Verification of Vehicle Dynamics CAE methods on System and Vehicle Level

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1. Abstract

In order to determine the validity of CAE models measurements are taken and compared to simulation results. First question to be answered is: how good is testing with respect to accuracy and repeatability? Next question is: how good can the vehicle dynamics behavior be predicted? Often some of the necessary input data for the CAE models is not available in the early stages of a development program so that the last question emerges: What can be forecasted in what quality in the course of a vehicle program?

A middle class passenger car has been used for all of the tests. Measurements on three different Kinematic & Compliance rigs showed consistent kinematic and primary compliance characteristics. Compliance quantities were somewhat different between rigs. Some extra steering system measurements have been done at one site only.
With this information available some changes have been made on the ADAMS model to get good correlation on system level.

The ‘real’ car went through 4 different events on the test track. 12 vehicle configurations have been used to find out if trends can be captured in physical testing as well as in numerical simulations. Each event has been driven several times so that statistical methods could be used on the characteristics and metrics.
All of the performed tests have been simulated with 4 CAE models which represented different levels of validation. The model with data available in the concept phase could predict trends well but the absolute value of most of the metrics had an offset to the measured data. The most complex model with lots of efforts spent in validation predicted not only trends very well but also most of the metrics were met in the confidence interval.

2. Background / Objective

The development process at FORD has two phases. The first one is called the design or downcascading phase. All starts with the voice of the customer. Customer expectations are translated into technical terms e.g. yaw gain. After this step the full vehicle targets are translated into system characteristics e.g. a roll-steer curve via parametric models. The last step is designing a suspension concept which best fits the system targets. For this step physical models like ADAMS are taken. Outcome are hardpoint coordinates and component characteristics e.g. bushing stiffnesses. If the suspension is carried over from the old car ADAMS models are already used for the process of deriving system targets.
The second phase is the verification or upcascading phase. In this phase it has to be shown that the designed component characterists leed to the expected system behavior and a step higher to the intended full vehicle behavior. During

this verification phase the CAE models are validated to be comparable to the hardware prototypes.
At FORD AdamsPre is used as vehicle dynamics CAE environment

For verification lots of measurements are done on K&C rigs. During the project FORD used 3 different K&C test rigs. One objective of the project was to assess the quality of the measurements on this rigs, how they compared to each other and how the CAE models could be correlated to them. Another objective was to find out know how good the handling measurements could be executed with respect to accuracy and repeatability and how good the ADAMS models predicted the measured behavior.
The CAE models change over time. At the beginning of the verification phase all is design intend. Over time more and more measured component data comes in, FE nets are built, prototypes are available and K&C measurements are done which can be used for validation. This ongoing process allows it to make the models more accurate over time. Nevertheless the question arose how the ADAMS models predicted the handling and steering behavior over time. Are the very early models accurate enough to base decisions on them?

3. Validation Results

All handling and K&C measurements have been done with a current production 5 seater passenger car.

3.1 Kinematic & Compliance

The car was sent to 3 different Kinematics and Compliance rigs. The same standard test procedure was used on each of the rigs.
Additionally tests were done to measure local subframe deflections under side and braking forces. This was an effort to correlate the FE models which were used in ADAMS during the project.
Measurements were done to assess the steering column compliance and the friction of the steering system.

FIG 3.1.1 shows roll-steer front, an example of a kinematic characteristic.
We see a very good correlation between the rigs. CAE is not shown here but lies line on line to the measured ones. On these rigs different wheel travels were used dependand on the design of the rigs.

