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To cite this article: A Widner and G Bári 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **393** 012034

View the article online for updates and enhancements.

Investigating the effects of roll center height in simulation, for safety-margin research

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Abstract. Understanding the vehicle behaviour in the tire saturation region, close to the grip limit, is really important when the safety during vehicle motion is concerned. In case of autonomous vehicle research, usually the so called "safety-margin" is defined to describe this limit behaviour. For this, often a simulation environment is used. These environments can over-simplify suspension parameters that leads to inaccurate results, in such conditions. This paper investigates the effect of these parameters, in a given simulation software, to understand if parameter changes, eg.: roll center height, creates the expected changes in vehicle behaviour. This way it is possible to validate, if the chosen environment is "good enough" for our safety-margin research in the future.

1. Introduction

The aim of this paper is to find a vehicle dynamics simulation software, which is suitable for control algorithm development and safety-margin research for autonomous vehicles, where the parameters which affect the controllability and stability of the vehicle are investigated.

These vehicles must be controllable and stable in the tire saturation region to be capable of rapid maneuvers and also maintain directional stability on the grip limit. Our aim is to build up a simulation environment where the parameters that has important effect on the vehicle's grip-limit-behavior, can be properly investigated.

After choosing the software in order to make sure that it is suitable for our demand we need to verify and validate it. In our case validation means 'choosing the right software' which handles the suspension parameters properly. This is necessary because most of the time, the team which developed the model also decides if the simulation is valid. [1] We investigate if the parameter changes creates the expected changes in vehicle behavior. According to Sargent this technique is the so called "Face Validity: Individuals knowledgeable about the system are asked whether the model and/or its behavior are reasonable. For example, is the logic in the conceptual model correct and are the model's input-output relationships reasonable." [2]

Carson's suggested framework for validation and verification:

- First test the model for face validity.
- Then test the model over a range of input parameters. (Sensitivity analysis)
- Finally, compare model predictions to past performance of the actual system or to a baseline model representing an existing system. When designing a new system, compare implemented model behaviour to assumptions and specifications. [3]

This paper covers the first step which is face validity.

"The goal of verification and validation is a model that is accurate when used to predict the performance of the real-world system that it represents, or to predict the difference in performance between two scenarios or two model configurations. The process of verifying and validating a model should also lead to improving a model's credibility with decision makers." [3]

There is no absolute validity according to many experts. [2] [4] [5] "A model's validity is only defined within the limits of the project and the intended application. Although a more comprehensive validity analysis increases the credibility of the model, it also comes with extra financial and time cost. Thus, a simulation model of a complex system can only be an approximation of the actual system." [1]

A simulation model can only be validated when the performance of the model meets the accuracy criteria. If the simulation model fulfils the defined validity criteria, then it can be deemed 'not invalid' under the defined specific set of operating conditions and limits. [1]

In this paper we address the selection and face validation of the simulation software for the above mentioned purpose.

2. Simulation environment

There is a wide range of vehicle dynamics simulation software and most of them has many functions beside the basics. From our perspective there are two major areas that need to be considered. First is sensor simulation and real time HIL tests - for the controller algorithm development. Second is how accurately the program handles the suspension parameters - for the safety-margin research.

2.1. Selection of the software

Autonomous vehicles use cameras, radar, lidar and other sensors to determine vehicle state (position, motion and information about the surrounding "objects"). These sensors produce hundred times more data than the ones that are used for a conventional driving assistant systems.

The chosen software must be able to simulate these sensors, for the control algorithm development. Also modules for real time HIL tests are necessary for the further part of the development. All the prevalent vehicle dynamics simulation software were examined by the following aspects.

- Sensor simulation (radar, lidar, camera)
- Matlab/Simulink integration
- Python integration
- Real-time environment for HIL simulations
- Price
- Suspension design tool

To properly compare these software, lot of information is necessary which is hard to gather if there is no chance to deeply test each. Based on the information we could gather, IPG Carmaker prove to be the most suitable for this project.

