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Twist Beam Suspensions: Using 2D Tables

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One of the most popular rear suspensions for small cars is the Twist beam, or "Torsion beam" suspension. A common design of the twist beam suspension is shown in Figure 1, where two trailing arms - one on each side left and right - are connected by a cross-beam. The structure is typically an H-shaped beam, but some are U-shaped, since the cross beam terminates to either pivots or wheels (Figure 1). The structure is flexible with moderate stiffness and damping, and when the car rolls, the beam twists.

Figure 1. Twist beam rear suspension: SUZUKI BALENO 2016.

Mechanical Simulation has made several twist-beam suspension models in CarSim in the last 13 years:

- 1st generation: CarSim version 6.0 (August 2004 – March 2007); discontinued
- 2nd generation: CarSim version 7.01 (June 2007 – present); the Twist Beam (Legacy)

- 3rd generation: CarSim version 9.0 (October 2014 – present); the Twist Beam (2016)

The first-generation model was based on an independent suspension model with two independent, 1D tables constraining each wheel's motion; toe with respect to jounce and toe with respect to roll. The second-generation model was based on a rigid-axle model with a force-geometric roll center. The third model was based on an independent suspension model with extended quasi-static compliances, and is described in an earlier Tech Memo: *Twist Beam Suspensions: Using VS Commands*. All three of those models are aimed at the same type of suspension, but with different modeling concepts. Although they are conceptually highly advanced, the parameters and data for those models can be difficult to measure using typical K&C tests.

The twist beam model described in this document is the newest: A fourth-generation model, included in version 2018.0 of both CarSim and TruckSim. The model works for both an independent suspension and twist beam, and each kinematics and compliance table can be extended from 1D to 2D (selectable) with an additional independent variable, typically jounce of the opposing side of the suspension. The model is inherently an independent suspension in that all kinematics and compliance tables are one-dimensional. However, the model works for twist beam suspensions such that wheel motion is influenced by the opposite side jounce, presented in 2-dimensional tables. Therefore, the new suspension model is named **Generic/Independent**. Because the name "Independent" has been used since CarSim was introduced, the name "Independent" still appears in many places.

Suspension Measurement and Characterization

The main objectives of the new twist beam model are:

The input data is to be based on the suspension characteristics, which we are able to measure and characterize by typical K&C tests, and

The calculations for wheel motions and force reaction are accurate in both static and dynamic maneuvers.

This section describes typical characteristics of the twist beam with the suspension modelling program, and focuses on how to measure and characterize the suspension using typical K&C tests. Figure 2 shows a twist beam suspension as modelled in SuspensionSim. The SuspensionSim model was created by David Hall, Senior Development and Consulting Engineer, Mechanical Simulation.

> **Note:** SuspensionSim® is one of the commercial simulation programs developed by Mechanical Simulation.

The model has a trailing arm on each side that consists of three parts connected with flexible joints. Both side-arms are connected by a cross-beam through the joints. The flexible joints possess three directional rotations with moderate stiffness. This helps to express the bend and twist of the suspension structure with both parallel and opposing strokes of left and right wheels.

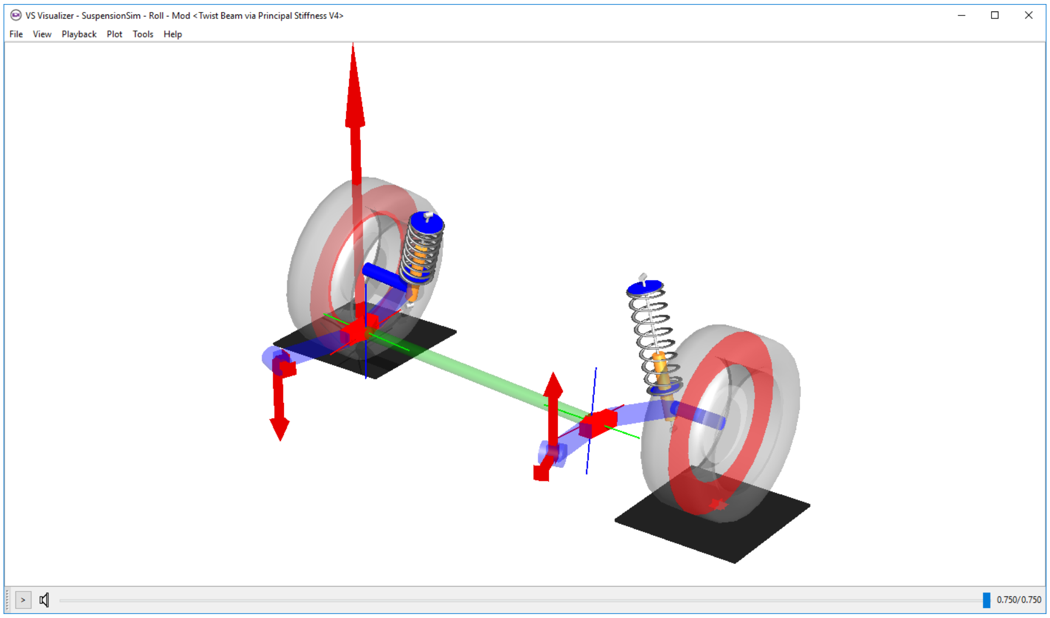


Figure 2. Twist beam Suspension in SuspensionSim®.

Suspension kinematics

Figure 3 shows suspension kinematics motion with parallel and opposing strokes on the left and right wheels. The tables provide the camber angle, dive angle, toe angle, longitudinal movement, lateral movement and spring compression with respect to wheel jounce of each wheel. As shown, the kinematics motions vary when the suspension heaves; e.g. left and right wheels have a parallel stroke as opposed to when it rolls (left and right wheels have an opposing stroke). In other words, each wheel's motion is influenced by the other side's jounce.

