Effective Prediction of Suspension Geometry Parameters for Optimized Ride and Handling

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Abstract

Ride and handling are the crucial factors of the suspension system. The behavior of the system is a subjective approach determined by the engineers, professionals, and driving experts. These behavioral parameters need to meet the design considerations to attain the desired ride and handling. On the other hand, the experimental approach requires development in the suspension system, leading to cost-effectiveness, and time consumption, and might not provide an optimum solution for the optimized ride and handling behavior.

This paper represents the optimization of the suspension geometry parameters using ADAMS/Car to obtain the desired ride and handling. A front vehicle model based on a B-segment concept vehicle is modeled by using ADAMS/Car. The vehicle front suspension model is simulated using a vertical-parallel movement test on ADAMS/Car. Same-segment vehicles with good rides and handling subjective reviews are considered for benchmarking. The resulting graphs of the benchmark vehicle suspension geometry are obtained by SPMM. Further, these results are correlated with the subjective reviews. The kinematics and compliances (K&C) of simulation are compared with the SPMM data of benchmarked vehicles. The best-fit suspension geometry curve trend for camber, caster, and toe is predicted in line with the benchmarked vehicles by changing hard points, to provide a best-fit correlation with a subjective approach. Comparing both the results, the best-fit ride and handling are generated.

Keywords: Suspension system, camber, caster, toe, ride and handling

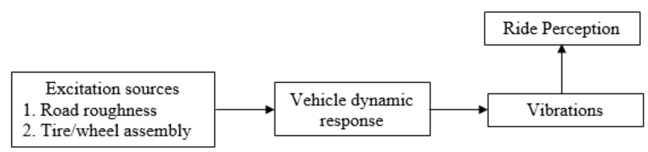
1. INTRODUCTION

The suspension system along with the tire is the interface between the vehicle body and the road surface. The suspension system should isolate the passenger from vibration and shock, provide clearance between the road and bottom portion of the vehicle, and also react to tire forces including acceleration, braking, and steering so that all four tires are in contact with the road while maneuvering. Ride and handling depend on the nature, mechanism, and forces associated with suspension, steering, and tire. All these systems' design parameters are correlated to each other, impacting the improvement of ride and handling.

1.2. Ride and Handling:

Ride study involves three main topics:

- Ride excitation sources
- Basic mechanics of vehicle vibration response
- Human perception and tolerance of vibrations



Vehicle dynamics model

Handling: Handling is the study concerned with the motion of vehicles on road surfaces. The dynamic behavior of a vehicle is determined by various kinds of forces such as gravitational force, aerodynamic force, and forces coming from the tires, acting on the vehicle. Handling constitutes the detailed study of all these forces imposed and their effect on the stability and cornering of the vehicle. To know how to handle the approach is to understand the turning behavior of vehicles at low speeds and high speeds. The importance of tire properties will arise in high-speed cornering.

2. Subjective assessments for benchmarked vehicles:

2.1.Subjective assessment of ride and handling :

The subjective approach of the vehicle ride and handling is estimated by the behavior of the vehicle conducted by the professionals. Opinions provided by the experts help customers to buy vehicles. Their feedback is much more valued in evaluating purchasing vehicles. Subjective feedback is in terms of phrases and deals with emotions based on the driving experiences of skilled drivers.

2.2.Benchmarked vehicle's subjective feedback:

Vehicle	BM -1	BM-2
Wheel base	2456	2430
Tyre size	185/60 R15	165/80 R14
Suspension type	Front -McPherson strut with stabilizer bar Rear - semi-independent trailing arm	Front - Macpherson strut Rear - Torsion beam
Subjective Feedback	1."Big car like" ride quality. Suspension setup ideal for Indian roads. 2. Neutral handling & mature road behavior. 3. The ride quality stays flat, even on the back seat, over fairly uneven patches. 4. Vertical movement is minimum. 5. Handling is fairly neutral, even under harsh cornering, and body roll well-controlled.	1. Flat ride enhances the comfort for long drive. 2. Harshness is minimized on highway potholes. 3. Handling is sharp with good grip levels. 4. Body roll controlled. 5. Controlled handling in ghat section, front end eager to change the direction. 6. Smooth turning & lane changed.