2.2. Validation of the chosen software

The above-mentioned environments use different methods – and neglect the effect of some parameters - when calculating vehicle motion. Generally, when a conventional driving assistant system is developed these simplifications have no major impact on the results. But, when the safety-margin of an autonomous vehicle is considered the over-simplification of suspension parameters could lead to inaccurate results. It can happen that the behavior on the tire grip limit has errors, or there are parameters that's effect is not handled at all. Therefore, one of the first steps is the investigation of the effect of these parameters, in the chosen simulation software, to understand if parameter changes, creates the expected changes in vehicle behavior in standard test cases.

3. Parameters of the investigated vehicle

Roll center has a significant effect on vehicle behavior at the grip limit by influencing the weight transfer, roll stiffness, jacking force and several other parameters. It can be less important in case of

road cars, but for our goals it is critical, therefore this paper focuses on the analysis of the effect of roll center.

All the simulations were carried out with a standard front wheel drive passenger car – defined in IPG Carmaker as an example car. The only parameter was changed is the roll center height of the front MacPherson suspension by lifting or lowering the inner pick-up point of the wishbone. The modification of the suspension has been done in IPG Kinematics.

4. Evaluation of simulation results

Two kind of simulation were executed. A steady-state skid pad to analyse weight transfer and a straight run with different toe angle to investigate the effect of jacking force.

"The simulation model output behavior can be explored either qualitatively or quantitatively. In qualitative analysis the directions of the output behaviors are examined and also possibly whether the magnitudes are "reasonable". In quantitative analysis both the directions and the precise magnitudes of the output behaviors are examined." [2]

The results of the simulations were qualitatively evaluated, that means we investigated if the results comply with the theory but we did not calculate with other method or compare the results to real measured values.

4.1. *Steady-state skid pad*

First, a steady-state skid pad simulation had been done with two suspension set-ups. First is a basic front suspension and the second has a higher roll center (by the modified inner pick-up points of the wishbone.
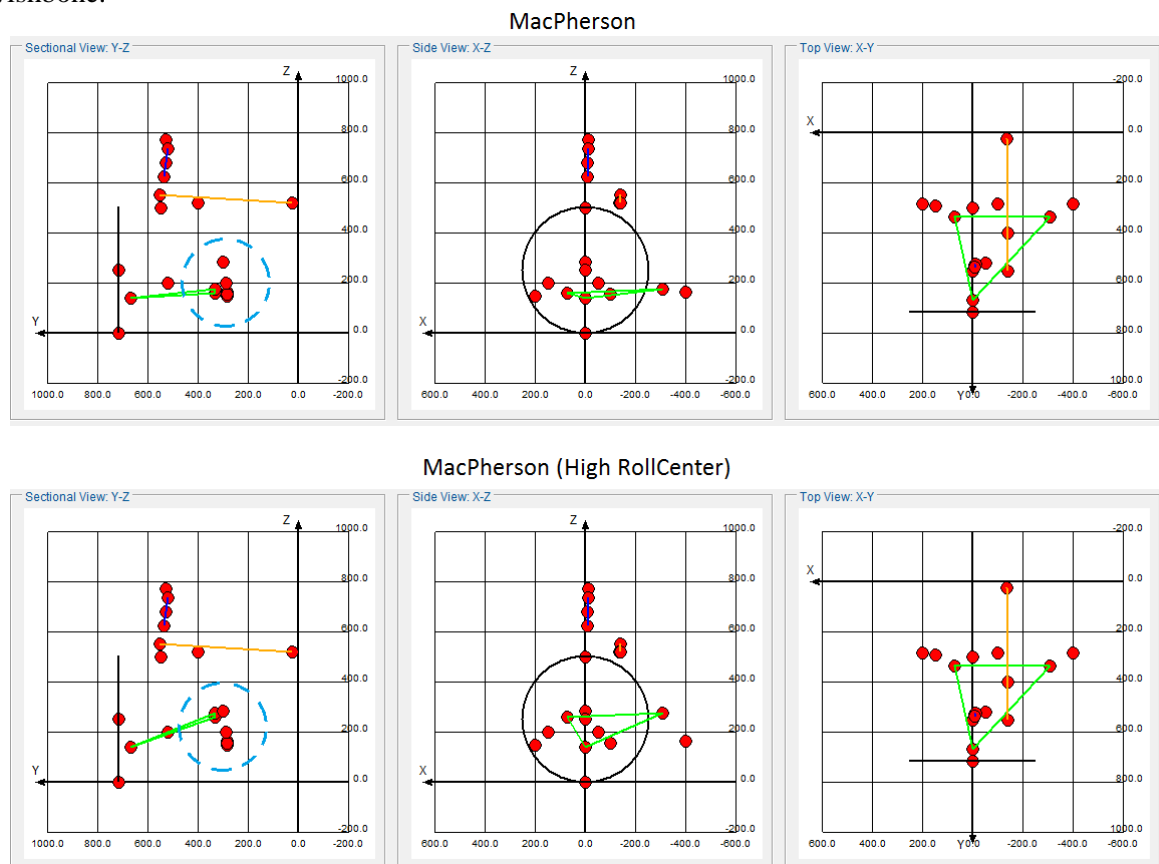

