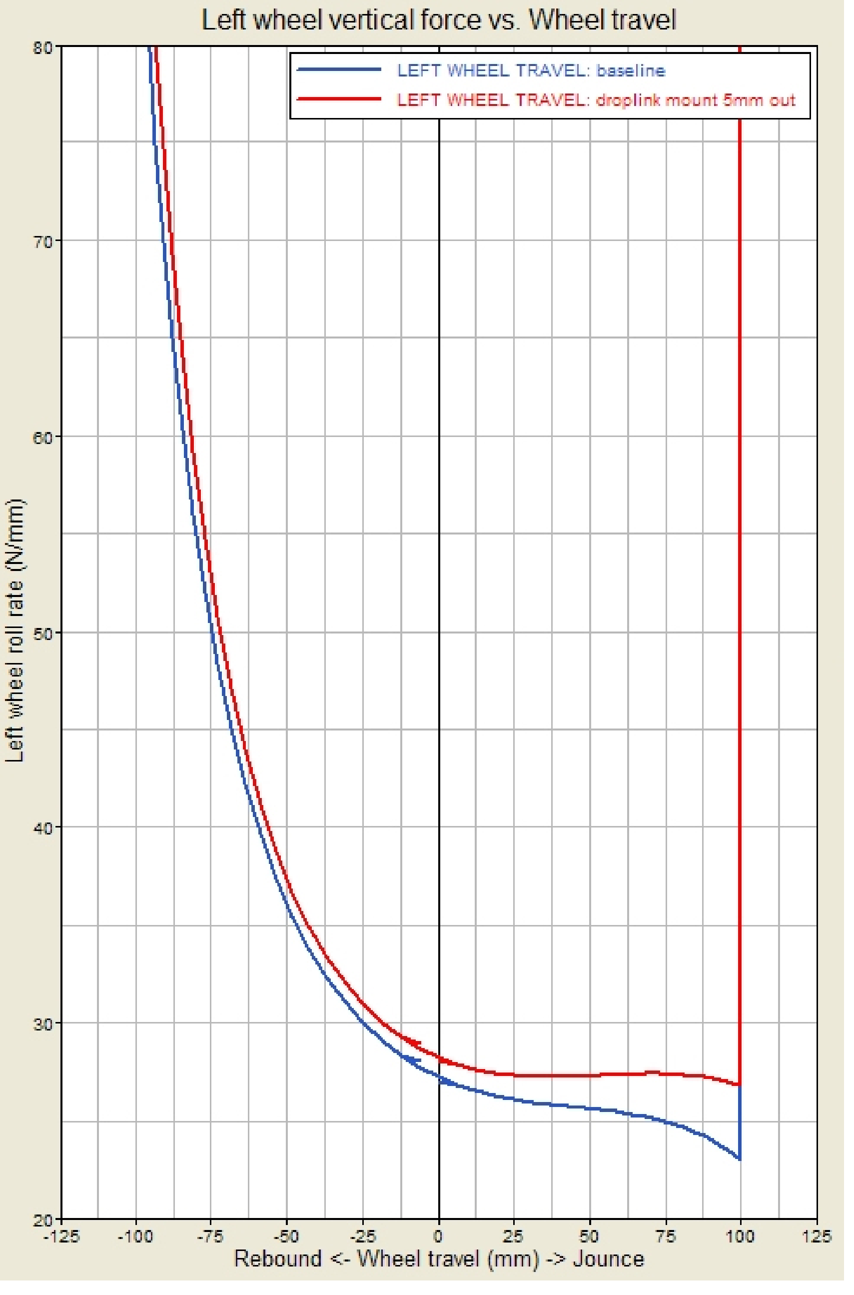


Figure 7 – Roll Stiffness

What this plot allows us to look at is the roll stiffness as a rate in N/mm, just like any other spring. In rebound the curves remain quite similar, however the jounce portion of the plot tells a different story. Here we can see that the red curve remains quite level, suggesting an essentially linear roll stiffness rate when the wheel is in jounce. The blue baseline setup however, shows the roll stiffness dropping off as jounce increases. Not only this, but it drops away quite suddenly towards the end.

This could be quite an undesirable trait when you think about the car being in a steady state, such as mid corner on a long sweeper. Imagine the car being settled mid corner, leaning to the outside which puts the outside wheel into jounce. If the wheel were to then go further into jounce due to either hitting a bump or the car turning a little harder, the roll stiffness could drop off quite suddenly upsetting the balance of the car, particularly if this is only occurring at one end of the car.

MBD Benefits:

:: less physical prototypes
:: less physical testing
:: more design iterations
:: better understanding of system
:: time & money savings

Summary

The examples shown here highlight just some of the benefits of modelling a mechanism such as a suspension system using MBD. Once the model is built, it's quick, simple and inexpensive to evaluate any number of changes to the system. Not only this, but you get an in depth understanding of the system and interactions between each component, in a way you could never achieve with physical testing alone.

More advanced analysis could incorporate:

-flexible links rather than rigid ones to allow calculation of stresses within a part

-compliant joints to represent rubber bushes in the system

-calculation and visualisation of instantaneous centres, roll centres and the like at any suspension position

-using shock potentiometer and steering angle data from a data logging system as inputs to the analysis, so you can actually visualise what the suspension and steering systems are doing

-using optimisation techniques to obtain desired system characteristics

MBD is a powerful tool and one that can be used to gain a better understanding of any mechanical system, whether you're starting a design from scratch or studying an existing mechanism.

Contact us now and let us work with you to find solutions to your CAE problems & benefits for your business.

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Bremar Automotion is an engineering design company based in Melbourne, Australia specialising in computer simulation of engineering problems at a practical, hands on level and is committed to making these simulation tools accessible to all levels of engineering and motorsport.

For more information, see www.bremarauto.com or contact Brett Longhurst on 03 9029 3323.