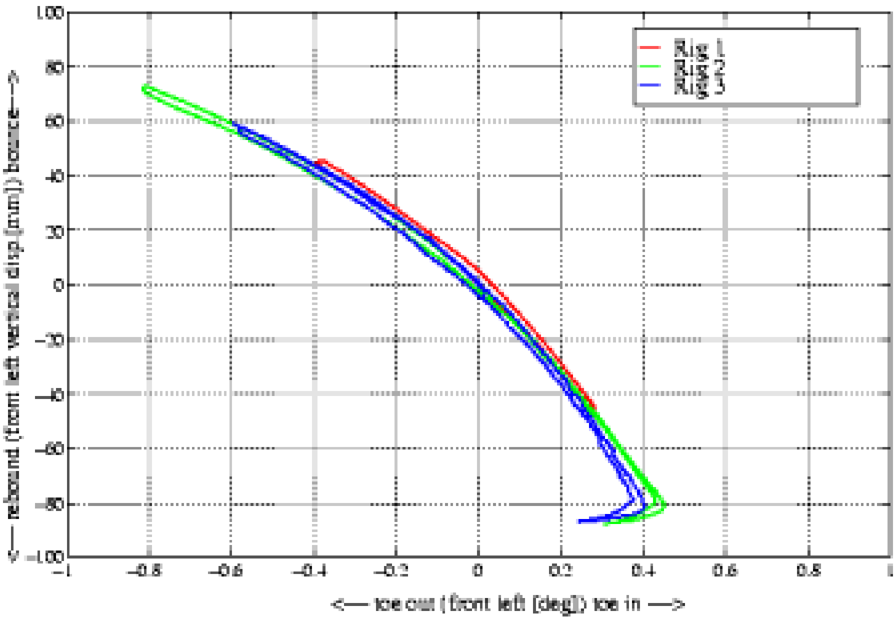

FIG 3.1.1

FIG 3.1.2 shows three examples of metrics which were derived from the kinematic characteristics. There are small differences between this metrics which depend on the rig type. CAE shows very good correlation.
Overall the three rigs came out with similar results for kinematic characteristics and there were only minor problems to correlate the CAE model to them.

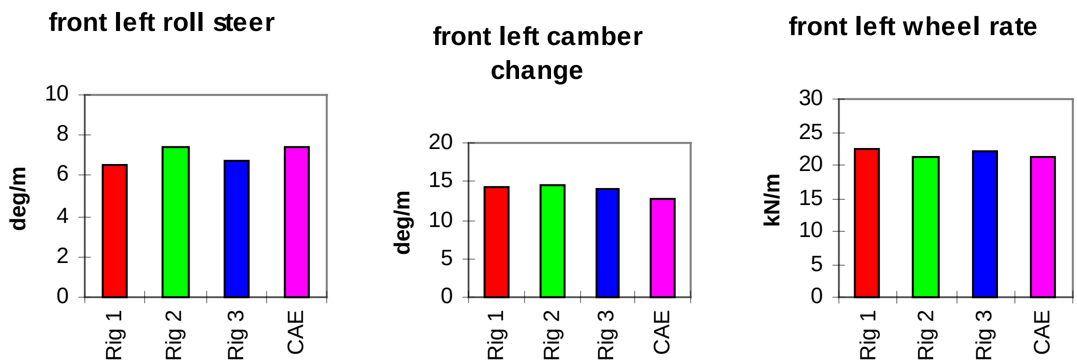

FIG 3.1.2

Unfortunately different results for the compliance characteristics were found. FIG 3.1.3 shows lateral compliance steer at the front suspension when parallel forces are acting on the wheels. Rig 3 came out totally different from the other ones. But also between rig one and two are significant differences. The reason for the deviation of Rig three is the different reference frame used for toe angle. Most unreliable were all characteristics for parallel forces of the front suspension of the tested car.
The big hysteresis is cause by the rubber behavior in the A-arm bushings. This effect can't be predicted by CAE up to now but there are efforts going on to get a solution in the near future.

