HEAVY TRUCK VEHICLE DYNAMICS MODEL & IMPACT OF THE TIRE

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Abstract

This paper aims at sharing the work that has been done at Michelin to better understand the impact of the tire on the truck convoys handling performance and safety for heavy loaded usage. It describes a measurement campaign that has been done on track with dynamometric wheel and additional sensors to carry out a correlation study with a vehicle model that has been designed with Trucksim software from Mechanical Simulation Corporation. As a good tire model correlation with tests was observed, a tire cornering stiffness effect has been simulated and tested. It shows that the tire has a significant impact on the performance and that a Performance Based Standard criterion should be described in the future to master this point as the current criteria don’t take into account all aspects of the tire impact.

Keywords: Heavy vehicles dynamics, vehicle model, tire model, handling performance, Performance Based Standards.

1. Introduction

As a tire manufacturer, Michelin is constantly aiming willing to adapt its product offer to meet the customer’s needs and new opportunities or challenges, even in the context of the society stakes regarding greenhouse gas emissions and safety.

For this reason, the tire manufacturers have to tailor the tire performances to the customer’s and vehicle’s needs. This work of optimizing the tire design to its usage consists of, among other things, designing the tire at the right level in terms of load capacity but also in terms of drivability.

The truck tire market proposes a variety of drivability properties and a truck convoy can be fitted with different types of tires on each axle. At the same time, the tires installed on the vehicle (truck and trailer) should keep the vehicle drivable and safe regardless of the remaining tire tread depth.

In this approach, Michelin was naturally wondering what would be the functional need of truck tire guiding properties and their impact on lateral vehicle stability. To start answering this question, we have done extensive work on tire-vehicle modelling for a typical truck configuration under typical loading conditions in the Chinese market, and we have carried out a model correlation study on that configuration. This paper presents the model validation results and a conclusion on the tire impact on the lateral vehicle stability.

2. Vehicle model construction

For several years, Michelin has been measuring and modelling passenger cars for tire virtual tests to help define tire design specifications. The vehicle characterization consists of, among other things, kinematics & compliance suspension tests, center of gravity height measurements, etc...

Figure 1 – Truck and semi trailer test rigs

More recently, these tests have been extended to heavy trucks (see Figure 1). It is now also possible to measure the suspension and body properties of the semi-trailer. The results of these tests can now serve as inputs to a virtual model. The software Michelin has chosen for Heavy Truck Vehicle Dynamics modelling is Trucksim.

Figure 2 – Typical Chinese convoy

The first study to validate our model has been done on a truck configuration with loads representative of a Chinese use case (tractor – typical Chinese 6x4 and tridem semitrailer).

For example the roll steer ratio needed to feed the model, amongst other parameters, can be identified with the K&C tests. And in our case study the value of this parameter is 0.103 °/°.

For the payload modelling, the approach followed was to calculate CoG longitudinal position, height and inertia by a CAD analysis (Figure 3) as it cannot be easily measured.

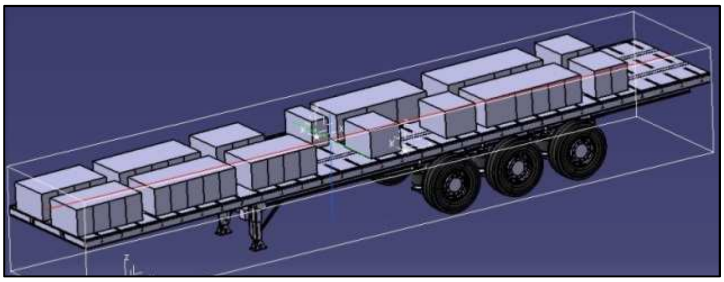


Figure 3 – semi-trailer and payload CAD model

3. Test conditions

3.1 Tire set up

The main target of the study was to see if we can sort by simulation a tire set up modification. A typical tire set up case of the Chinese market is to have highly worn tires on the semi-trailer (as it is tire end of life position), then high cornering stiffness on the semi-trailer. Therefore we tested lower tire stiffness on the tractor only. On figure 5 are presented the cornering stiffness versus vertical load of the market tires used in this study.