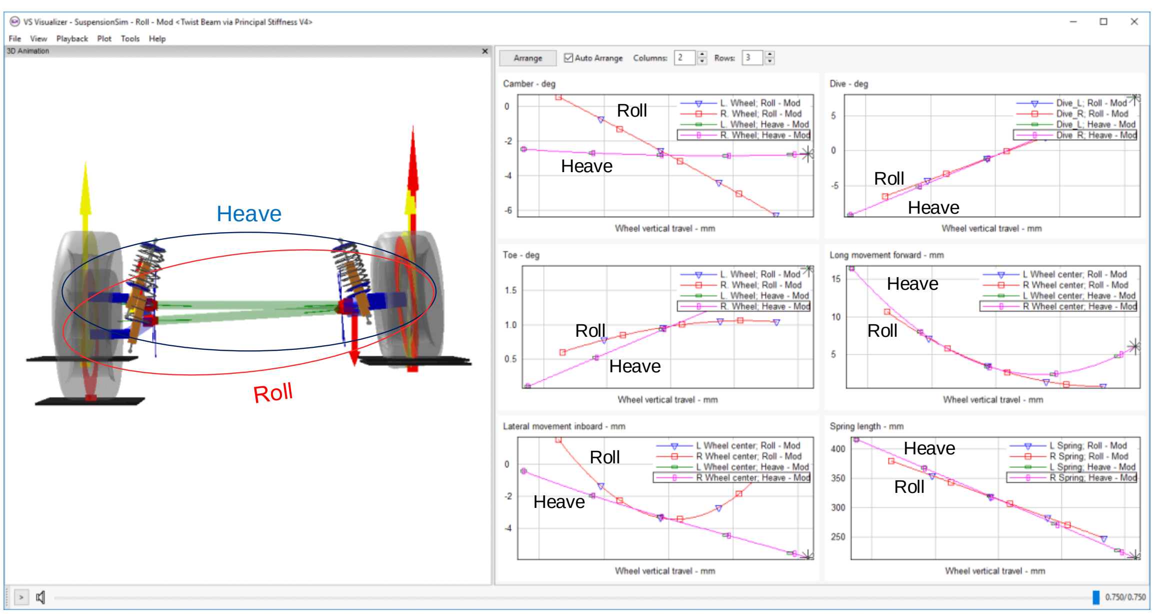


Figure 3. Suspension kinematics motions with parallel and opposed strokes.

To characterize the suspension kinematics and motion disrupted by the other side of wheel, the motions, such as camber, dive, toe, and wheel positions, can be measured with wheel jounce while the wheel on the other side is fixed at various jounce levels.

Figure 4 shows the wheel toe angle and lateral position with respect to the jounce of ±90mm on the measuring wheel while the other side wheel is fixed at various jounce levels as: -90, -60, -30, 0, 30 and 60mm. Figure 5 shows three other kinematics motions (camber, dive, toe, longitudinal and lateral position) in the same manner. As shown in these figures, each of those five kinematics motions can be expressed by a 2D table which has two independent input variables: jounce on the measuring side and the jounce on the other side. Those five 2D tables are the input data to the independent suspension kinematics screen as described in the next section.

The spring, damper, jounce stop, and rebound stop compressions can also be entered as 2D tables of jounce and jounce on the other side. These are entered on the independent suspension compliance screen as described in the next section. For this SuspensionSim model, these compression changes are identical because the model uses coil-overs (spring, damper, bump stops all in one assembly). The measured spring length data (Figure 6) thus may be used to compute the spring, damper, jounce stop, and rebound stop compression once the initial spring length is known.

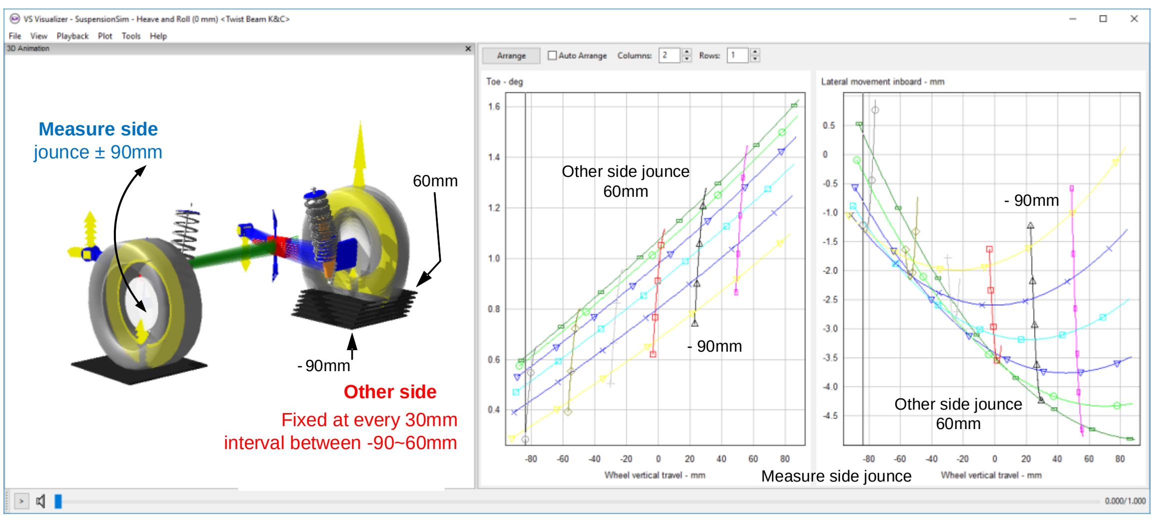


Figure 4. Suspension kinematics motion - toe and lateral position.

Note: Most K&C test facilities should be able to measure the suspension kinematics data like that shown in Figure 4, Figure 5, and Figure 6. However, it may need some data processing after physical measurements. Alternatively, the data can be created by using multibody kinematics analysis programs such as SuspensionSim, ADAMS, etc.

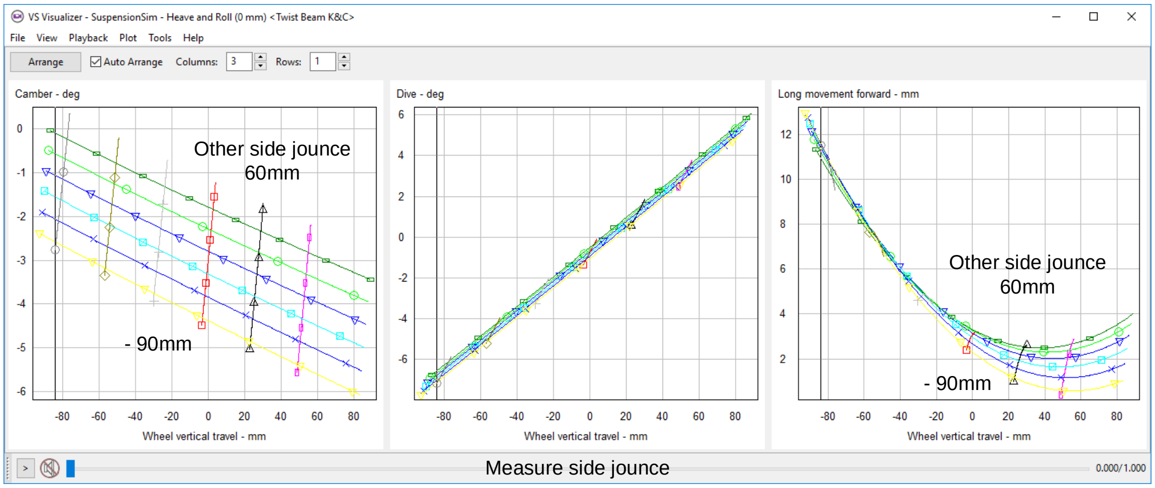


Figure 5. Camber, dive, and longitudinal kinematic motions from the SuspensionSim model.