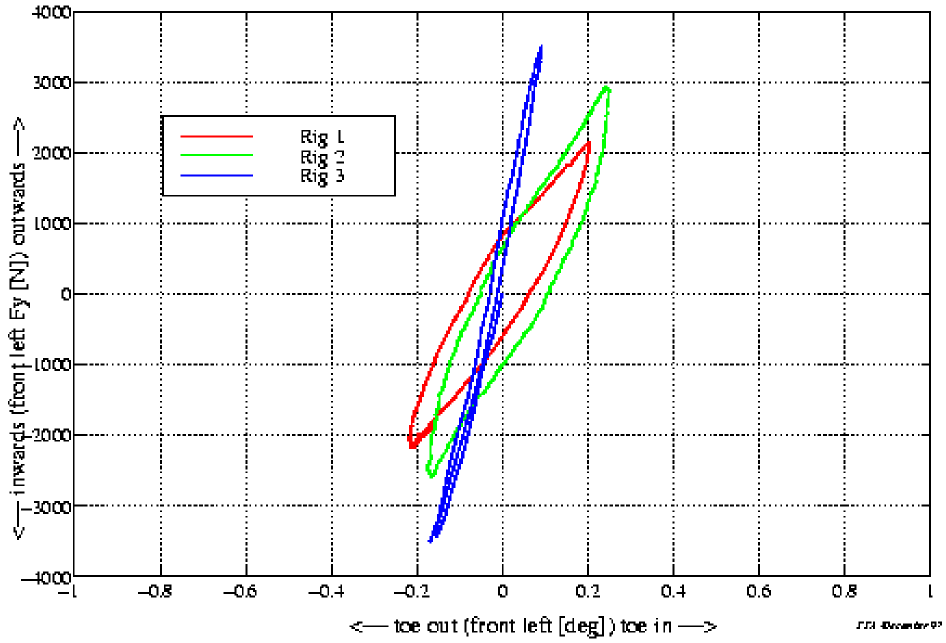

FIG 3.1.3

FIG 3.1.4 shows three typical metrics derived from the compliance characteristics. There are significant differences between them. Unfortunately no overall trend could be detected at the first look which could explain the differences. When measurements differ this much it is difficult to validate the CAE model. The decision was taken to validate against Rig 2 which had been used as the main facility at that time. In the meantime this type of rig has been installed at Lommel Proving Ground late summer this year.
It is very important to know how the rigs are operated e.g. how forces are applied and how the measurement process works .e.g. reference frame used.

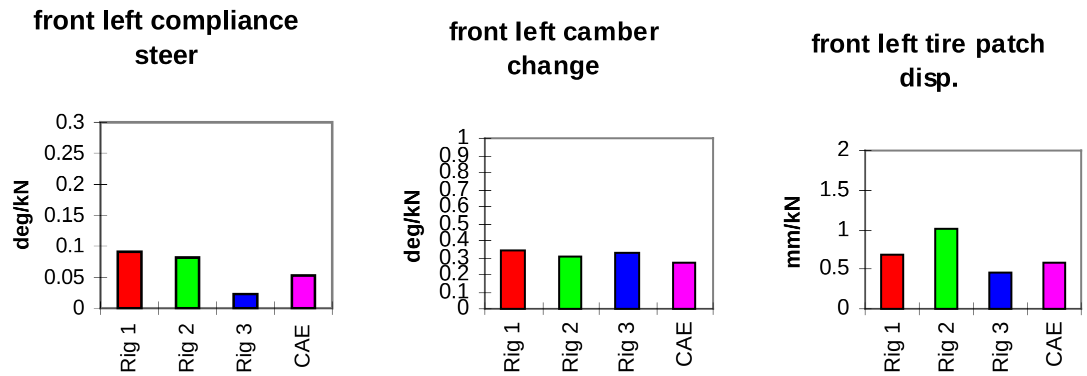

FIG 3.1.4

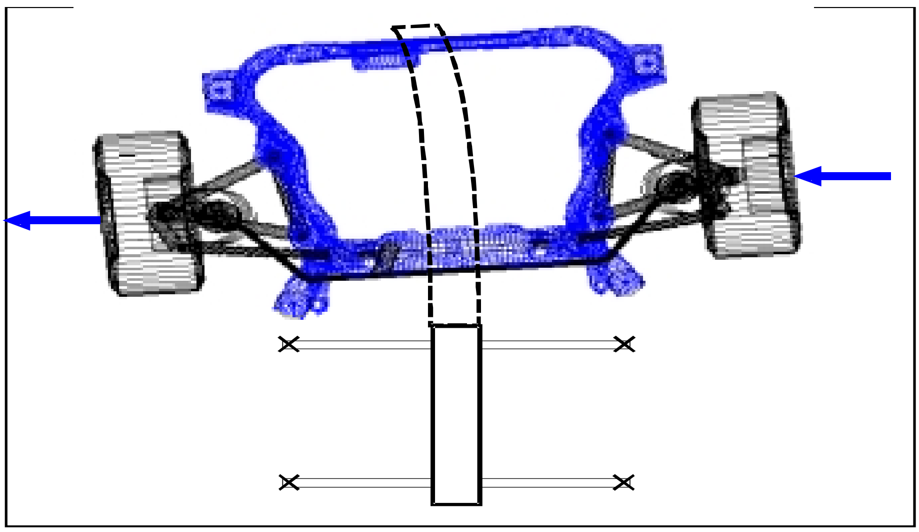

FIG 3.1.5

To get closer to reality it was decided to include FE structures into the model of the front suspension. Especially the front subframe and the front knuckle needed to be modeled this way because they showed significant contributions to the compliance metrics. In the full vehicle model extra bushing stiffnesses at the A-arm bushings and at the tie-rod to knuckle joint were added to get the simulation time down. The calculations showed that this simplifications didn't change the model behavior significantly. When parallel forces are applied it is important to take body bending into account (FIG 3.1.5). Typically the car body is clamped somwhere in the middle of the car which leads to an extra compliance and compliance steer at the wheels. This effect wasn't modeled but the resulting toe angle and displacements were taken into account for the validation.