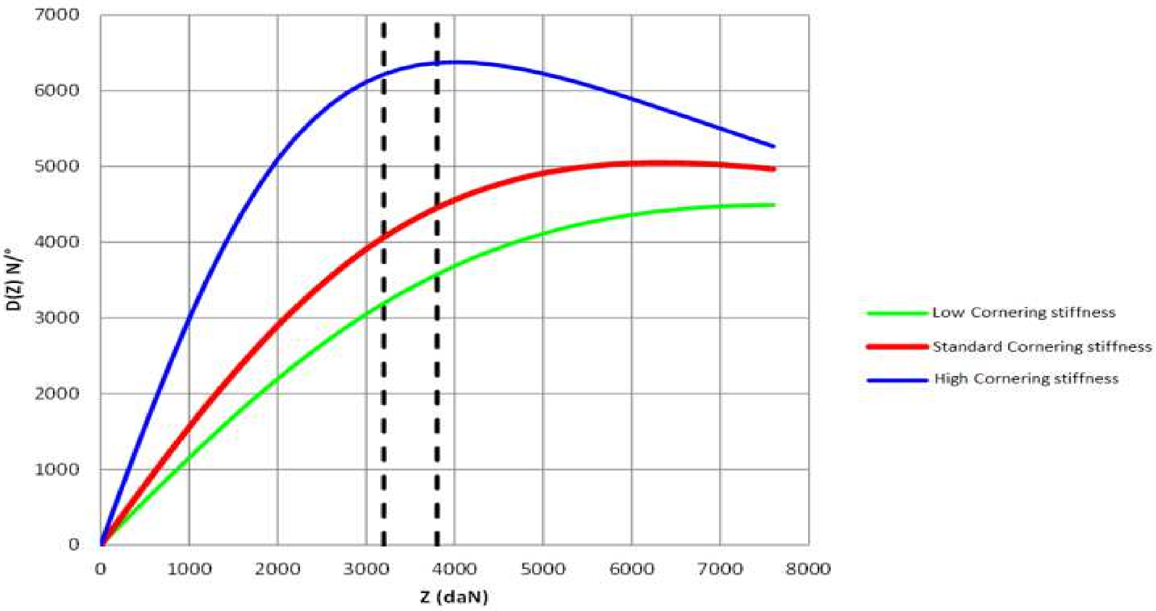


Figure 5 – Tire cornering stiffness against vertical load

The tires above have been fitted on the vehicule as described in table 1 :

Convoy configuration	Steer tire	Drive tires	Trailer tires	Dynamometric wheel fitted
Config1	Std	Std	Std	For all positions, successively
Config2	Low	Low	High	w/o
Config3	Std	Low	High	w/o

Table 1 – Convoy tire set up

3.2 Maneuvers

The tests have been run on one track of Michelin research center that proposes various turning radii then a variety of lateral acceleration for a constant given speed. Many speeds have been used: 30, 40, and 55 kph to test wide range of lateral accelerations and turning radii independently. The track has been modeled with Trucksim (Figure 4). The driver model target is to follow the path at the middle of the track. As we didn't want to spend too much time to tune the driver model parameters, we tested firstly the default settings in Trucksim and as the results where suitable for us, we didn't investigate further to tune the driver model parameters.

However, the real test driver was requested to have a steady state driving behavior by locking the steering wheel angle as long as possible what results in a facetted driving. This requirement had priority on following the path at the middle of the track, and then some path mismatch can be observed.

Furthermore, we have added to these steady state tests some lane change tests on a straight line track for the transient correlation study. The speed is fixed ate 60kph with sinus steering wheel angle +/-100° at various frequencies 0.25, 0.33 and 0.5Hz.

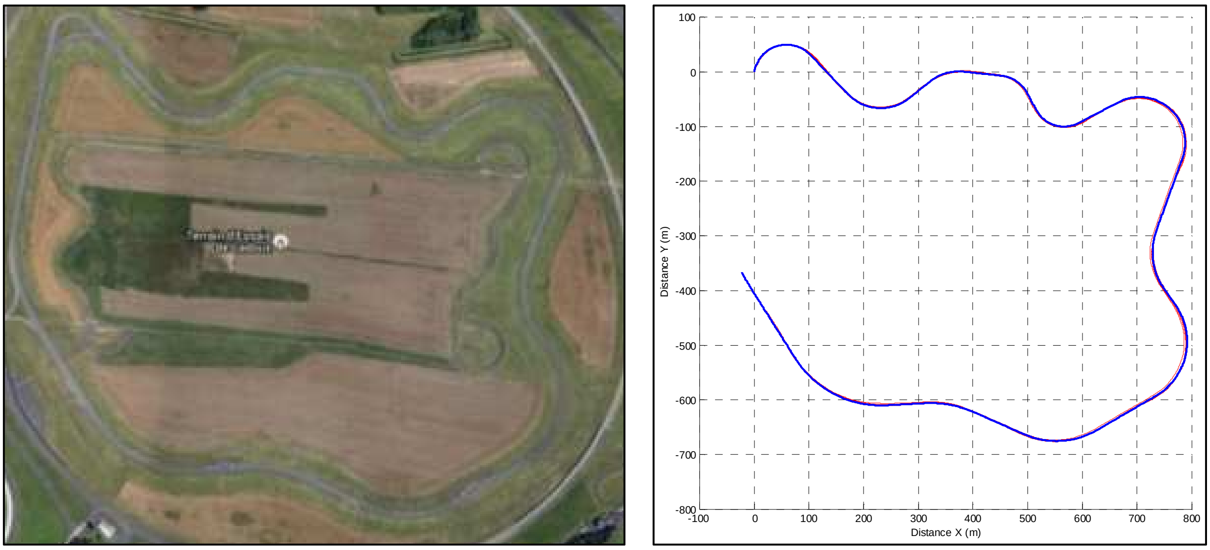


Figure 4 – Test track and its model

3.3 Sensor mounting

The vehicle sensor mounting is described on following drawing:

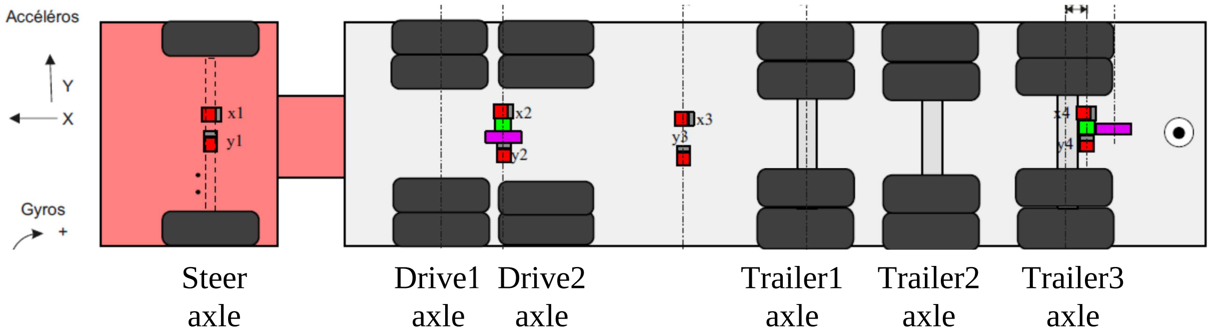


Figure 6 - Vehicle sensor mounting

- 1 Kistler dynamometric wheel (see Figure 7, only for Config1)
- Steering wheel torque and angle.
- Tractor and semi-trailer roll angle.
- Tractor and semi-trailer slip angle at points 2 and 4
- Lateral accelerations and yaw speed at points 1, 2, 3, and 4.
- Centimetric GPS rear point of the semi-trailer.

Figure 7 – Wheel dynamometer

4. Model validation with Config1 tire set up

4.1 Static load validation

The first point to be checked is the correlation of loads per hub between the real truck and the model as we have defined the loading just by the point mass and its position:

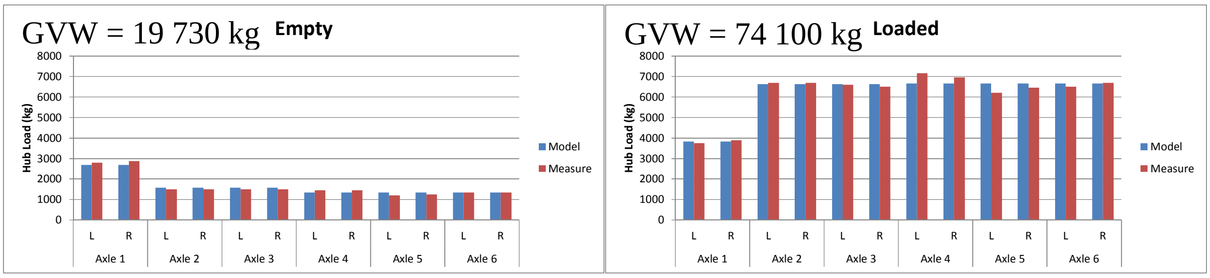


Figure 8 - Static load validation

The correlation is quite good for the static load (mean absolute error is 4%). This gives us confidence to go further on the steady state model validation.

4.2 Steady state validation

The following plots present the clockwise steady state tests @40kph for the standard tire mounting configuration (Config1). Each point is a steady state condition while steering angle and lateral acceleration are constant. The lateral forces show a good correlation between test and simulation as we can see on figure 9 and 10.