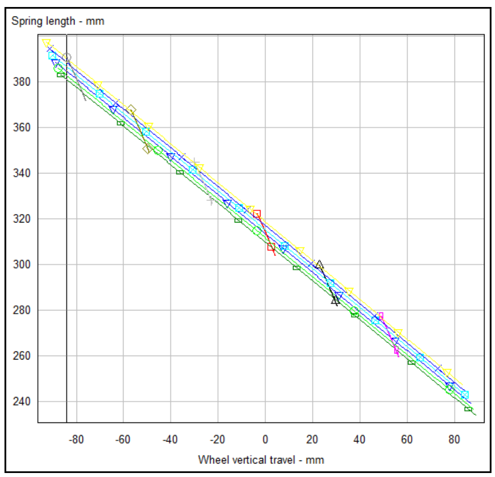


Figure 6. Spring length may also be measured in SuspensionSim.

Suspension compliances

Figure 7 shows suspension compliances such as camber, toe and longitudinal deflection, with tire longitudinal forces acting in a parallel and opposing directions on left and right wheels. Figure 8 shows suspension compliances - camber, toe and lateral deflection - with lateral forces on tire acting in parallel and opposing directions on left and right wheels. As shown in these figures, the wheel movements differ when the tire forces act in parallel or opposing directions on the left and right wheels. In other words, each wheel's compliances are influenced by both sides of the wheel's tire forces.

To characterize the suspension compliances disrupted by the other side's tire forces, the wheel movements (such as camber, toe, and wheel deflections) can be measured with tire forces applied on both sides in parallel and opposite.

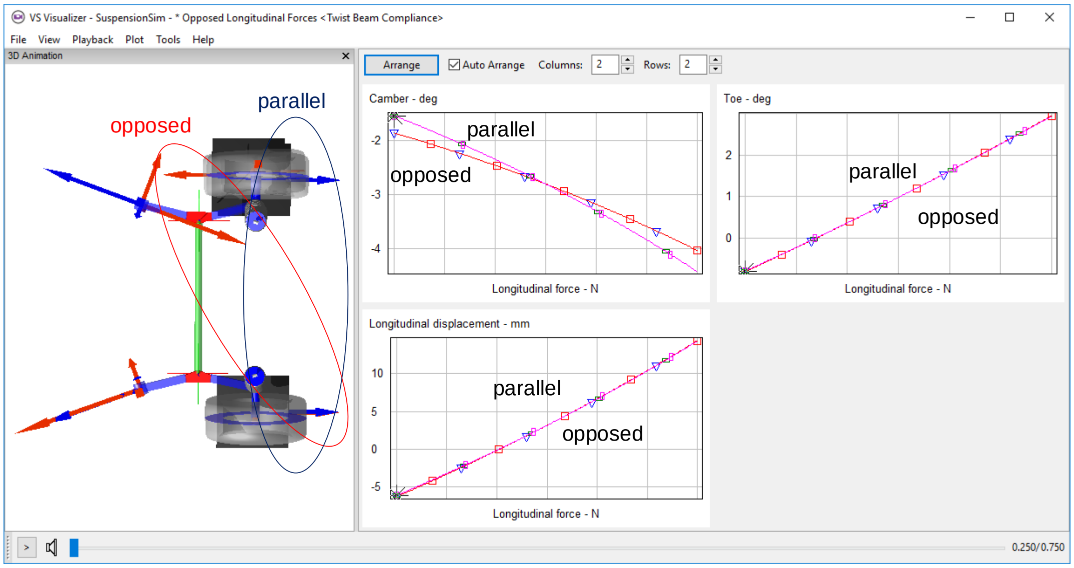


Figure 7. Suspension compliances with parallel and opposed longitudinal tire forces.

Figure 9 shows the suspension camber angle change with respect to the longitudinal tire force of ±3000N applied on the measuring wheel while various levels of constant longitudinal tire force applied on the other side wheel as: -3000, -2000, -1000, 0, 1000 and 2000N. Figure 10 shows the suspension camber angle change and lateral deflection with respect to the lateral tire force of ±3000N applied on the measuring wheel while various levels of constant lateral tire force applied on the other side wheel as similar manner.

As shown in Figure 9 and Figure 10, suspension compliance can be expressed by a 2D table which has two independent variables of input (tire forces on the measuring side and the other side). CarSim has 9 existing suspension compliance tables and they can be extended from 1D to 2D tables, and those data settings are described in the next chapter.

