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Heavy Truck Model Validation concerning Handling

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Abstract

The dynamic handling performance of heavy trucks is highly dependent on the nonlinear force and moment characteristics of tires and the vehicle configuration.

The computer simulation of handling performance of vehicles offers possibilities of evaluating influences of tire design changes on handling properties. Thus, modern simulation techniques may contribute on the building and testing of tires in an early design stage.

The goal of this work is to visualize the methodology for validating a truck-semi-trailer combination by performing outdoor vehicle handling tests and ADAMS full vehicle model handling simulations of a 40 t truck.

Extensive tire characteristic testing on road and test stand was done to get input data for the tire model.

Vehicle handling tests as steady-state circular and lateral transient response tests were done for the empty and laden vehicle with different tires to prove the vehicle model. Test and simulation results will be compared.

Vehicle dynamic simulation studies up to instability as spinout, jackknifing, and rollover can be performed using modern CAE-methods without harming man and environment, but subjective and objective tire evaluation still remains necessary for approving and validating the predicted results.

Introduction

The need to clearly understand what effects heavy vehicle stability is paramount for the design and development of the whole vehicle system. Factors as center of gravity, roll threshold, payload configuration, and tire properties control vehicle stability.

One of the most important aims in the tire design process is an optimal fit of a tire to the vehicle. The ease and confidence with which a vehicle can be driven in any situation is of great importance for the tire and vehicle development.

During the development of new truck tire lines, the design engineer has to meet different requirements as:

- low rolling resistance
- endurance
- tread wear
- high mileage

- tire/road noise
- wet grip performance
- traction and braking performance
- tire/vehicle safety (stability)

Different simulation technologies are available for the design process. For instance, the FEM is used to optimize the tire endurance, rolling resistance etc.

In the case of investigating the handling performance of commercial vehicles, simulation technologies are useful for predicting tire influences on the tire/vehicle system behaviour already before the first prototype stage. Other advantages are the possibility of varying parameters of the investigated tire within a short time and the evaluation of the effects of the variations on the system behaviour in an objective manner.

Thus, modern simulation techniques may contribute to reduce the costs and time for the development of new commercial vehicle tires.

Vehicle dynamic simulation studies up to instability as spinout, jack-knifing, and roll-over can be performed using modern CAE-methods without harming man and environment, but subjective and objective tire evaluation still remains necessary for approving and validating the predicted results.

Tire Force and Moment Model

The vehicle motions are caused primarily by tire forces and moments that result from power train, braking, and steering inputs. Tire forces represent a significant part of the vehicle dynamic behaviour. A comprehensive tire model is therefore of considerable importance.

Tire forces and moments interact with wheel spin, steering system behaviour, and vehicle lateral, longitudinal, and inertia dynamics. Thus, the tire model should properly represent tire force and moment properties to inputs of lateral- and longitudinal slip, wheel load and camber.

To complete the tire force and moment model, the delay in force production should additionally be taken into account. The delay in the tire force can be explained as the tire has to roll through some distance in order to produce desired slip angle.

For the representation of the steady state force and moment properties of tires within full vehicle handling simulations at Continental the empirical Magic Formula [1,2] tire model is used. The tire force and moment delay is modelled as first or second order filter applied to tire model inputs. The tire model is coupled to the vehicle model by the TIRE statement and user written subroutines, which are set up, that each tire of a vehicle model can have individual tire properties.

Tire Force and Moment Testing

The tire force and moment testing was done on our proving ground with the University of Hanover mobile tire tester. The mobile tire tester is explained in [3, 4]. It is a tractor-semitrailer with a gross weight of 38 t. Tire testing was done on a 500 m straight an even lane of the proving ground.

Tires in the sizes 315/80 R 22.5 and 315/60 R 22.5 were chosen for the tractor, 385/65 R 22.5 was chosen for the semitrailer.

For the measurement of the tire lateral force behaviour the tires can be steered from -2° to +11° slip angle, longitudinal forces are caused by hydraulic disk brakes.

For each of the tested tires 21 single tire measurements were done. All tires ran through a brake in procedure before testing. The test conditions for every single tire are shown in table 1.

Table1: Tire Measurements

Test No.	Slip Angle	Wheel Load	Velocity	Measurement
	°	kN	kph	
1	-1	20	40	Fx(s),Fy(Fx)
2	-1	30	40	Fx(s),Fy(Fx)
3	0	20	40	Fx(s),Fy(Fx)
4	0	30	40	Fx(s),Fy(Fx)
5	0	40	40	Fx(s),Fy(Fx)
6	1	20	40	Fx(s),Fy(Fx)
7	1	30	40	Fx(s),Fy(Fx)
8	2	20	40	Fx(s),Fy(Fx)
9	2	30	40	Fx(s),Fy(Fx)
10	2	40	40	Fx(s),Fy(Fx)
11	4	40	40	Fx(s),Fy(Fx)
12	-2 to 10	20	40	Fy(α),Mz(α)
13	-2 to 10	30	40	Fy(α),Mz(α)
14	-2 to 10	40	40	Fy(α),Mz(α)
15	-2 to 10	50	40	Fy(α),Mz(α)

Test No.	Slip Angle	Wheel Load	Velocity	Measurement
	°	kN	kph	
16	-2 to 10	20	60	Fy(α),Mz(α)
17	-2 to 10	30	60	Fy(α),Mz(α)
18	-2 to 10	40	60	Fy(α),Mz(α)
19	+/- 1	40	40	Fy(t),α(t)
20	*/- 1	40	60	Fy(t),α(t)
20	+/- 1	40	75	Fy(t),α(t)

Figure 1 shows the lateral force and self-aligning torque characteristics of one of our test tires as measured and represented by the Magic Formula tire model in the tire tester coordinate system.