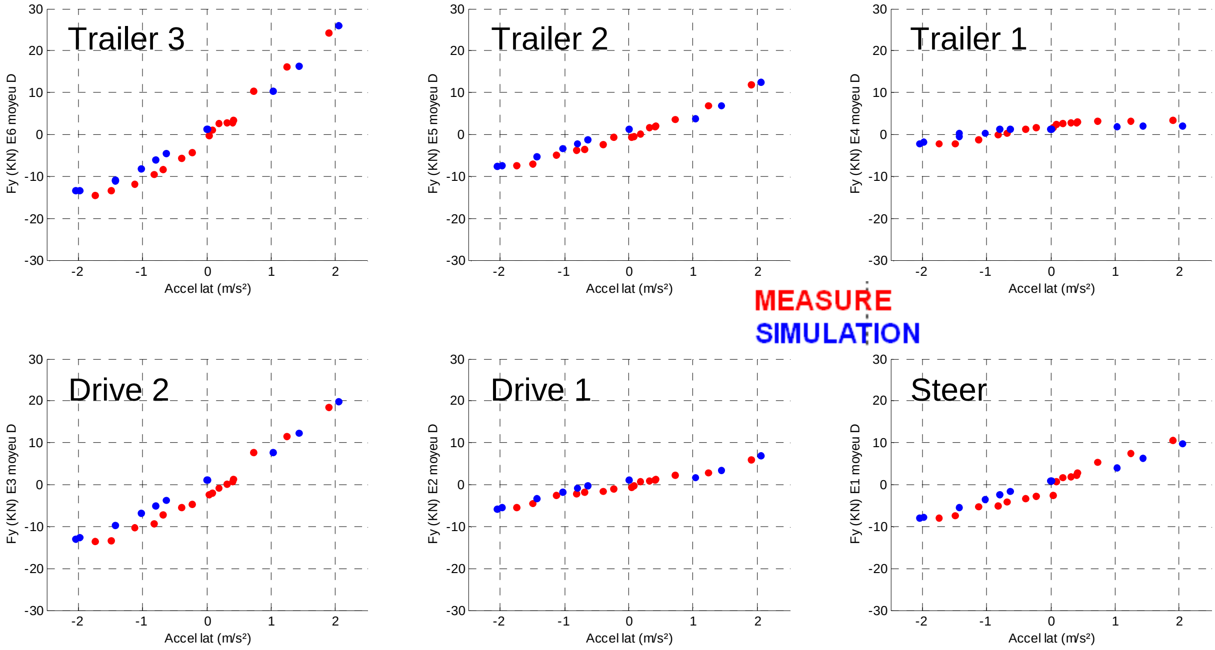


Figure 9 – Lateral force against lateral acceleration : measure Vs simulation

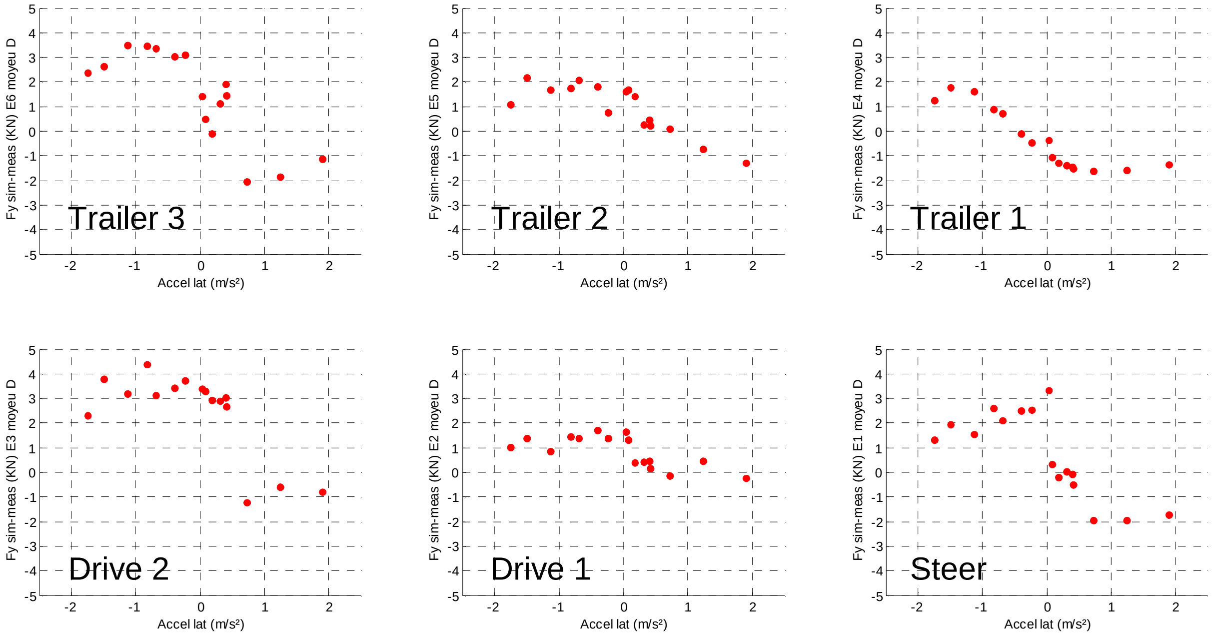


Figure 10 – Lateral force against lateral acceleration : delta between measure & simulation

For vertical forces we are also satisfied by the correlation between test and simulation, even if the payload CoG height should have been optimized (CAD estimation to be updated).