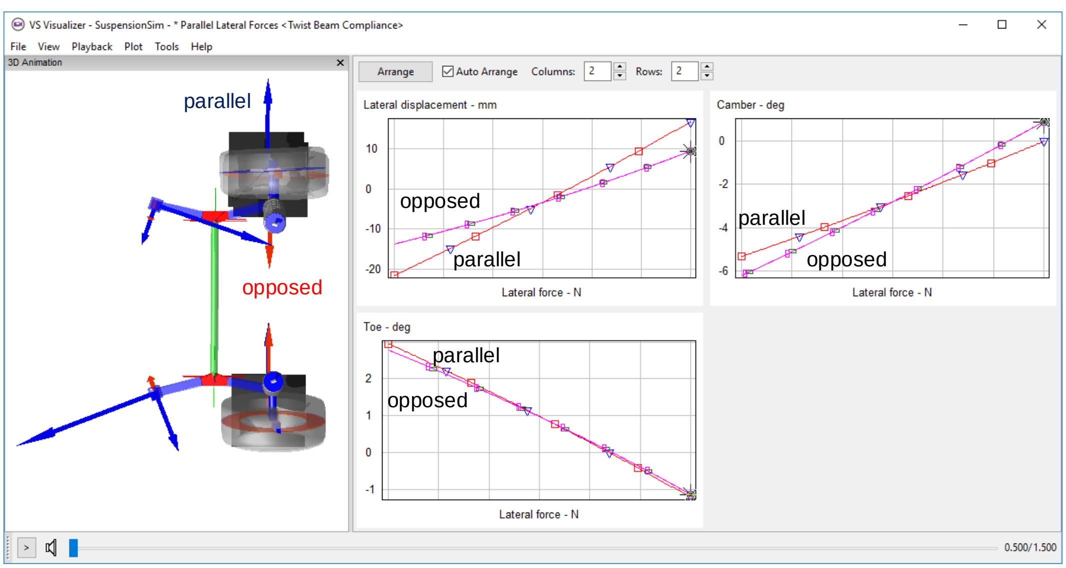


Figure 8. Suspension compliances with parallel and opposed lateral tire forces.

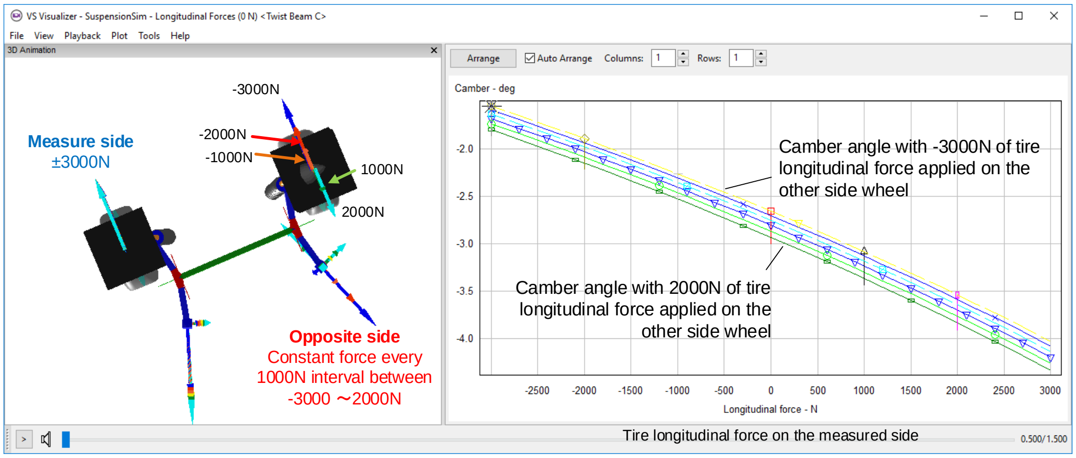


Figure 9. Suspension camber angle change w.r.t the longitudinal tire force.

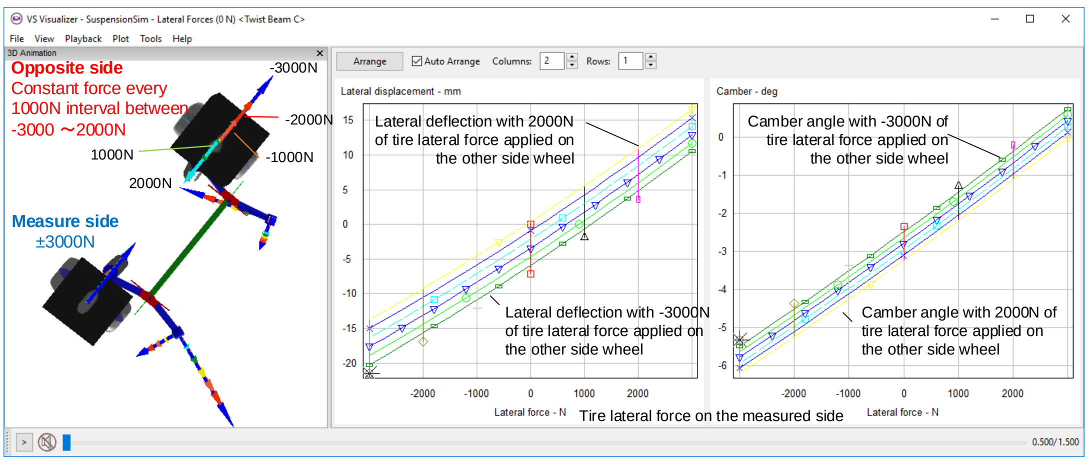


Figure 10. Lateral deflection and camber angle change w.r.t the lateral tire force.

Note: Most K&C test facilities should be able to measure the suspension compliances like those shown in Figure 9 and Figure 10. However, it may need some data processing after the measurement. The data can be created by using multibody kinematics analysis programs such as SuspensionSim, ADAMS, etc.

Data Settings in CarSim and TruckSim

Starting with version 2018.0, configurable functions for suspension kinematics and compliance for the existing independent suspension model are extended from 1D to 2D tables, and the K&C measurements from the twist beam suspension can be set by 2D options.

Drop-down lists on the **Vehicle: Assembly** screen (CarSim), all vehicle lead unit screens (TruckSim), and all trailer screens (CarSim and TruckSim) are used to choose the suspension type for each axle. The existing independent suspension works for both independent and twist beam. The name appears on the list as **Generic/Independent** in CarSim (Figure 11).

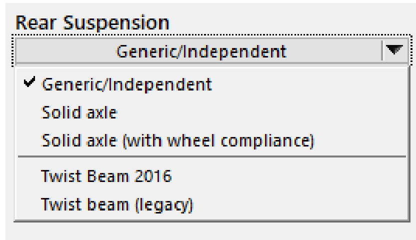


Figure 11. Selection of the Generic suspension in CarSim

Note: The name of **Independent suspension** remains in the suspension type drop-down menu in TruckSim.

Suspension kinematics

There are nine configurable functions for the suspension kinematics that can be expressed by 2D tables with two independent input variables of the suspension jounce on the measured side and opposite side of axle. Table 1 lists those table library screens which are linked from five suspension kinematics blue fields on **Independent Kinematics** library screen (Figure 12).

Table 1. Suspension kinematical table libraries with the 2D option.