3.2 Full Vehicle Handling

The following standard handling maneuevers were used:

- constant radius
- frequency response
- on-center
- low-g swept
- parking efforts

The following parameters were changed:

- 3 different tires; two sizes; 2 suppliers for one of the sizes
- 2 tire pressures
- 3 loadings

Each test with each setting was run 10 times to get an idea of the repeatability and the confidence interval of physical testing.

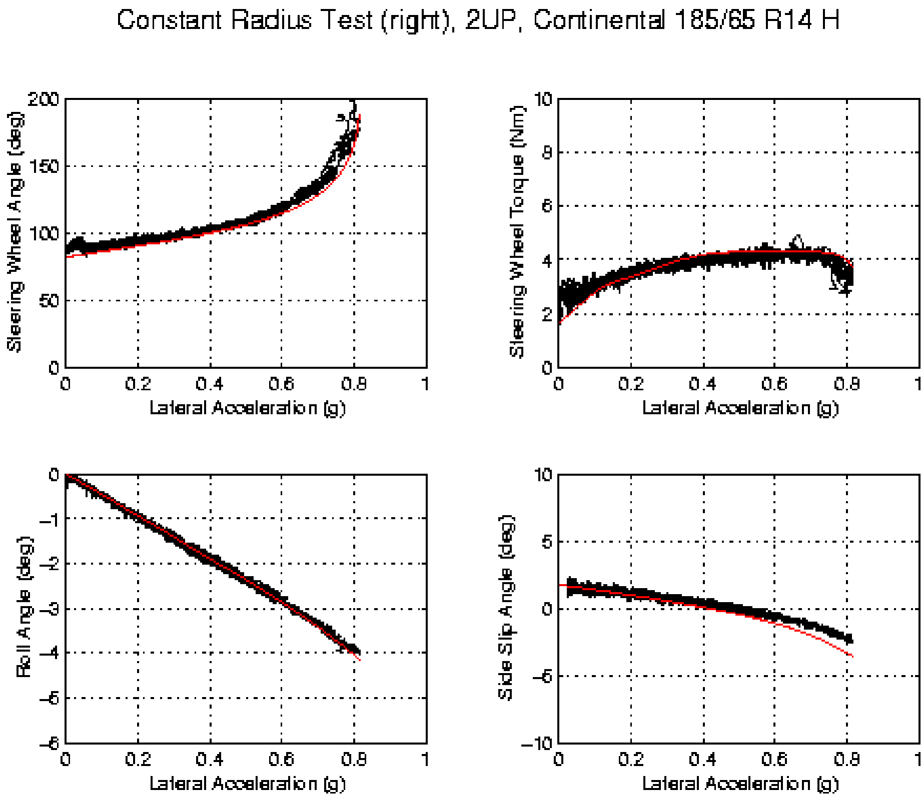

FIG 3.2.1

FIG 3.2.1 shows four typical graphs of the constant radius test. Black are all 10 measurements on top of each other, red are the CAE results. CAE lies on top of the measurement range up to high levels of lateral acceleration.

Note the significant scatter of the steering torque vs lateral acceleration plot. It is caused by the friction in the steering system. This scatter makes it difficult to derive meaningful metrics from this characteristic for example the steering torque gradient.

FIG 3.2.2 shows typical metrics derived from the characteristics of the constant radius test. For the steering wheel angle gradient the absolute values are met as well as the trends. The side slip angle gradient has an offset in the absolute value but trends are captured well in general. The offset can be explained by the difference in the location of the transducer. Neither the absolute value nor the trends of the steering torque gradient were predicted right all the times. On the measurement side it is difficult to derive a metric from the cloud of curves. On the CAE side the steering model needs to be updated.