On figure 11 is plotted the tire lateral force against slip angle for simulation and tests. We should notice that the load for each point depends on lateral force as there are lateral load transfers. In other words, this plot is not fully analytic and includes some vertical force variation with lateral force, but it gives a global view of the tire model accuracy.

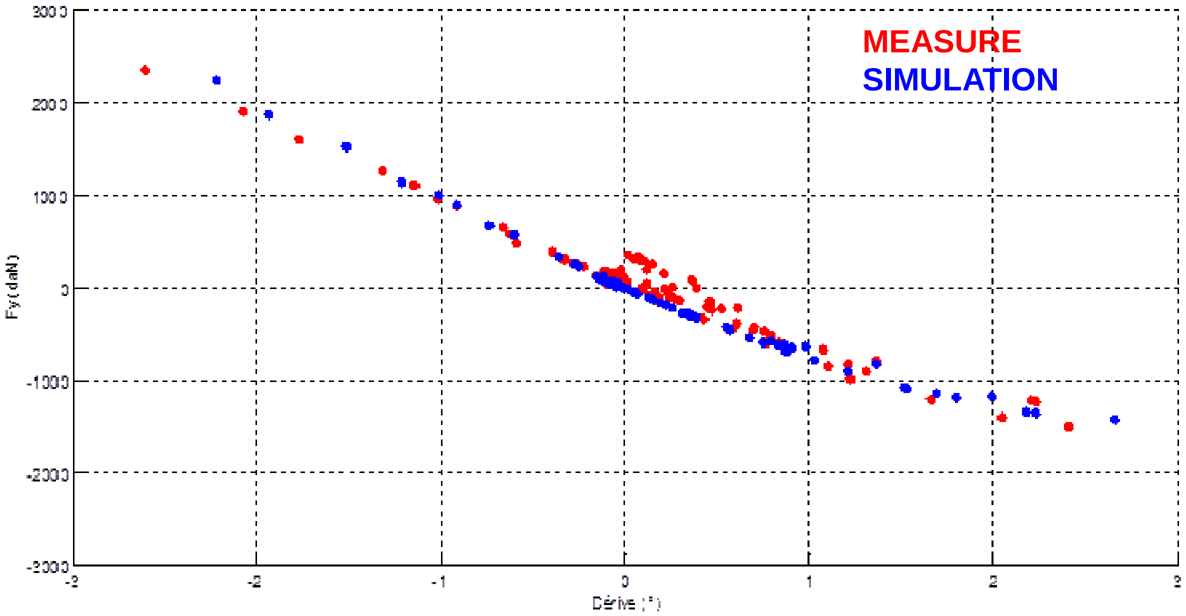


Figure 11 – Lat. force against slip angle : measure Vs simulation

The tire model has a good response versus the track measurements. As a conclusion we validate the steady state model which allows us continue with the transient model validation.

4.3 Transient validation

We have validated the model response for 3 frequencies of steering wheel angle sinusoidal input on the Config1 tire mounting configuration. Here are presented the comparison of lateral forces for 0.25 Hz.