Figure 1. Pick-up points of the basic and the modified front suspension for steady-state skid pad simulation (front, side and top view).
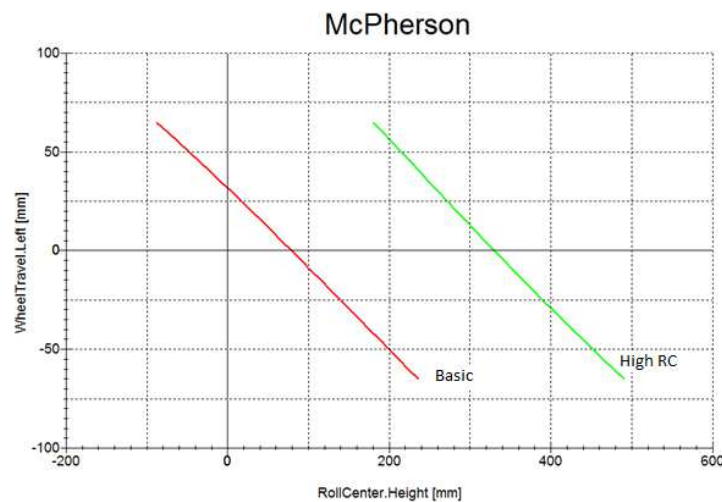
Figure 2. Roll center height characteristics of the basic and modified front suspension for steady-state skid pad simulation.