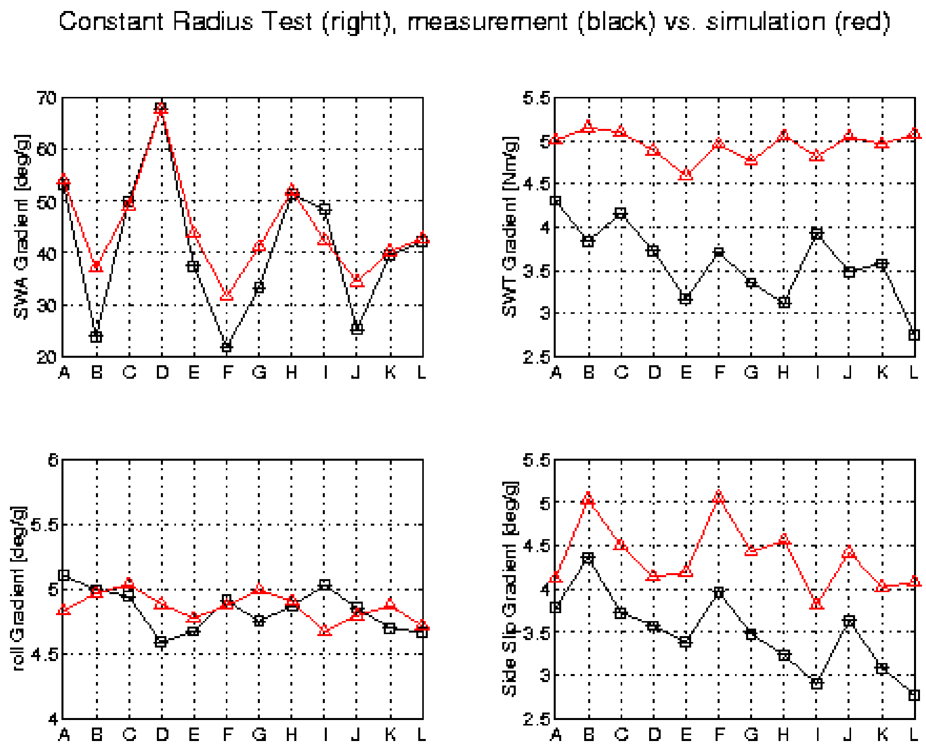

FIG 3.2.2

FIG 3.2.3 shows the results of the frequency response test. The same swept sine input to the steering wheel was applied in the CAE model and in the measurements. The correlation in the gains is very good up to 2 Hz. Over 2Hz the confidence level of the measurement drops significantly. Very good are the predicted phase angles which used to be far more off in the past.