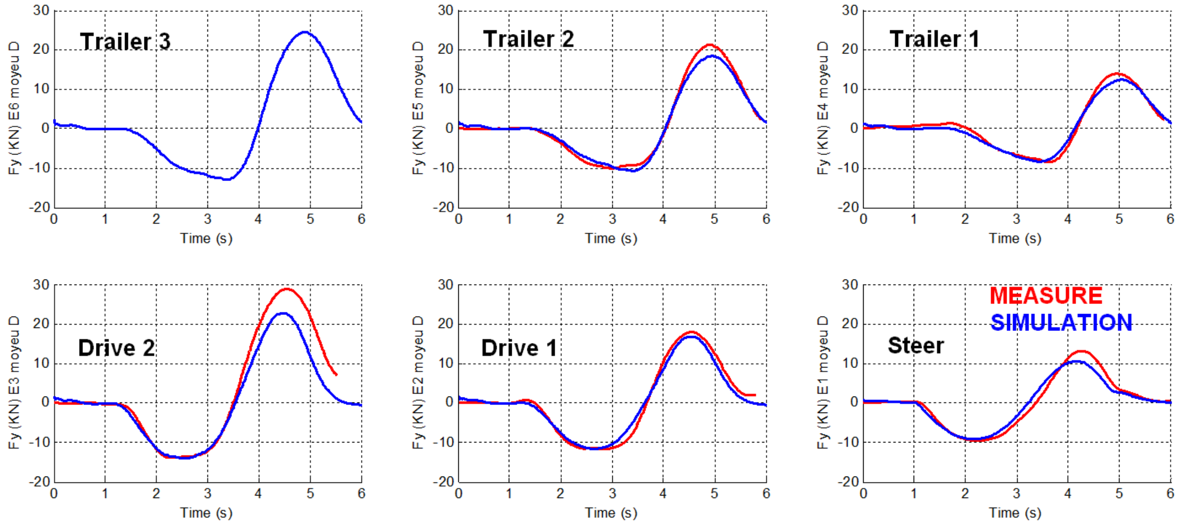


Figure 12 – Lateral force against time under transient state

The drive 2 axle has a worst prediction quality: the real track has a light banking not homogenous in the width and the run when the dynamometric wheel was fitted in drive 2 position is clearly in a different area of the track. For the vertical forces, the model shows the same level of accuracy. Therefore, the correlation is good for the dynamic usage of the model as well, and we can check the model's ranking power on a specific but realistic tire mounting configuration case of Chinese market.

5. Tire impact lateral dynamic

The simulation can rank the tire mounting configuration effects on the various steady state test conditions studied. The prediction is good on all axles even on the axles that experience scrubbing. The results are in line with what we would expect: the semi-trailer becomes more understeered with the Config2 tire mounting configuration than in Config1, as it can be seen on the figure 13, and the Config3, which is a Config2 with stiffer steer tires, has a lower understeer coefficient than Config2.

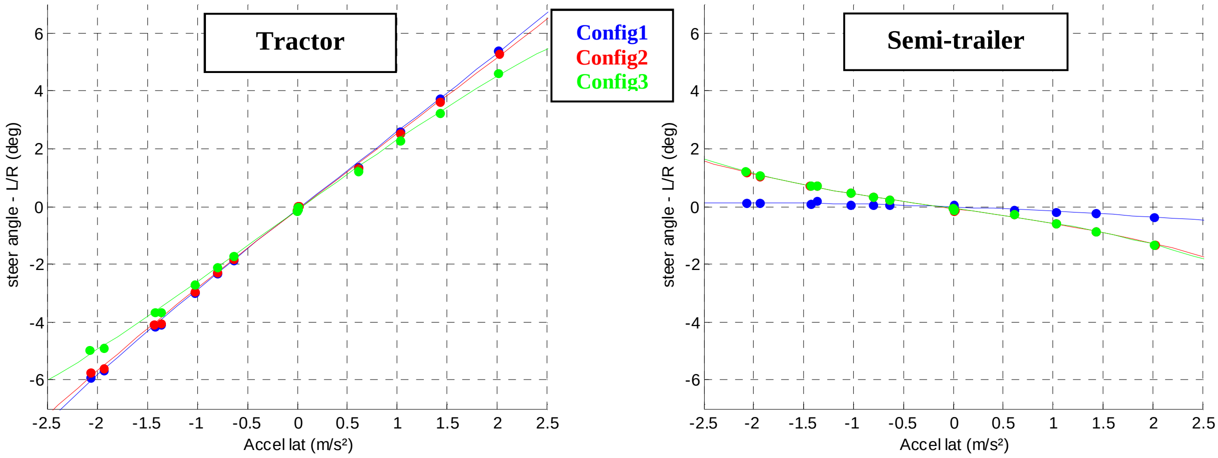


Figure 13 – Impact of convoy tire set up on slip angle rates

The lane change tests were carried out for a limited number of frequencies because it is very time consuming and the tire could evolve in terms of temperature and wear with too many runs. Thus, we decided to compare the frequency response of the rearward amplification for each tire mounting configuration by simulation. As the steady state results show that the semi-trailer is more understeered than the tractor, we wanted to know how to rank the convoy tire set up with a criterion that could suit to a PBS approach. A multiple frequency approach is needed because the critical frequency for the rearward amplification depends on the inertia and stiffness.

There is no significant impact on maximum rearward amplification (what is even improved with Config2 and 3), but the hitch angle response relative to the steering wheel input shows a clear different vehicle handling performance (figure 14).