Library Screen	**Root Keyword(s)**
Suspension: Camber Angle	CAMBER
Suspension: Dive Angle (Caster Change)	SUSP_DIVE
Suspension: Lateral Movement Due to Jounce	SUSP_LAT
Suspension: Longitudinal Movement	SUSP_X
Suspension: Toe Angle	TOE

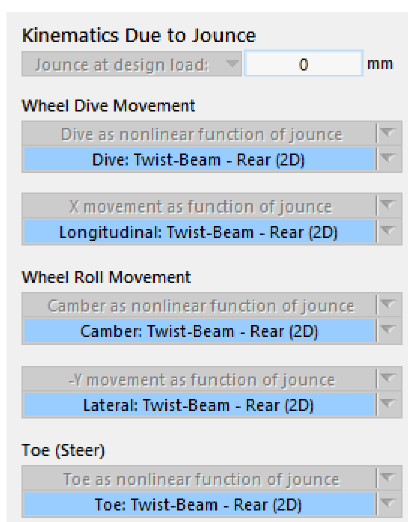


Figure 12. Suspension kinematics from the Independent Kinematics library screen.

Figure 13 shows one of the kinematics table libraries (lateral movement). Select **2D spline interpolation & extrapolation** from the drop-down list of configurable functions ① to use the 2D option.

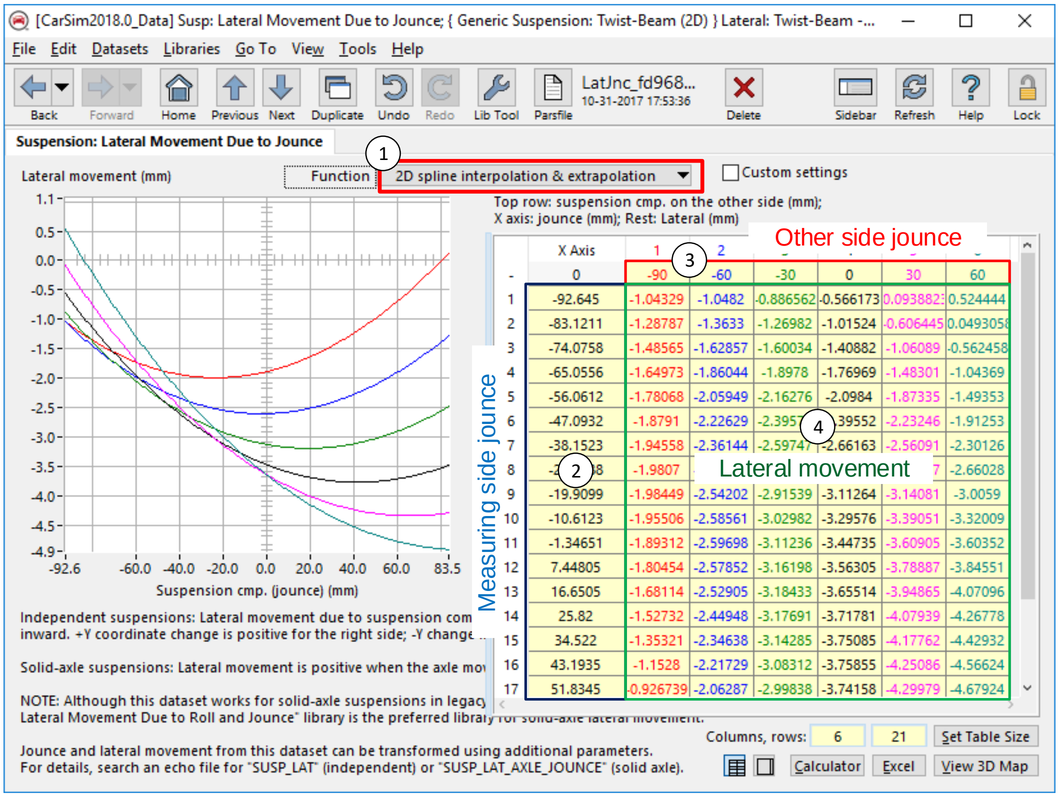
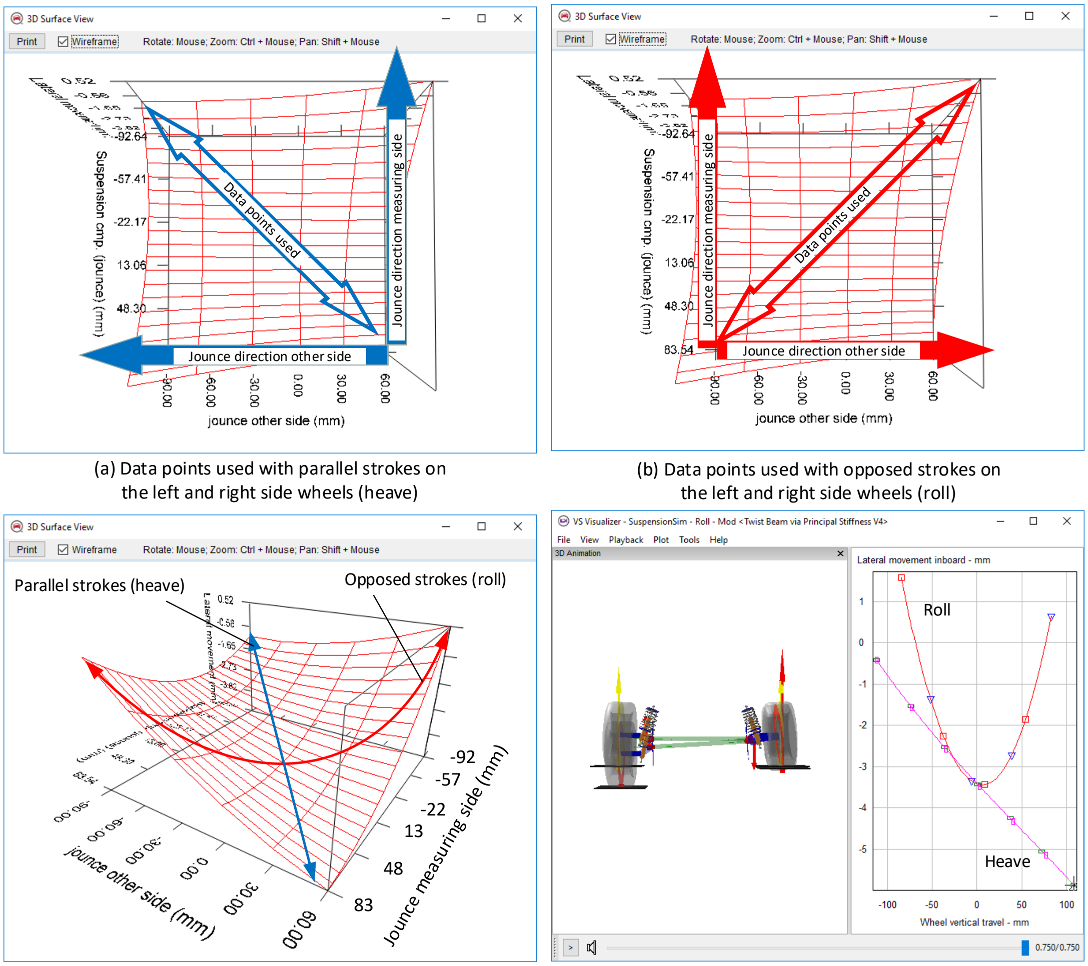


Figure 13. Table library for lateral movement due to jounce with the 2D spline option.