Tire lateral force transient response is displayed in figure 2.

Vehicle Testing

The vehicle handling tests were conducted on a Mercedes Benz 1850 LS tractor and a Kässbohrer SB 10-24 L semitrailer. All tests were done for the empty and laden vehicle on different sets of tires.

The vehicle was equipped with 36 sensors from which 32 signals were recorded by a measuring device. Steering wheel angle, -torque, steer angle, lateral-, longitudinal acceleration, yaw velocity, side slip angle, tire deflections are just a few to be named. Dependent on the vehicle test, different sensor signals were detected.

Each set of new tires was broken in before any vehicle test was done.

As vehicle tests

- Steady State Cornering
- Sinusoidal Steering Wheel Input
- Single Lane Change and
- Braking While Cornering

were done.

Steady State Cornering was done for R = 30 m and R = 100 m right and left turn, lateral accelerations up to 6 m/s^2 could be realized.

Figure 2 shows three different test procedures, which were tested at the beginning of the evaluation. Variant 3 has been proved to be the one with the best reproducibility, but is the most time consuming one.

Sinusoidal Steering Wheel Input was done for v = 60 kph and v = 75 kph starting from a steering wheel input frequency of 0.2 Hz with an increment of 0.2 Hz up to the limit of the drivers performance. The steering wheel amplitude was set to a value which caused a lateral acceleration of 2.5 m/s^2 at 0.2 Hz.

The *Single Lane Change* maneuver was carried out by driving the vehicle on a desired path which was marked by pylons at the right and left boundary of the path. Figure 3 shows the testing conditions for the single lane change. The vehicle handling tests were started with a velocity of 50 kph increased by an increment of 5 kph up to the vehicle stability limit. These test were also carried out for the empty vehicle on a wet road.

Braking While Cornering was done on the dry R = 100 m circle, all breaking tests were done from a lateral acceleration of 2.5 m/s^2 with increasing longitudinal deceleration.

Validation of the Tire/Vehicle System

The test data obtained from the vehicle handling tests was used to validate the vehicle model.

Therefore the validation is not meant as fitting the simulated data exactly to the measured data, but as gaining confidence that the vehicle handling simulation is giving insight into the behaviour of the simulated vehicle.

Geometrical and physical data for the build-up of the vehicle model were taken either from drawings, technical data sheets, or directly from the vehicle. For the investigation of the influence of tire properties on the vehicle stability, it is important to have an appropriate vehicle model for the maneuvers of interest.

The test data was used to check whether the input parameters for the vehicle model are reasonable.

Steady State Cornering

The steady state cornering test will now be taken for the validation of the vehicle model. The test was repeated several times to gain confidence in the test data.

One of the major influences on the vehicle behaviour obtained from this test is the change of the tire properties with increasing tire wear caused by cornering.

Our tests were done with new sets of tires for right and left turn.

Different test procedures as shown in figure 3 cause test data which is effected by the tire changes due to wear.

Procedures one and two do not deliver reproducible results, because the driving of the vehicle at high lateral accelerations with high lateral forces cause extreme tire wear. This tire wear changes cornering stiffness and self aligning torque the most. That means that already the second run of the vehicle test starts with different tire characteristics than the first.

Test procedure three repeats each lateral acceleration step and thus, the change of tire properties for each lateral acceleration step in the lower range can nearly be neglected. The influence of tire wear has to be regarded for higher lateral accelerations.

Figure 5 shows that the steering characteristics of the vehicle agree with good accuracy to the measured data.

The greater differences for lateral accelerations around 0.5 g are caused by tire property changes which were not taken into consideration for the simulation.

Figure 6 shows the influence of tire property changes on the lateral behaviour of the vehicle. Only small changes around 3% in the cornering stiffness of the tires of the front axle and less than 2% on the rear axle cause the dashed curves. The steering effort and tractor side slip angle are now less than for the previous test.

Application of the IPG-Driver for the Single Lane Change Maneuver

After the vehicle model of the empty truck was proved to be of appropriate accuracy for the steady state and transient maneuvers, the IPG-Driver was coupled to the vehicle model.

The path for the vehicle in the simulation was the one shown in figure 4. In figure 7 the reactions of the truck are displayed. The evaluation of the results in the time domain shows steering wheel angle, lateral acceleration, and yaw velocity for the tractor. Figure 8 shows these variables for the trailer.