Vehicle	BM-3	BM-4
Wheel base	2525	2489
Tyre size	High end - 185/65 R14 Low end - 175/70 R14	175/65 R14
Suspension type	Front - Macpherson strut Rear - Coupled Torsion beam axle with coil spring	Front - Macpherson strut with dual path top mount Rear - Semi-independent twist beam and coil spring
Feedback	1. The suspension is fairly absorbent and stays that way over small to medium sized bumps. 2. Straight line stability is satisfactory. 3. Excessive vertical movement. 4. Light steering that feels vague on the highway, and is extremely sensitive at speed, it reacts much too quickly for comfort.	1. Rides and handles flawlessly for a car of this size. Though the ride may not be as complaint as you might want through the potholes and ruts, will never get jarred on the inside. 2. The handling is absolutely squat and flat through any corner you throw at it and you can really push the vehicle around a bend so much quicker than you'd think was possible with a mundane hatch.

Table 1 : Benchmarked vehicles data

2.3. Suspension geometry parameters and their effects:

Ride rate: The larger static deflection (W/Ks) is necessary for lower undamped natural frequencies. That is why ride rate or suspension stiffness should be less for a good ride. A comparison of the ride rate of benchmarked vehicles for front suspension is as below,

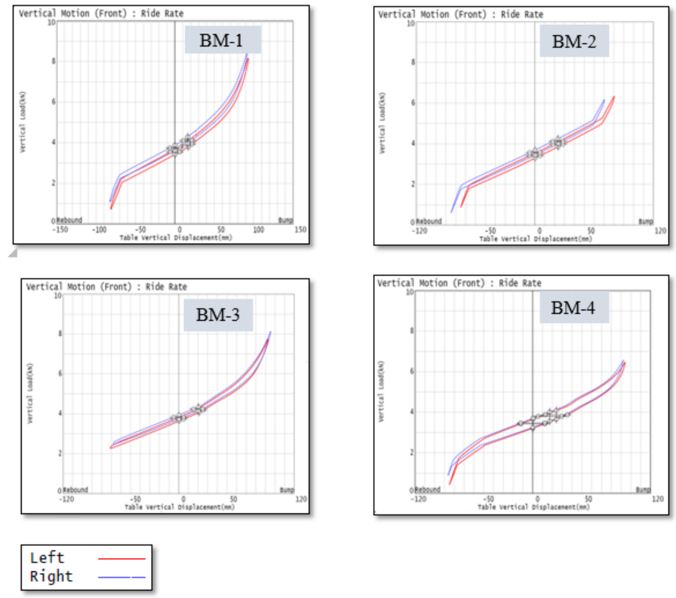


Fig.1. Ride rate graph for benchmarked vehicles

2.3.1. Benchmarked vehicle camber change curve:

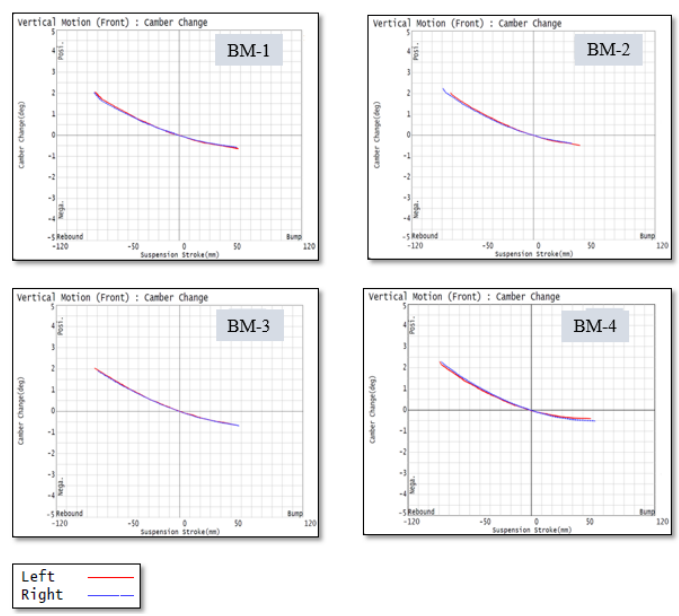


Fig.2. Camber change graph for benchmarked vehicles

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2.3.2. Benchmarked vehicle toe change curve:

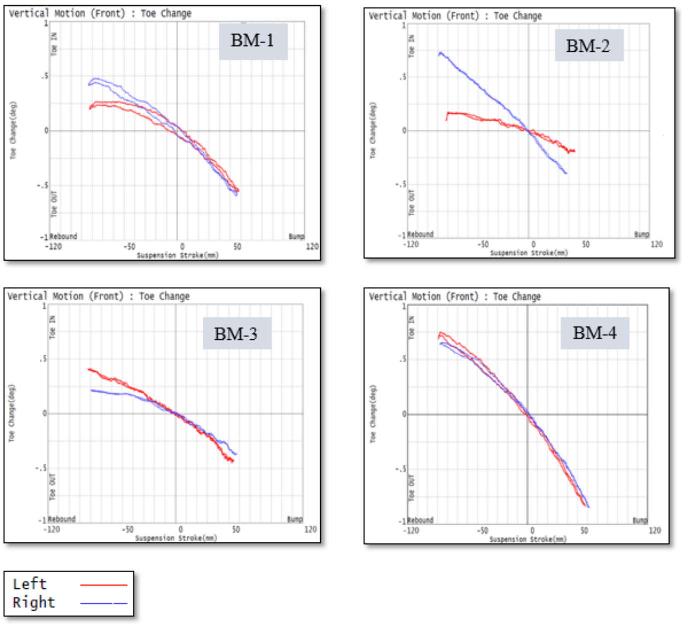


Fig.3. Toe change graph for benchmarked vehicles

2.3.3. Benchmarked vehicle caster change curve:

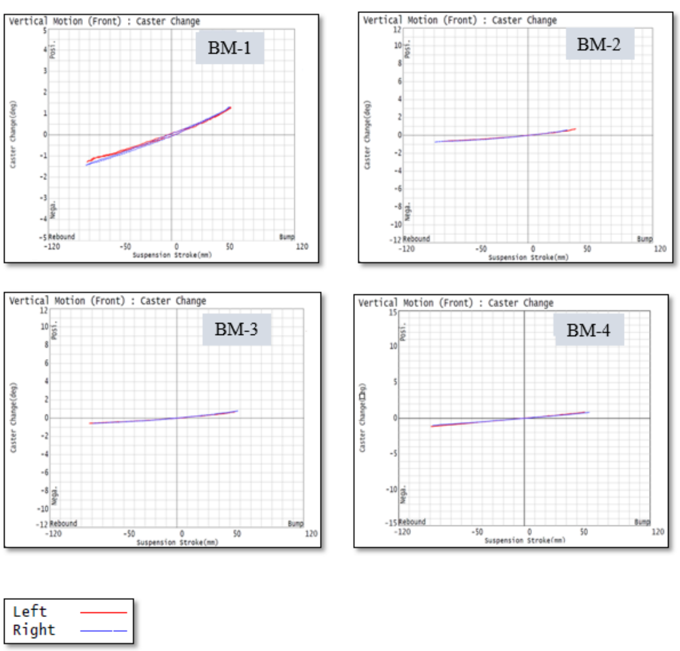


Fig.4. Caster change graph for benchmarked vehicles

3. Front suspension modeling and analysis in ADAMS/Car:

To study the behavior of suspension geometry parameters, a multi-body model of a concept vehicle is modeled in ADAMS/CAR. Different sub-systems of concept vehicles, such as suspension systems, steering systems, and wheels, were built according to the specifications and assembled to carry out the simulations. The data used to build the model is shown in Table 1.

Vehicle Specs	B - Segment concept vehicle
Track Front (mm)	1500
Track Rear (mm)	1500
Wheel base (mm)	2500
Brake Ratio (F:R)	0.82
Drive ratio (R:F) (1 if RWD)	0
FAW (kg)	790
RAW (kg)	540
CG Height (mm)	573
Tyre Size	195/55 R16
SLR (mm)	290.7
Suspension Type	
Front	Macpherson strut
Rear	Twist beam
Static angles (at front)	
Toe (in)	0.033
Camber	-0.48

Table 2: B-segment concept vehicle specification

B- Segment concept vehicle			
Suspension Hard points			
Description	X	Y	Z
hpr_drive_shaft_inr	-30.00	325.00	45.00
hpr_lca_front	10.00	373.00	-62.00
hpr_lca_outer	-10.00	733.00	-80.00
hpr_lca_rear	274.00	380.00	-60.00
hpr_spring_lwr_seat	35.00	615.00	380.00
hpr_strut_lwr_mount	15.00	625.00	115.00
hpr_subframe_front	70.00	450.00	86.00
hpr_subframe_rear	375.00	415.00	-75.00
hpr_tierod_inner	150.00	315.00	25.00
hpr_tierod_outer	128.00	688.00	15.00
hpr_top_mount	50.00	585.00	588.00
hpr_wheel_center	0.00	750.00	45.00
Steering Hard points			
hpr_rack_house_mount	185.00	143.00	25.00
hpr_tierod_inner	150.00	315.00	25.00
hps_intermediate_shaft_forward	215.00	210.00	240.00
hps_intermediate_shaft_rearward	425.00	330.00	460.00
hps_pinion_pivot	140.00	200.00	9.00
hps_steering_wheel_center	895.00	330.00	690.00