As shown in Figure 13, the first column ② is the suspension jounce on the measuring side while the first row ③ is the jounce on the other side of the axle. The rest of data ④ are the lateral displacements of the wheel. The data points on the 2D table are used diagonally in most vehicle maneuvers (heave and roll), but the direction is different when the left and right wheels stroke in parallel or opposite, as shown in Figure 14 (a) and (b). The tabular data in 3D view shows that the wheel trajectory is highly nonlinear when the suspension rolls while the trajectory is linear when it heaves as shown in Figure 14 (c). The characteristics are correlated with the SuspensionSim analysis in Figure 14 (d), which is the source of the tabular data.



(a) Data points used with parallel strokes on the left and right side wheels (heave)

(b) Data points used with opposed strokes on the left and right side wheels (roll)

(c) Data points used with parallel and opposed strokes on the left and right side wheels (3D view)

(d) Lateral movement with parallel and opposed strokes on the left and right wheels simulated by SuspensionSim®

Figure 14. 2D kinematics data points: (a) heave condition; (b) roll condition; (c) kinematic data in 3D view; and (d) original data from SuspensionSim®

The other four 2D configurable functions for the suspension kinematics are set from the **Independent Compliance** library screen. These establish the spring, damper, jounce stop, and rebound stop compressions as functions of jounce and jounce on the other side. The root keywords are `CMP_SPR_SEAT`, `CMP_DAMP`, `CMP_JSTOP`, and `CMP_RSTOP`, respectively. For many CarSim and TruckSim example vehicles, these data are entered as 1D coefficients (component compression divided by wheel jounce) using the yellow fields. For the 2D twist beam example, the option to use the blue link is selected, Figure 15, which allows linking to a **Generic Table** library screen which establishes the 2D compression relation (Figure 16).

> **Note:** The spring, damper, jounce stop, and rebound stop compressions as 2D tables was new for version 2021.1. Prior to this version, these keywords of `CMP_SPR_SEAT`, `CMP_DAMP`, `CMP_JSTOP`, and `CMP_RSTOP` were supported for 1D tables only (jounce, but not jounce on the other side).

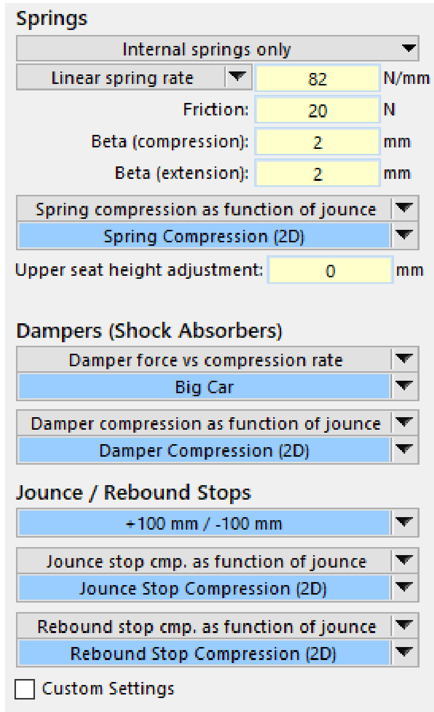


Figure 15. Using blue links on the Independent Compliance library screen to establish the spring, damper, jounce stop, and rebound stop compressions as 2D tables.

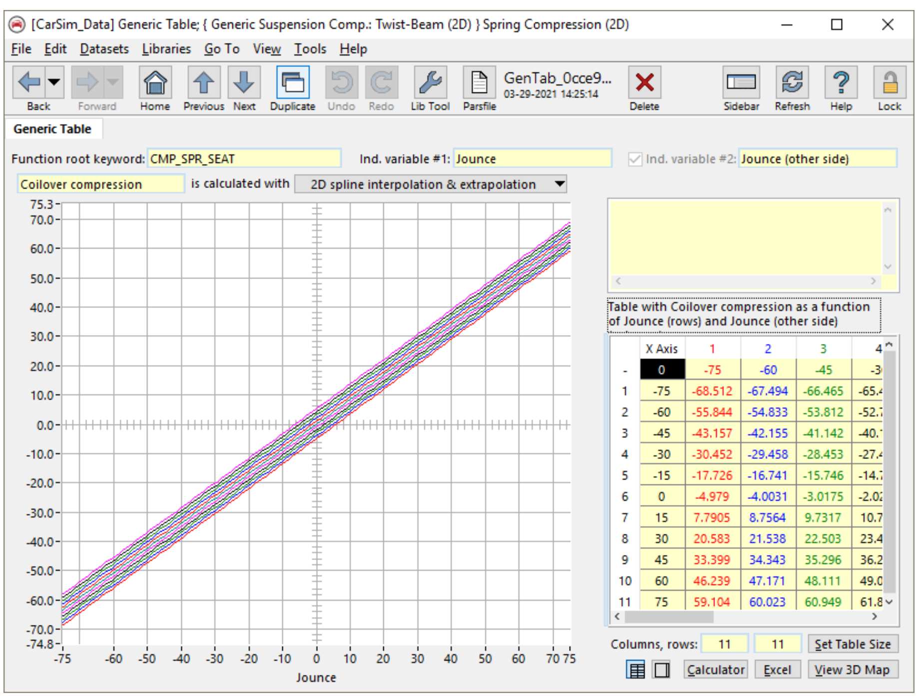


Figure 16. The spring compression given as a function of jounce and jounce on the other side.