The vehicle rides on a 100m diameter circle path with constant velocity. The theory is that the total weight transfer depends mainly on only three parameters: lateral acceleration, track width and center of gravity height [6]. And the distribution of weight transfer between front and aft axle is proportional with the roll stiffness of the given axis. Roll center height influences the roll stiffness. The higher the roll center the larger the roll stiffness of the give axis. [6]
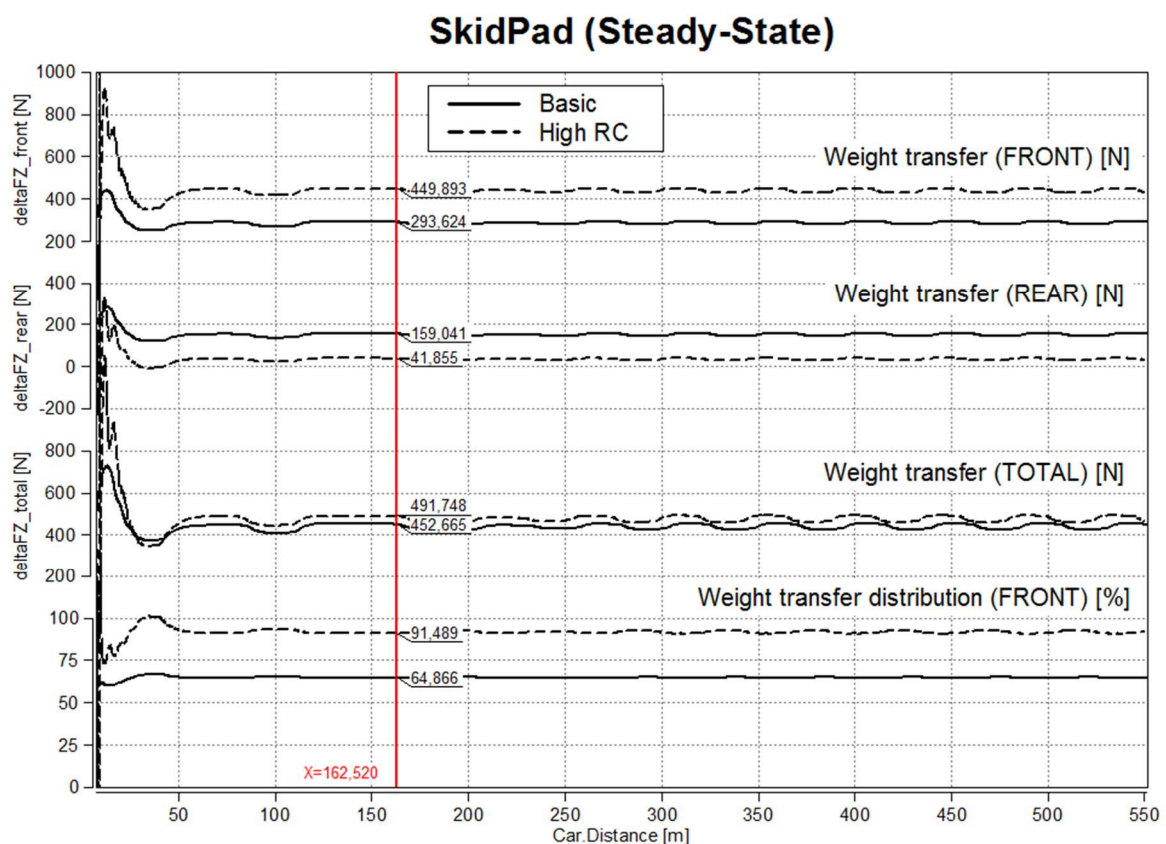
**Figure 3.** Steady-state skid pad weight transfer.

As it can be seen on the above diagram the front weight transfer distribution is increased with the higher roll center. Motion ratio of the ride springs has also affects the roll stiffness. The dislocation of inner pick-up point of the wishbone reduced the motion ratio, therefore the reason of the above seen phenomenon is surely the roll center height variation.

The total weight transfer has also slightly increased, which can be the result of the arisen center of gravity caused by the higher roll center induced jacking force.

4.2. Jacking force

In this case three different front roll center height was investigated. Basic suspension, one with higher roll center and one roll center below the ground. See the configurations on Figure 4 and roll center height on Figure 5.