Table 3: B-segment concept vehicle hard points

3.1 Analysis of front suspension:

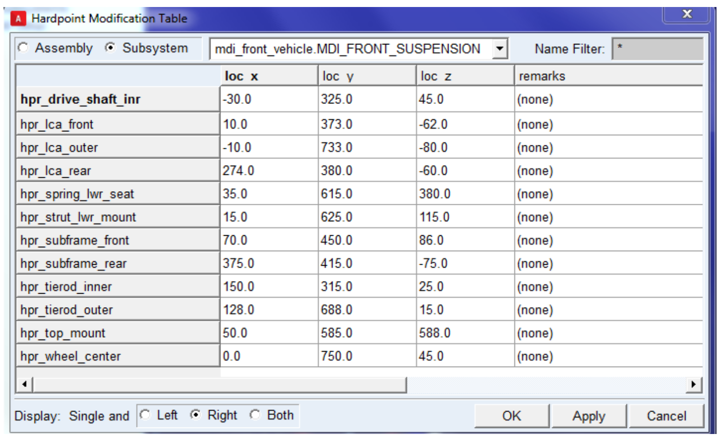
The following steps are performed to simulate suspension analysis.

Step 1: Hard points considered in suspension and steering template:

The following hard points are considered for preliminary study and to make a layout of the front suspension.

Step 2: Hard points updated to match with specified hard points:

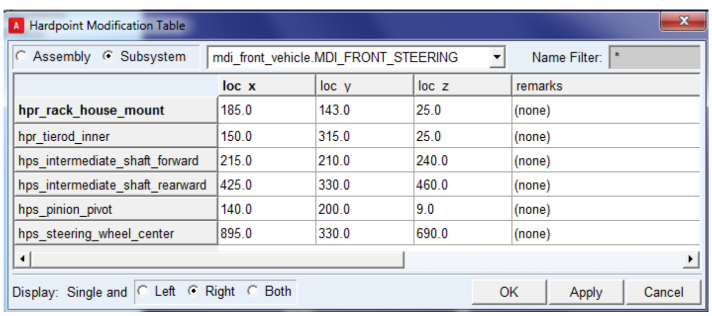
Suspension hard points:



	loc x	loc y	loc z	remarks
hpr_drive_shaft_inr	-30.0	325.0	45.0	(none)
hpr_lca_front	10.0	373.0	-62.0	(none)
hpr_lca_outer	-10.0	733.0	-80.0	(none)
hpr_lca_rear	274.0	380.0	-60.0	(none)
hpr_spring_lwr_seat	35.0	615.0	380.0	(none)
hpr_strut_lwr_mount	15.0	625.0	115.0	(none)
hpr_subframe_front	70.0	450.0	86.0	(none)
hpr_subframe_rear	375.0	415.0	-75.0	(none)
hpr_tierod_inner	150.0	315.0	25.0	(none)
hpr_tierod_outer	128.0	688.0	15.0	(none)
hpr_top_mount	50.0	585.0	588.0	(none)
hpr_wheel_center	0.0	750.0	45.0	(none)

Fig.5: Suspension template and sub-system hard points updated

Steering hard points:



	loc x	loc y	loc z	remarks
hpr_rack_house_mount	185.0	143.0	25.0	(none)
hpr_tierod_inner	150.0	315.0	25.0	(none)
hps_intermediate_shaft_forward	215.0	210.0	240.0	(none)
hps_intermediate_shaft_rearward	425.0	330.0	460.0	(none)
hps_pinion_pivot	140.0	200.0	9.0	(none)
hps_steering_wheel_center	895.0	330.0	690.0	(none)

Fig.6: Steering template and sub-system hard points updated

Step 3: Suspension analysis:

Pre-requisites for suspension analysis, setting up the suspension properties:

Before performing a suspension analysis, the setup parameters of the vehicle are specified. These parameters include the vehicle's wheelbase and sprung mass, whether or not the suspension is front or rear-wheel drive, and the braking ratio. For this analysis, the suspension properties are set as mentioned in the topic discussed earlier. Parameters to indicate front-wheel drive and a brake ratio of 82% front and 18% rear are assigned.

There are two types of suspension analysis performed:

1. Parallel wheel travel
2. Roll or opposite wheel travel

1. **Parallel wheel travel :**
   For parallel wheel travel, both wheels are traveled from rebound to bump by keeping the steering fixed. Required parameters for suspension analysis for parallel wheel travel are filled. Where 70mm bump travel and 90mm rebound travel are provided, note that the rebound travel should be provided with a negative value. Wheel travels are provided relative to the wheel center or contact patch.