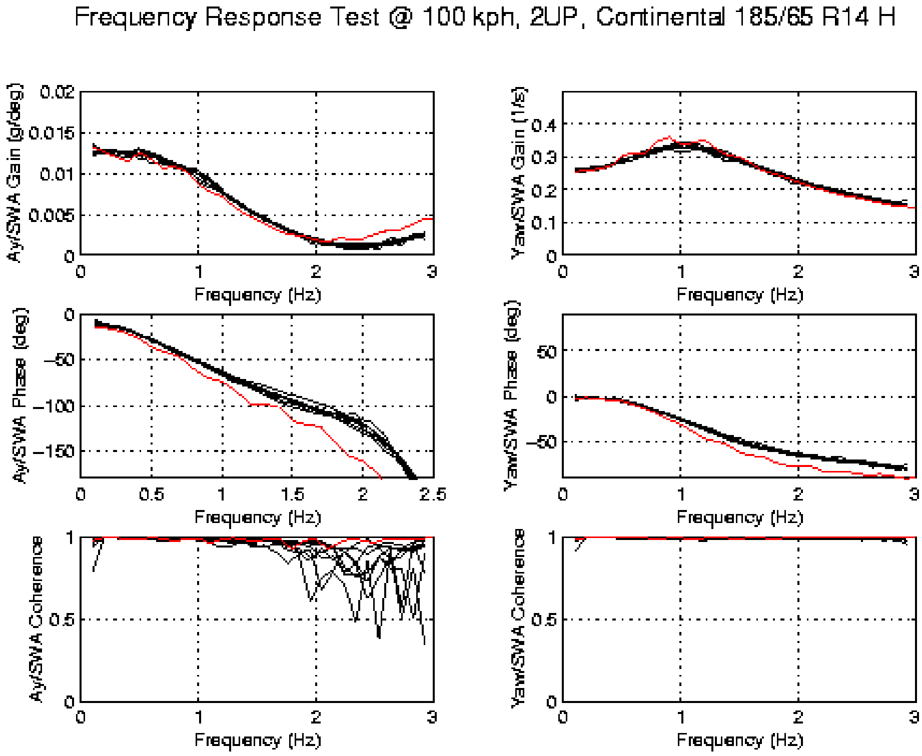

FIG 3.2.3

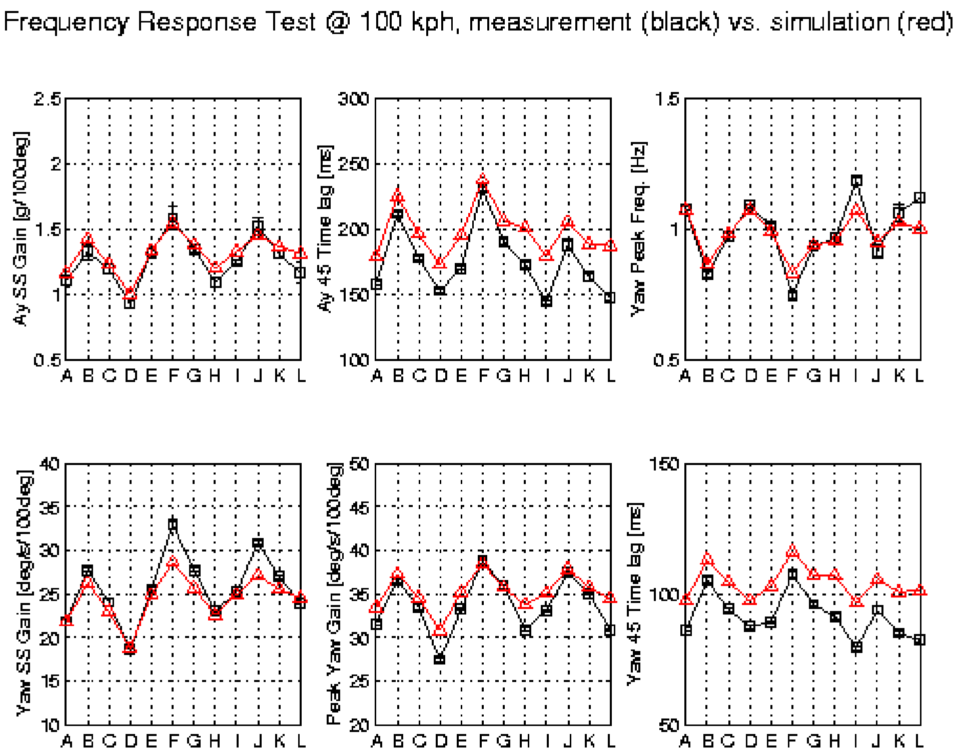

FIG 3.2.4

FIG 3.2.4 shows metrics derived from the curves shown in FIG 3.2.3.
Nearly all absolute values could be achieved and all trends are right.

Reasons for the good correlation are:

- big efforts to validate the model on system level
- same batches of tires were used for handling measurements and flat track measurements to derive the tire model coefficients
- same postprocessing tool for measurements and CAE

4. CAE Validation Levels

It was decided to use four different levels of validation depth.

- level 1
  all input data is design intent; nothing is measured
- level 2
  only kinematic characteristics are available for validation
- level 3
  compliances are measured as well and can be used to validate
- level 4
  steering system measurements have been done additionally

The following small paragraphs explain what differences occurred between the validation levels on the validation car.

Modifications between level 1 and level 2:

- roll-steer curve left front changed (see FIG 4.1)
- spring length front and rear
- bump stop contact points
- roll bar diameters front and rear

Modifications between level 2 and level 3:

- introduction of FE subframe front
- introduction of FE knuckle front
- hub compliance

FIG 4.2 shows the effect of this changes on front lateral compliance steer.