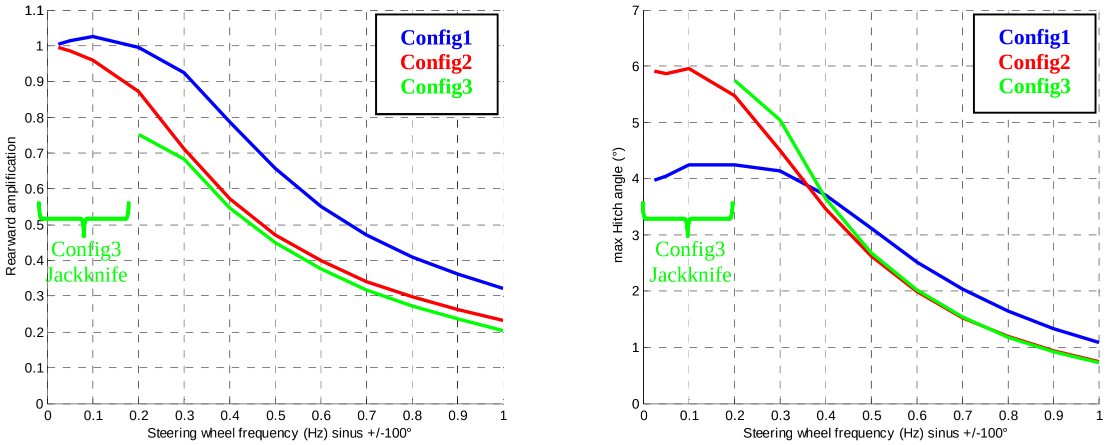


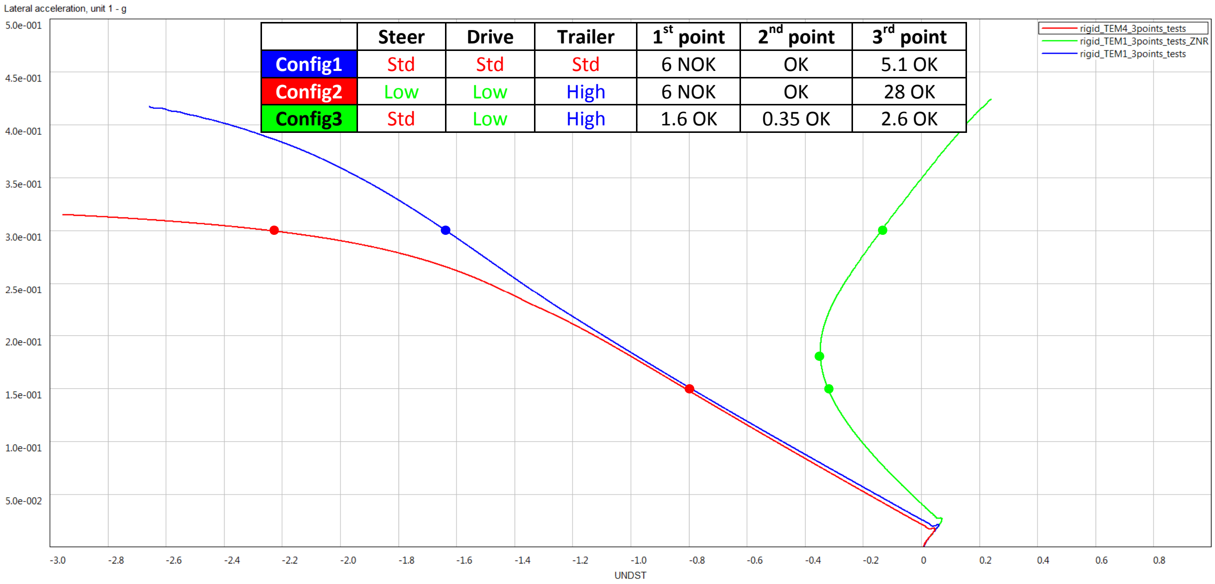
Figure 14 – Impact of convoy tire set up on Rearward amplification. Simulation results

As we can see on the maximum hitch angle plot on the right, the values seems to be confined for Config1 configuration what is not the case for Config2 in low frequencies, then the steady state analysis should be sufficient to determine the handling quality for this kind of issue.

We didn't find in the literature a final position on the way to standardize the C15 criterion on handling quality. For a jackknife situation, only an oversteer/understeer analysis seems to be able to highlight the issue.

The 'three-point' handling method, developed by El-Gindy and Woodrooffe in 1990 was a first proposal to set limits on the handling performance in the PBS framework but found not robust enough to be incorporated as a performance standard. The maneuver proposed was based on a ramp-steer rate of .03°/s when vehicle is running at 100kph.
- First point: the understeer coefficient at lateral acceleration of 0.15 g should be within 0.5°/g and 2°/g.
- Second point: the lateral acceleration at which the vehicle switches from understeer to oversteer should be higher than 0.2g.
- Third point: the understeer coefficient at certain lateral acceleration should be higher than the critical understeer coefficient.

In our example, the understeer diagram is given figure 15. We added another configuration Config3 what is a Config2 with standard tires in steer position that leads to unstable steer diagram. We can see that this Config3 is compliant with the 3 points even if it is unstable.