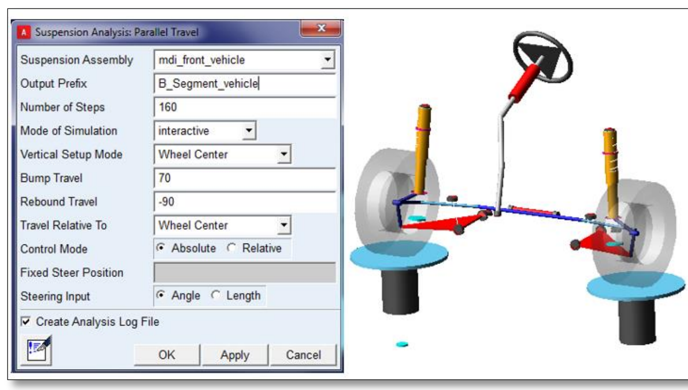


Fig. 7: Parallel wheel travel analysis

2. **Opposite wheel travel:**
   Along similar lines to the above analysis, an opposite-wheel travel analysis was conducted. In this analysis, when one wheel goes in a bump the other wheel simultaneously goes in rebound. This analysis is performed to simulate the roll behavior of the vehicle. This is opposite-wheel travel.

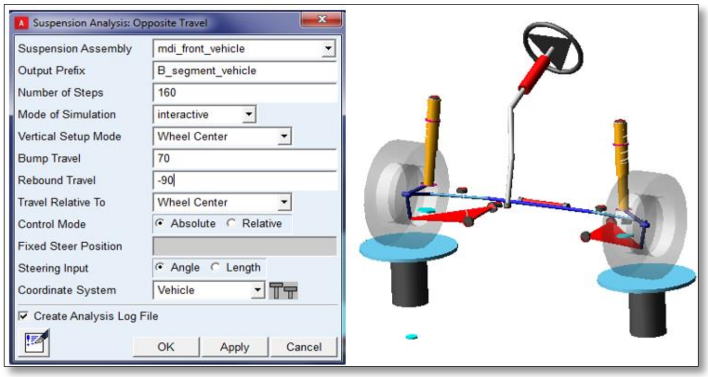


Fig.8: Opposite wheel travel analysis

Step 4: Plotting results

After performing analysis results are plotted for suspension geometry parameters with respect to wheel travel to find out the change and nature of parameters at the desired position of the wheel during wheel travel. The best-fit curve for the suspension geometry parameters is obtained by performing above mentioned steps with the change in hard points. In this project, the effective prediction of suspension geometry parameters done by changing hard points is covered. The following iterations are performed to find out the best-fit curve for suspension geometry parameters.

Analysis and results for front suspension assembly

With reference to the suspension and steering subsystems from the benchmarked vehicle, modeling of the front vehicle assembly is done. In this section, parallel wheel travel analysis and the results are plotted to find out the best-fit curve for suspension geometry parameters.

Preliminary analysis, Iteration 1:

In this section, we are using hard points from the basic provided layout and will perform analysis. Results will be plotted to study the nature of suspension geometry curves. The suspension geometry curves are compared and studied with respect to the ideal curve nature and also with the trends of benchmarking vehicles.

Hard points:

B- Segment concept vehicle			
Suspension Hard points			
Description	X	Y	Z
hpr_drive_shaft_inr	-30.00	325.00	45.00
hpr_lca_front	10.00	373.00	-62.00
hpr_lca_outer	-10.00	733.00	-80.00
hpr_lca_rear	274.00	380.00	-60.00
hpr_spring_lwr_seat	35.00	615.00	380.00
hpr_strut_lwr_mount	15.00	625.00	115.00
hpr_subframe_front	70.00	450.00	86.00
hpr_subframe_rear	375.00	415.00	-75.00
hpr_tierod_inner	150.00	315.00	25.00
hpr_tierod_outer	128.00	688.00	15.00
hpr_top_mount	50.00	585.00	588.00
hpr_wheel_center	0.00	750.00	45.00
Steering Hard points			
hpr_rack_house_mount	185.00	143.00	25.00
hpr_tierod_inner	150.00	315.00	25.00
hps_intermediate_shaft_forward	215.00	210.00	240.00
hps_intermediate_shaft_rearward	425.00	330.00	460.00
hps_pinion_pivot	140.00	200.00	9.00
hps_steering_wheel_center	895.00	330.00	690.00