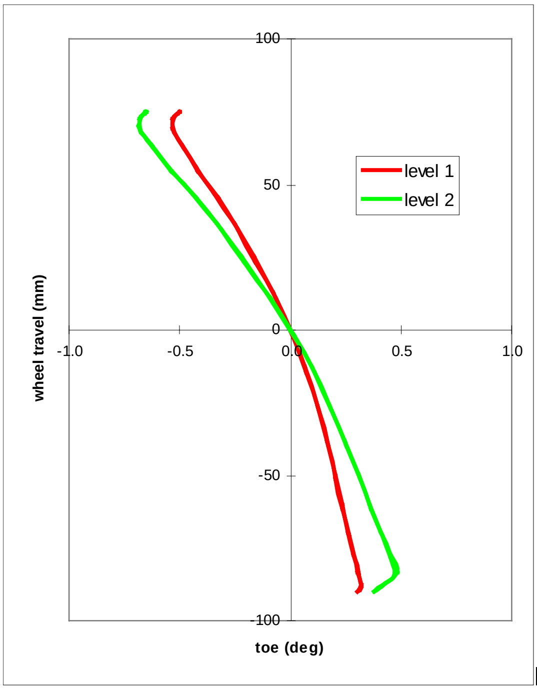

FIG 4.1

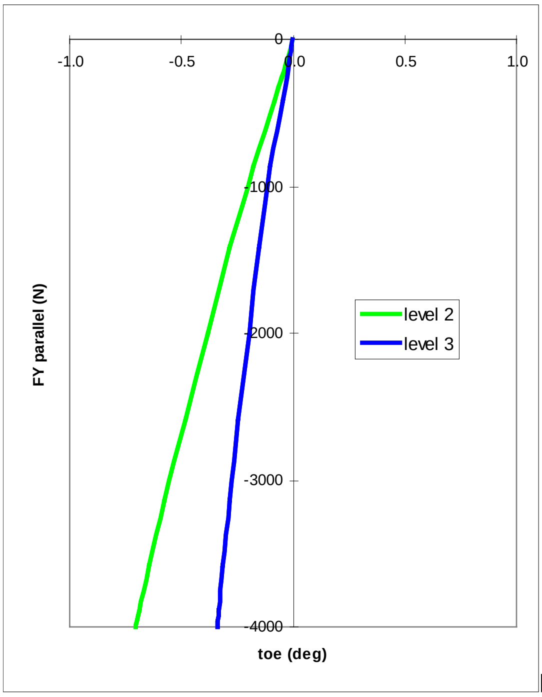

FIG 4.2

Modifications between level 3 and level 4:

- less steering compliance and a nonlinear characteristic
- friction in rack and column

FIG 4.3 shows both effects.

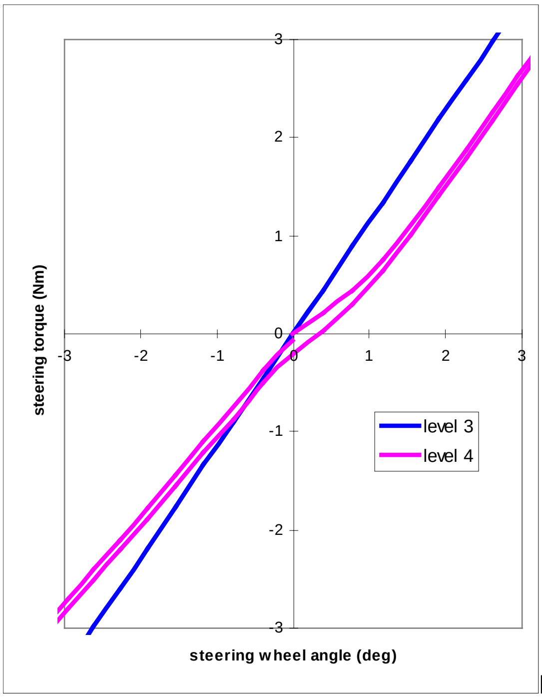

FIG 4.3

For the investigation on the full vehicle level the same tests and the same 12 configurations were run.