Suspension compliance

There are nine configurable functions for the suspension compliance that can be expressed with 2D tables, using two independent input variables of the tire forces on measuring side and opposite side (Table 2). Those nine 2D tables for the suspension compliance are assembled by the **Suspension: Compliance (Nonlinear)** screen shown in Figure 17. On this screen, **Suspension type** should be set as **Independent suspension** 1.

Table 2. Configurable Functions available for the 2D table.

Root Name	Description
CT_FX	Toe angle deflection due to Fx
CS_FY	Steer angle deflection due to Fy
CS_MZ	Steer angle deflection due to Mz
CC_FX	Camber angle deflection due to Fx
CI_FY	Inclination angle deflection due to Fy
CD_MY	Dive angle deflection due to braking torque
CI_MZ	Inclination angle deflection due to Mz
C_LONG	Longitudinal deflection due to Fx
C_LAT	Lateral deflection due to Fy

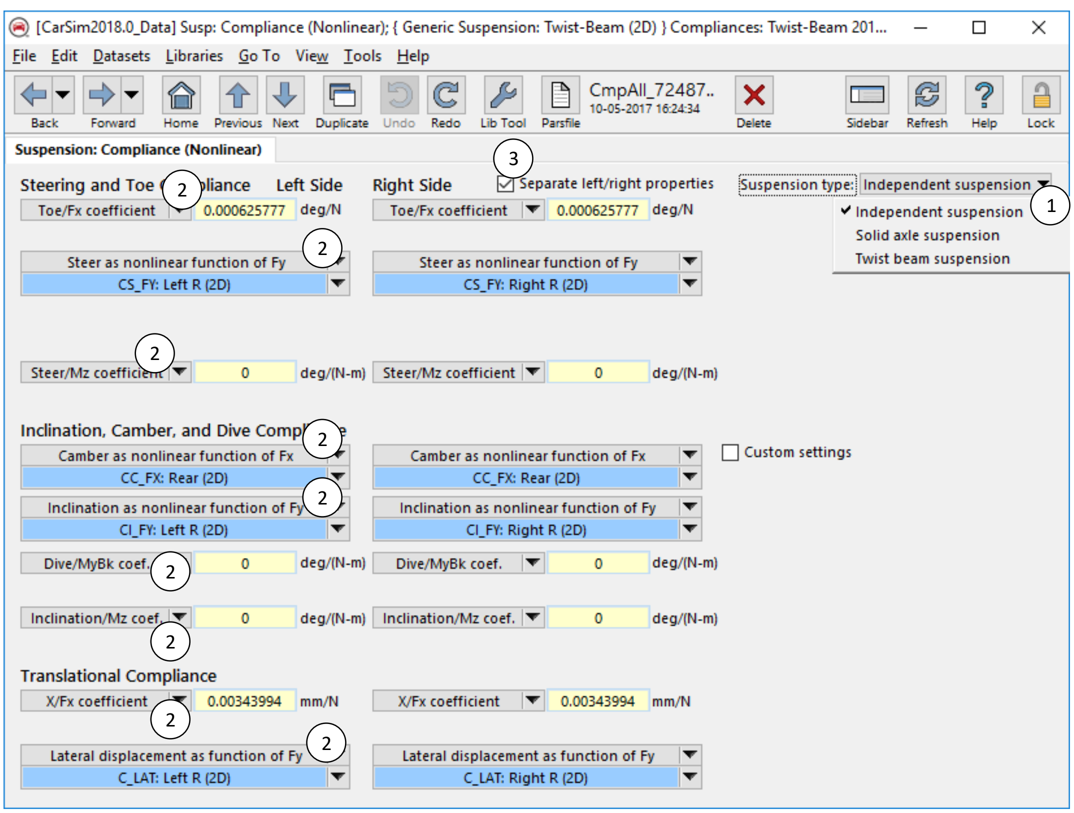


Figure 17. The Suspension: Compliance (Nonlinear) screen.

Each compliance effect is represented on the screen with a drop-down control ② used to specify whether the compliance function should be configured to use a linear coefficient or a blue link to a dataset, from the **Generic Table** library that enables a 2D table. The screen has a checkbox ③ to specify whether separate properties are used for the left and right sides.

> **Note** **Twist beam suspension** in the drop-down list ① is for **Twist Beam (Legacy)** model and is not for this twist beam approach.

Each compliance effect can be specified by either a linear coefficient or 1D table for the independent suspension. These measurements are made by either parallel identical longitudinal forces, or opposed lateral forces and aligning moments on the left and right wheels. However, for the twist beam suspension, some of the nine compliance effects (doesn't need to be all of them) should be measured by both parallel and opposed forces on the left and right wheels and need to be specified by 2D tables.

Figure 18 shows one of nine configurable functions for the suspension compliance (camber vs. Fx) specified on the **Generic Table** library. On this screen, the root keyword of the configurable function, which is an exact name from Table 2, is specified ① and **2D spline interpolation & extrapolation** is selected on the drop-down list ②. The first column ③ is the tire longitudinal force on the measuring side wheel while first row ④ is the tire longitudinal force on the other side of the wheel. The rest of the data ⑤ are the camber angles.