Table 5: Iteration 1 hard points

Analysis performed:

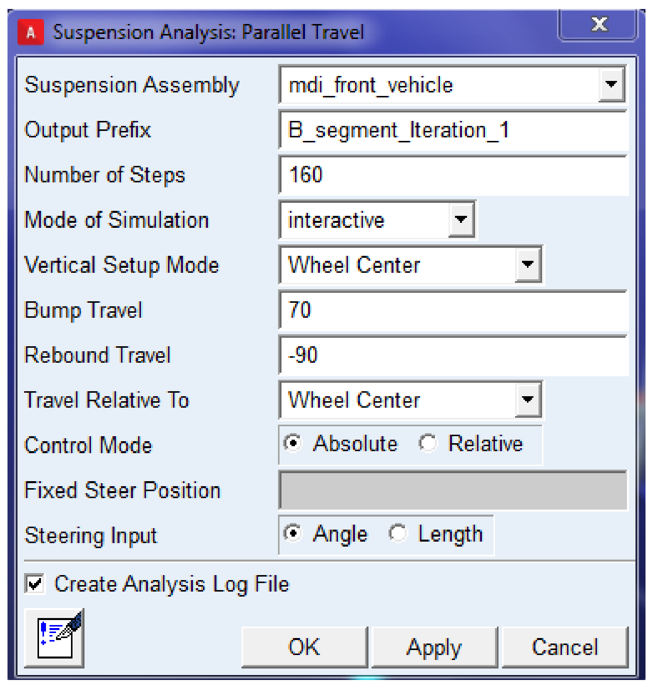


Fig.9: Parallel wheel travel analysis: Iteration1

Results plotted:

Camber change:

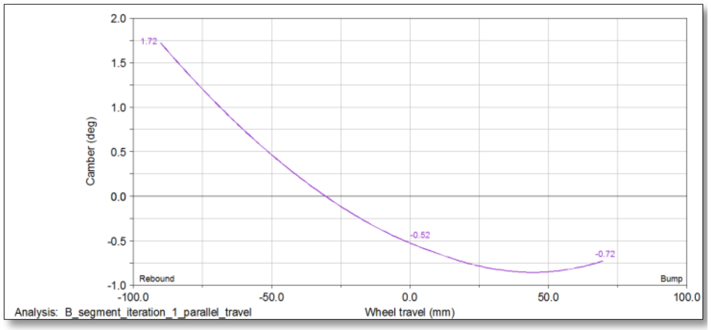


Fig.10: Camber changes with respect to wheel travel for Iteration 1.

Camber change gradients (deg/mm)				
BM-1	BM-2	BM-3	BM-4	B-segment Iteration 1
-0.015	-0.015	-0.018	-0.016	-0.012

Table 6: Camber change gradient for iteration 1

The trend of camber change with respect to wheel travel is similar to the ideal curve, but the camber change gradient shows a lesser value. The Camber curve needs to be improved, hence hard points need to be changed.

Caster change:

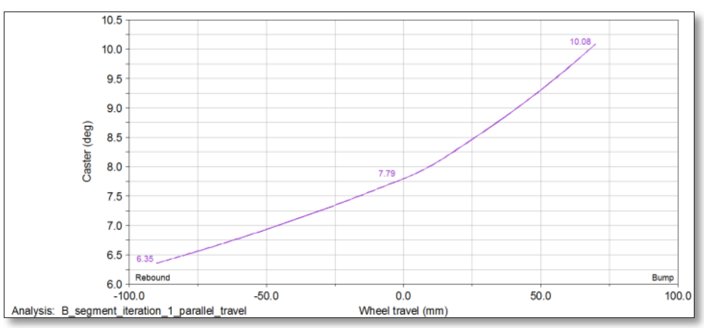


Fig.11: Caster change with respect to wheel travel for Iteration 1.

Caster change gradients (deg/mm)				
BM-1	BM-2	BM-3	BM-4	B-segment Iteration 1
0.018	0.012	0.010	0.013	0.019

Table 7: Caster change gradient for iteration 1

The trend of caster change with respect to wheel travel is similar to the ideal curve, and also the caster change gradient is in line with the benchmarked vehicles, but the caster has having large value. The caster curve needs to be improved, hence hard points need to be changed.