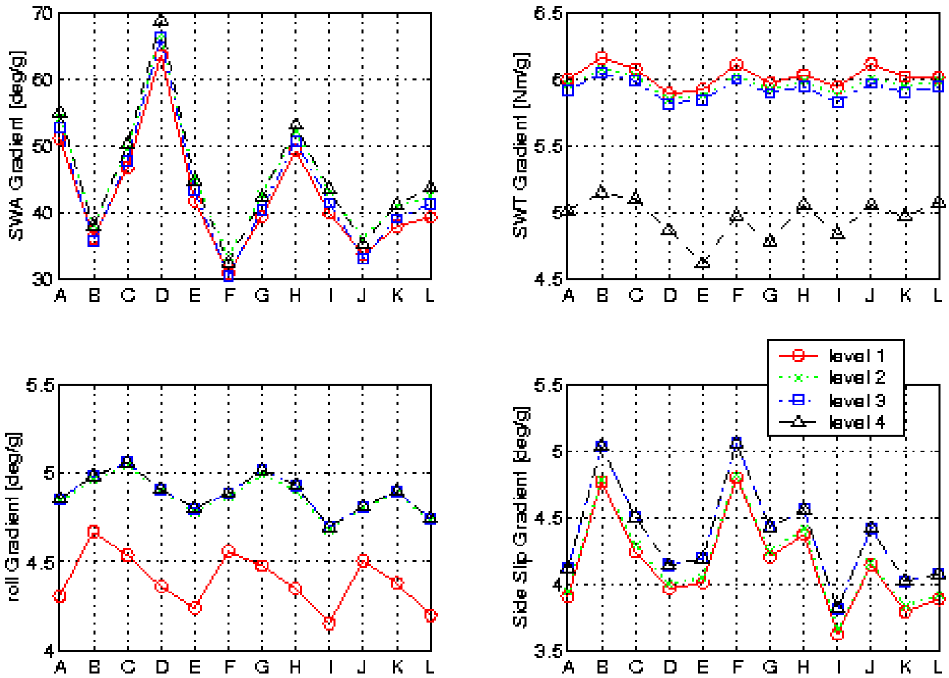

FIG 4.4

FIG 4.4 shows results for the constant radius test. Only the metrics derived from the characteristics are shown to get an overall impression. Remarkable is the difference in roll gradient between level 1 and level 2 due to the changes to the roll bar diameters..

The steering torque gradient changes significantly with the introduction of the steering compliance, trends are always the same though.
There are differences in the absolute values of side slip angle but for all four levels the trends are met very well.

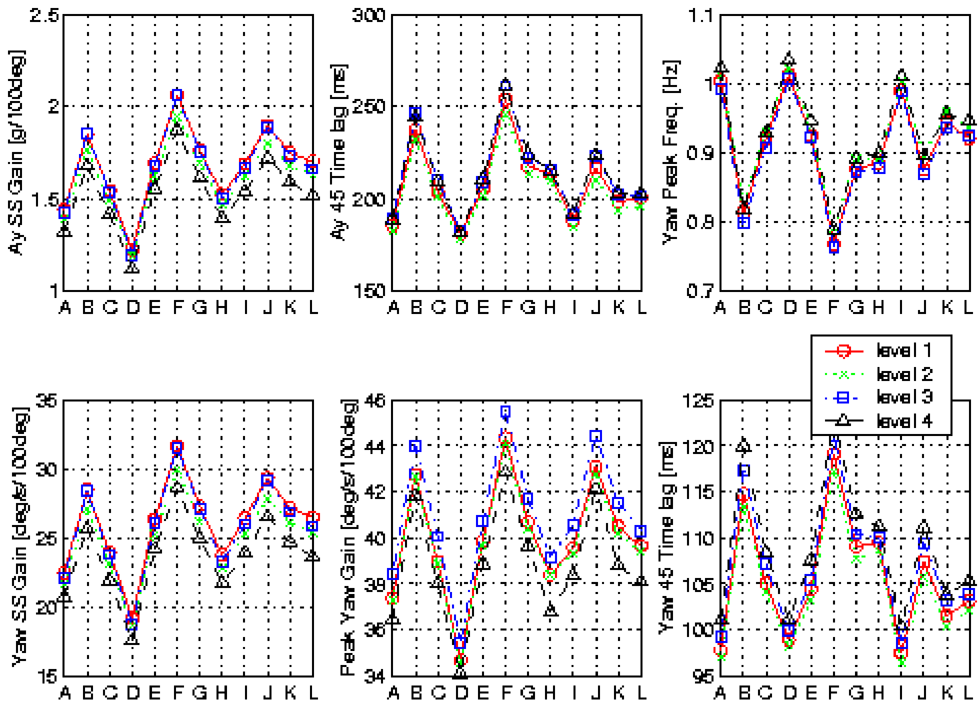

FIG 4.5

For the frequency response test the differences in the values are smaller. And all trends are captured very well (FIG 4.5).

5. Conclusion

- Kinematics can be predicted very well.
- Secondary compliances are a major source of errors especially if complex soft structures are involved. If this is the case it is important to include FE structures as early as possible or use fudge factors in the bushings.
- The steering system needs extra efforts of validation. To get better answers in some steering metrics the tools and methods need to be updated.
- Trends in handling calculations are captured very well for most of the metrics for most of the tests for all four validation levels.
- The absolute value of some metrics differ between validation levels and between measured metrics (steering).
- Spring and roll rates need to be right because this makes the biggest difference on some of the handling metrics.
- If the model contains most of the relevant data and has the right spring and roll rates it can already been used for A to B comparison very early in the verification phase.