Roll center has a horizontal-vertical coupling effect, the lateral force from the tires has a lifting or lowering effect on the sprung mass depending on instant center location. The lateral force generates a
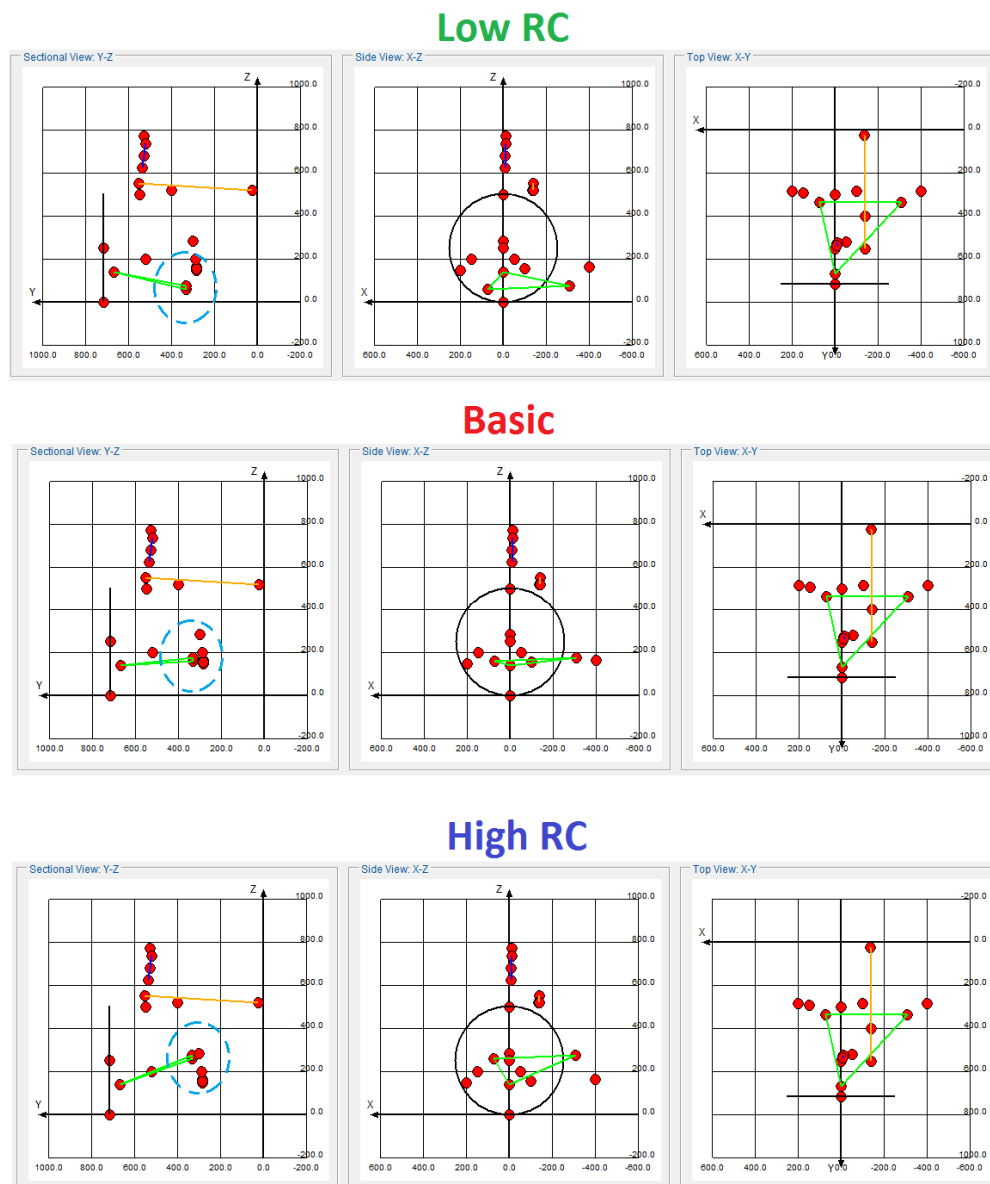
Figure 4. Pick-up points of the three front suspension configurations for jacking force investigation (front, side and top view).
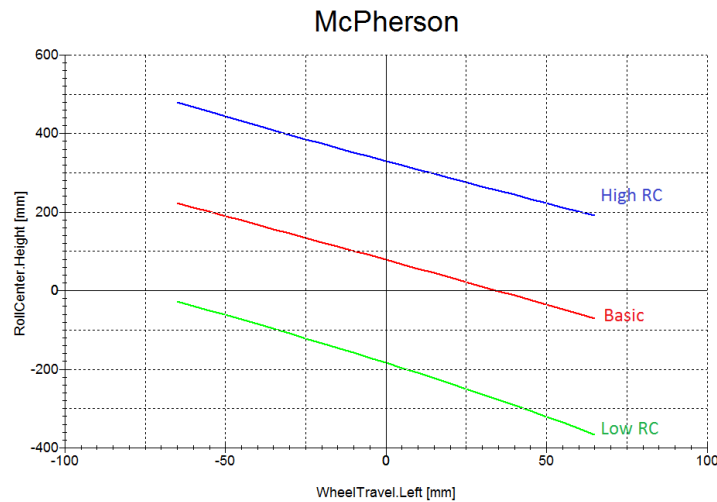
Figure 5. Roll center height characteristics of the three front suspension.