Toe change:

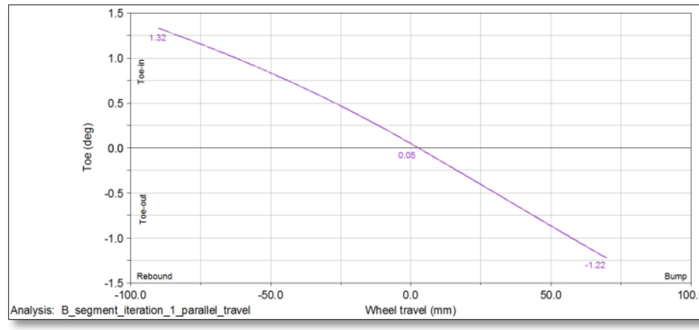


Fig.11: Toe change with respect to wheel travel for Iteration 1.

Toe change gradients (deg/mm)				
BM-1	BM-2	BM-3	BM-4	B-segment Iteration 1
-0.008	-0.007	-0.005	-0.011	-0.018

Table 8: Toe change gradient for iteration 1

The trend of the change with respect to wheel travel is similar to the ideal curve, but the toe change gradient shows a higher value. The toe curve needs to be improved, hence hard points need to be changed.

Suspension layout updating with change in hard points:

As per the above results toe change and camber change show a similar trend to that of the ideal curve, but the toe change gradient and camber change gradient are showing higher and lesser values in comparison to benchmarked vehicles respectively. To achieve the best-fit curve trend both curves need to be improved, hence affecting hard points needs to change. The following table shows, hard points and their coordinates affecting the suspension geometry parameters.

	Camber	Caster	Toe
hpr_lca_front	Y, Z	Z	Y, Z
hpr_lca_outer	Y, Z	X , Z	X , Y , Z
hpr_lca_rear	Y, Z	Z	Y , Z
hpr_top_mount	Y, Z	X , Z	Y, Z
hpr_strut_lwr_mount	Y	-	X , Y
hpr_tierod_inner	Z	-	X , Y , Z
hpr_tierod_outer	Z	-	X ,Y , Z

Table 9: Affecting hard points

In reference to the above discussion, iterations were performed to enhance the camber, caster, and toe trends of the vehicle. Table 10 shows the change in hard points for iteration 1 and iteration 2 respectively.

B- Segment concept vehicle - Suspension Hard points						
	Iteration 1			Iteration 2		
Description	X	Y	Z	X	Y	Z
hpr_drive_shaft_inr	-30.00	325.00	45.00	-30.00	325.00	45.00
hpr_lca_front	10.00	373.00	-62.00	5.00	370.00	-65.00
hpr_lca_outer	-10.00	733.00	-80.00	-12.00	732.00	-85.00
hpr_lca_rear	274.00	380.00	-60.00	274.00	410.00	-45.00
hpr_spring_lwr_seat	35.00	615.00	380.00	35.00	615.00	380.00
hpr_strut_lwr_mount	15.00	625.00	115.00	16.00	640.00	120.00
hpr_subframe_front	70.00	450.00	86.00	70.00	450.00	86.00
hpr_subframe_rear	375.00	415.00	-75.00	375.00	415.00	-75.00
hpr_tierod_inner	150.00	315.00	25.00	150.00	315.00	5.00
hpr_tierod_outer	128.00	688.00	15.00	123.00	698.00	-3.00
hpr_top_mount	50.00	585.00	588.00	30.00	580.00	588.00
hpr_wheel_center	0.00	750.00	45.00	0.00	750.00	45.00
Steering Hard points						
hpr_rack_house_mount	185.00	143.00	25.00	185.00	143.00	25.00
hpr_tierod_inner	150.00	315.00	25.00	150.00	315.00	5.00
hps_intermediate_shaft_forward	215.00	210.00	240.00	215.00	210.00	240.00
hps_intermediate_shaft_rearward	425.00	330.00	460.00	425.00	330.00	460.00
hps_pinion_pivot	140.00	200.00	9.00	140.00	200.00	9.00
hps_steering_wheel_center	895.00	330.00	690.00	895.00	330.00	690.00

Table 10: Changed hard points

Camber change:

Fig.12: Camber changes with respect to wheel travel: best-fit curve.

Camber change gradients (deg/mm)					
BM-1	BM-2	BM-3	BM-4	B-segment Iteration 1	B-segment Iteration 2
-0.015	-0.015	-0.018	-0.016	-0.012	-0.015

Table 11: Camber change gradient

Fig. 12 represents the camber change curve for all iterations. The trend of camber change with respect to wheel travel for all iterations is similar to the ideal curve. The camber change gradient is improved in iteration 2, compared to that of iteration 1. Camber change gradient and trend are achieved by changing hpr_lca_front in z (from -62 to -65), hpr_lca_rear in y (from 380 to 410), and in z (from -60 to -45), hpr_tierod_inner in z (from 25 to 5) and hpr_tierod_outer in z (from 15 to -3). The result shows that the camber change gradient in iteration 2 is in line with a range of benchmark values. This is the optimized camber curve in packaging prospect as well as in handling prospect.