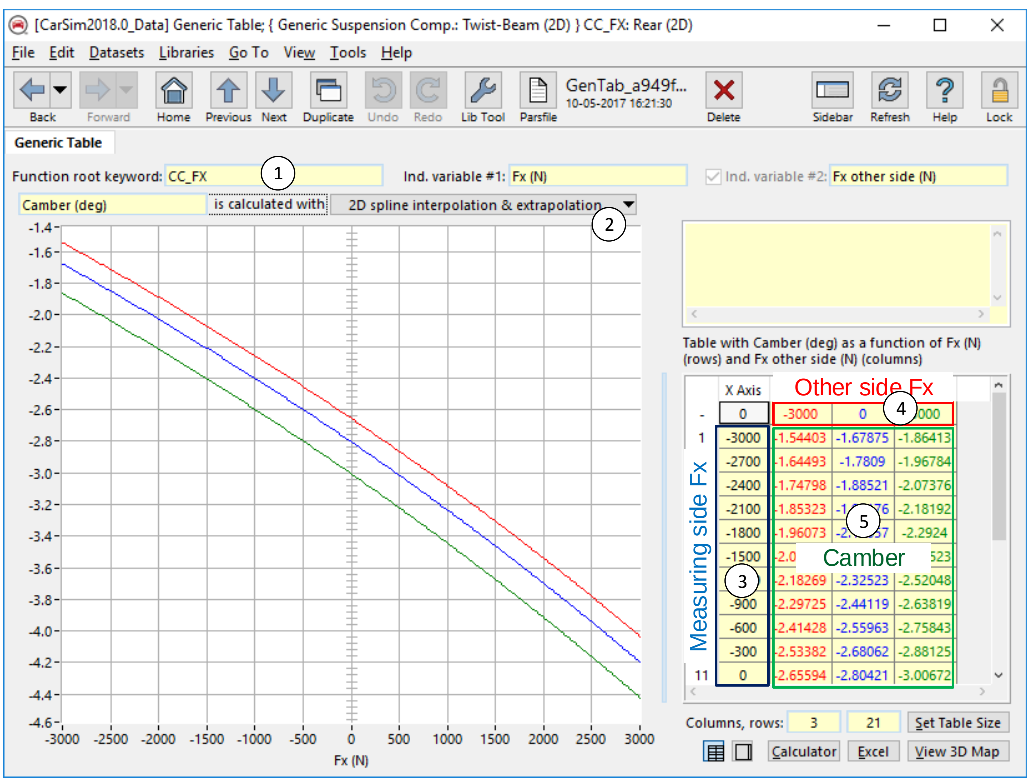


Figure 18. The Generic table library specifying the camber compliance.

Figure 19 shows the 3D-view of the camber compliance due to the tire longitudinal forces on the measuring side and opposite side: 1st and 3rd quadrants are parallel tire longitudinal forces; and 2nd and 4th quadrants are opposed tire forces.

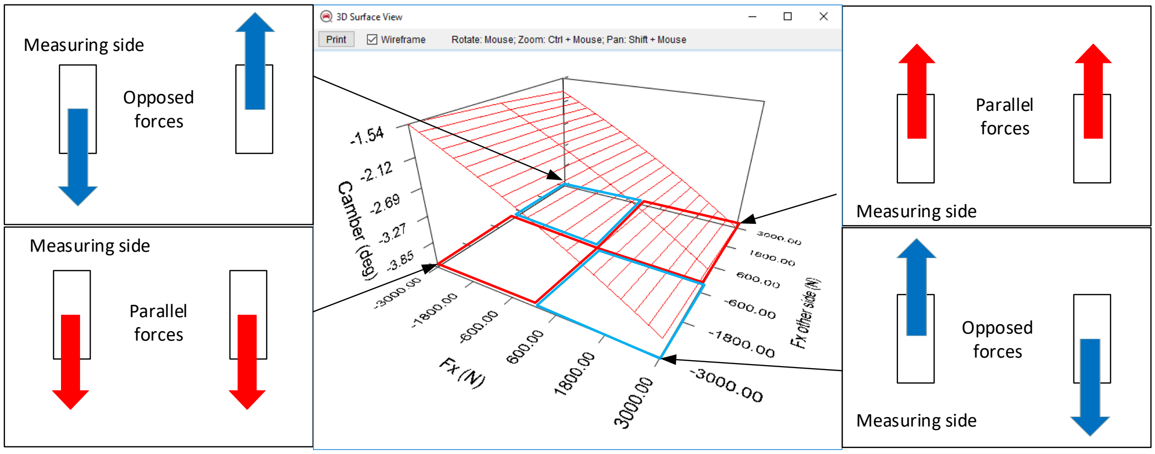


Figure 19. 3D view of the camber compliance 2D tabular data.

Simulation results (example)

Several simulation examples are included in the database of CarSim (See the **Datasets Category** from the **Run Control** screen "`Twist Beam (2D Tables)`"). Two examples simulate virtual K&C tests on heave and roll conditions.

As shown in Figure 20, the suspension kinematics motions match those from the SuspensionSim model (Figure 3) that is the source of the suspension kinematics and compliance data.

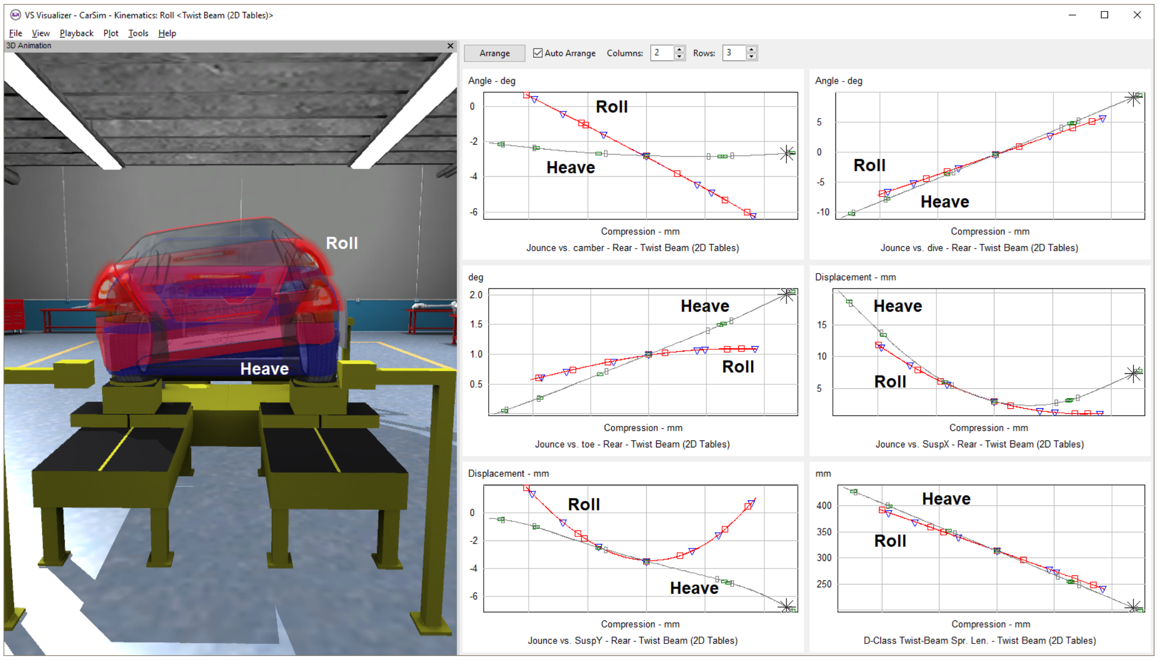


Figure 20. CarSim simulation results of K&C test heave and roll conditions.