moment about the instant center, if the instant center is above the ground level this moment lifts the chassis, if the roll center is below the ground level the moment pushes the chassis down. [6] This is the so called jacking force effect. This test case is a straight run with constant velocity, the toe angle of the front axle was modified during the simulation (Table 1.) to generate lateral force.

Table 1. Toe angle variation during the simulation.

Time [s]	Toe [rad]
0-20	0
20-30	-0,1 (toe out)
30-40	0,1 (toe in)
40-60	0

As shown on Figure 6. we obtained the results corresponding to the theory. Both cases with roll centers above the ground the CoG arisen when the two lateral force point to each other (toe in) and decayed when point away from each other (toe out). The magnitude of the CoG height variation is larger in case of the higher roll center. As expected with roll center below the ground this phenomenon is opposite.
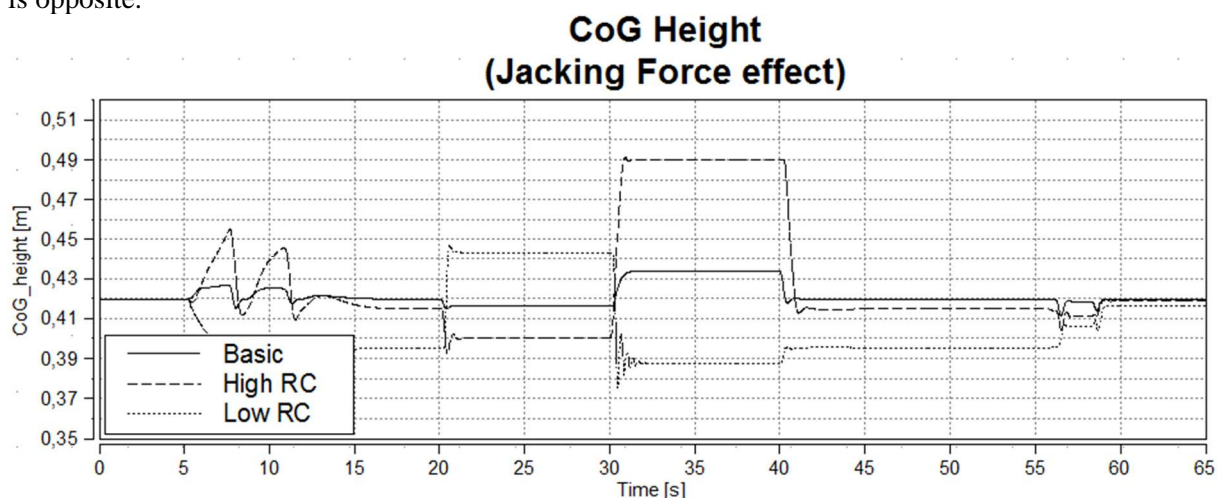
Figure 6. Center of gravity height variation due to jacking force.

5. Conclusion

Verification and validation of the simulation environment is critical in the development of a safety-margin simulation. Unfortunately, there is no standard test that can easily be applied to determine the suitability of the environment. During the simulations all the expected changes has occurred so it can be said that there are no significant neglecting. Although the investigated simulation environment seems to be good for our research, more investigation needs to be taken such as sensitivity analysis and also the comparison of simulation results with experimental test data.

Acknowledgments

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