Caster change:

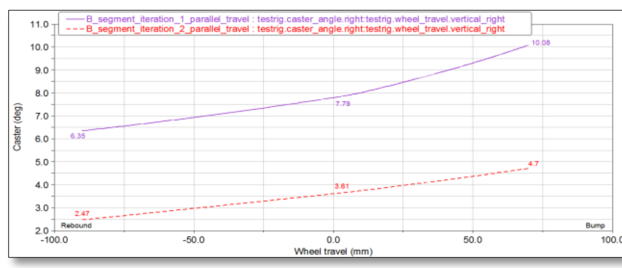


Fig.13: Caster change with respect to wheel travel: best-fit curve.

Caster change gradients (deg/mm)					
BM-1	BM-2	BM-3	BM-4	B-segment Iteration 1	B-segment Iteration 2
0.018	0.012	0.010	0.013	0.019	0.013

Table 12: Caster change gradient

Fig.13 represents the caster change curve for all iterations. The trend of caster change with respect to wheel travel for all iterations is similar to the ideal curve. The caster change gradient in iteration 2 is in line with the benchmarking value range. This change is a result of changing hpr_lca_outer in x (from -10 to -12) and in z (from -80 to -85) and hpr_top_mount in x (from 50 to 30).Fig.37 shows that the caster change curve in iteration 2 is shifted to the desired range of caster values and this is the optimized caster curve in the packaging prospect as well as in the handling prospect.

Toe change:

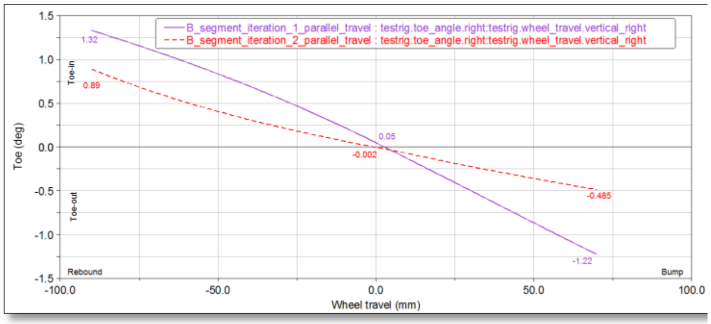


Fig.14: Toe change with respect to wheel travel: best-fit curve.

Toe change gradients (deg/mm)					
BM-1	BM-2	BM-3	BM-4	B-segment Iteration 1	B-segment Iteration 2
-0.008	-0.007	-0.005	-0.011	-0.018	-0.007

Table 13: Toe change gradient

Fig.14 represents the toe change curve for all iterations. The trend of the change with respect to wheel travel for all iterations is similar to the ideal curve. The toe change gradient is improved in iteration 2, compared to that of iteration 1. Toe change gradient and trend is achieved by changing hpr_tierod_inner in z (from 25 to 5), hpr_tierod_outer in z (from 15 to -3), hpr_lca_front in z (from -62 to -65), hpr_lca_rear in y (from 380 to 410) and in z (from -60 to -45). The result shows that the toe change gradient in iteration 2 is in line with a range of benchmark values. This is the optimized toe change curve in packaging prospect as well as in handling prospect.

4.CONCLUSION

Kinematic analysis was performed on the basic layout hard points. The nature of graphs obtained from the results for suspension geometry parameters have been studied. These graphs are compared with the benchmarked vehicle curve trends. It is easier to predict the vehicle handling behavior virtually at the primary stage of the hard point finalization. The number of iterations performed by ADAMS/Car analysis to finalize the set of hard points. The study of change in hard points in iterations indicates that a slight change in the value of affecting hard points mentioned have a significant change in toe followed by camber and caster change. The suspension geometry parameters curve achieved in the final iteration are similar to benchmarked vehicles which were selected based on the subjective reviews.

The final iteration of hard points and suspension geometry parameters curves are matching with the desired results and characteristic. Thus, it has been concluded that the suspension geometry parameters curves achieved in Iteration 2 are best-fit curves for the derived hard points set. Setting these hard points and suspension geometry parameters curve trend will give effective results for optimized ride and handling of B-segment concept vehicle at the virtual condition.

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