	Steer	Drive	Trailer	1st point	2nd point	3rd point
Config1	Std	Std	Std	6 NOK	OK	5.1 OK
Config2	Low	Low	High	6 NOK	OK	28 OK
Config3	Std	Low	High	1.6 OK	0.35 OK	2.6 OK

Figure 15 – Impact of convoy tire set up on underteer diagram. Simulation results

Finally, all these configurations could be accepted either through a Rearward Amplification analysis, or through a 3 points handling method analysis. All of them are on the road in China but the configuration is not really critical as there is just one articulation joint and such a configuration is quite stable, but a handling performance criteria is still needed and especially to rank tire set up.

To be noticed that Coleman from the NTC proposed in his paper at HVTT11, the ECE R13.11 directional stability control requirement can answer that question (with Dwell sine steering wheel angle input), even if this would mainly mandate the active safety technology than the passive safety performance and may ask the question of dependability.

We think a performance standard has still to be defined and are willing to collaborate on a criterion definition to help validate more efficient truck configurations by taking into account the tire mounting configuration.

6. Tires performance trade off

In the context of longer and heavier vehicles through a PBS approach, the increased GVW makes the number of axle increase in a bigger proportion what leads to a lower weight per axle, then a lower load carried by the tire.

The tire size should be adapted to this new load usage and that could be done by a smaller tire dimension fitting. The tire downsizing will probably lead to a lower cornering stiffness while the LHV have more articulations then a lower stability performance.

Figure 16 shows that the cornering stiffness is quite well correlated to the load index. Then designing a lower load index tire with a higher cornering stiffness is not a common tradeoff for standard market tires.

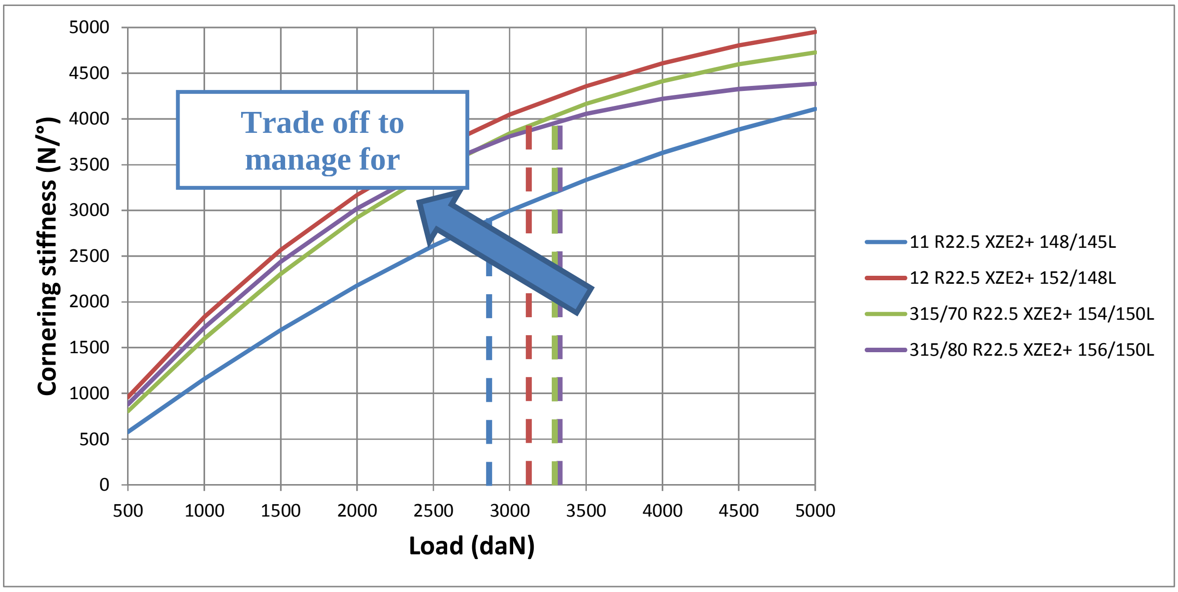


Figure 16 – Michelin market tire cornering stiffness and load index (dot line : load indexin duals)

7. Conclusion

This work validates the simulation approach to rank tire mounting configurations effects on heavy truck vehicle dynamics.

We have seen that the tire is a key parameter of the modelling quality and that the common usage of tire mounting configurations on the convoy could have a significant impact on vehicle performance.

As the tire properties evolve throughout its lifetime, the vehicle handling quality could evolve too and a complete validation of a new vehicle configuration compliance with PBS safety items should take this variation into account.

Finally it has been shown that a criterion to quote the handling quality in the PBS approach is missing and this is mainly on that performance that the tire could influence the vehicle response. This question is crucial for the tire manufacturer to propose a tire load index and cornering stiffness specification adapted to the LHV's usage and optimization.

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