Tire forces are displayed in figure 9 and 10. The forces predicted in the dynamic simulation of the single lane change maneuvers can now be used as input for FEM calculations of tires under realistic loading conditions. The next figure displays the path center line and the center of gravity path of the tractor, while the vehicle drove very smooth with small lateral acceleration through the lane change.

Summary and Conclusion

In this paper a way of validating a tire/vehicle model of a heavy truck by comparing simulation results with experimental data was introduced.

The simulation predictions were qualitatively compared to the measured data by simply displaying it in the same graph.

Tire measurements, which were done on the Continental proving ground 'Contidrom' could be accurately represented within the vehicle handling simulation by the empirical Magic Formula tire model. Tire transient effects were covered by applying first and/or second order filters to the tire model inputs.

The full vehicle handling simulation showed by the example of steady state cornering of the empty vehicle, that the input data for the vehicle model is reasonable and the vehicle model represents the vehicle handling characteristics of interest with good accuracy.

Finally an application of the IPG-Driver within the full vehicle handling simulation was shown.

The conclusions made from this paper are that vehicle handling simulations can be performed with good agreement to experimental data. Validated models can furthermore be used to give feedback on parameter changes and influences of design variables on the vehicle handling. Objective and subjective testing still remains necessary for approving and validating the simulation results.

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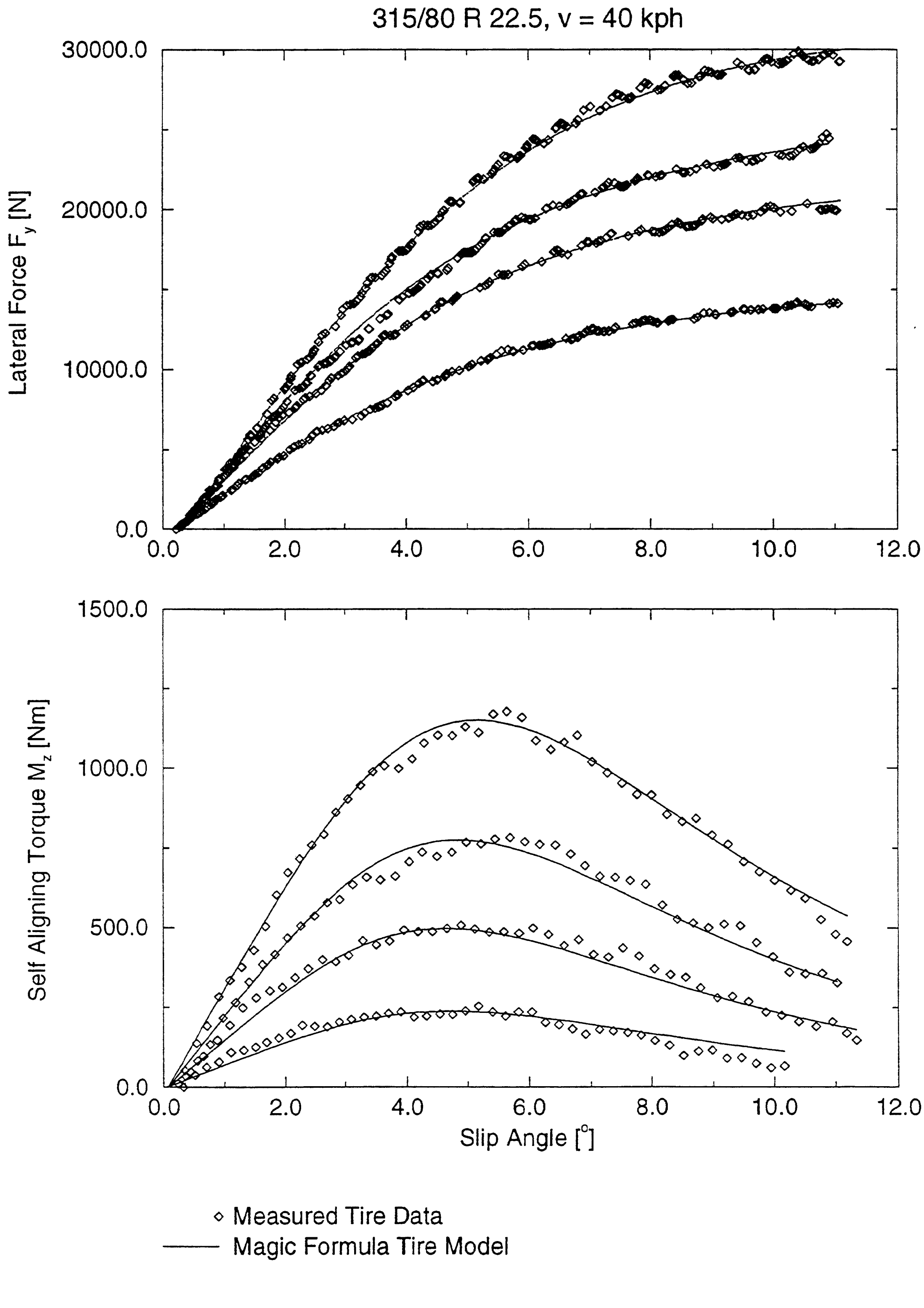

Figure 1 : Lateral Force and Self Aligning Torque of a Test Tire

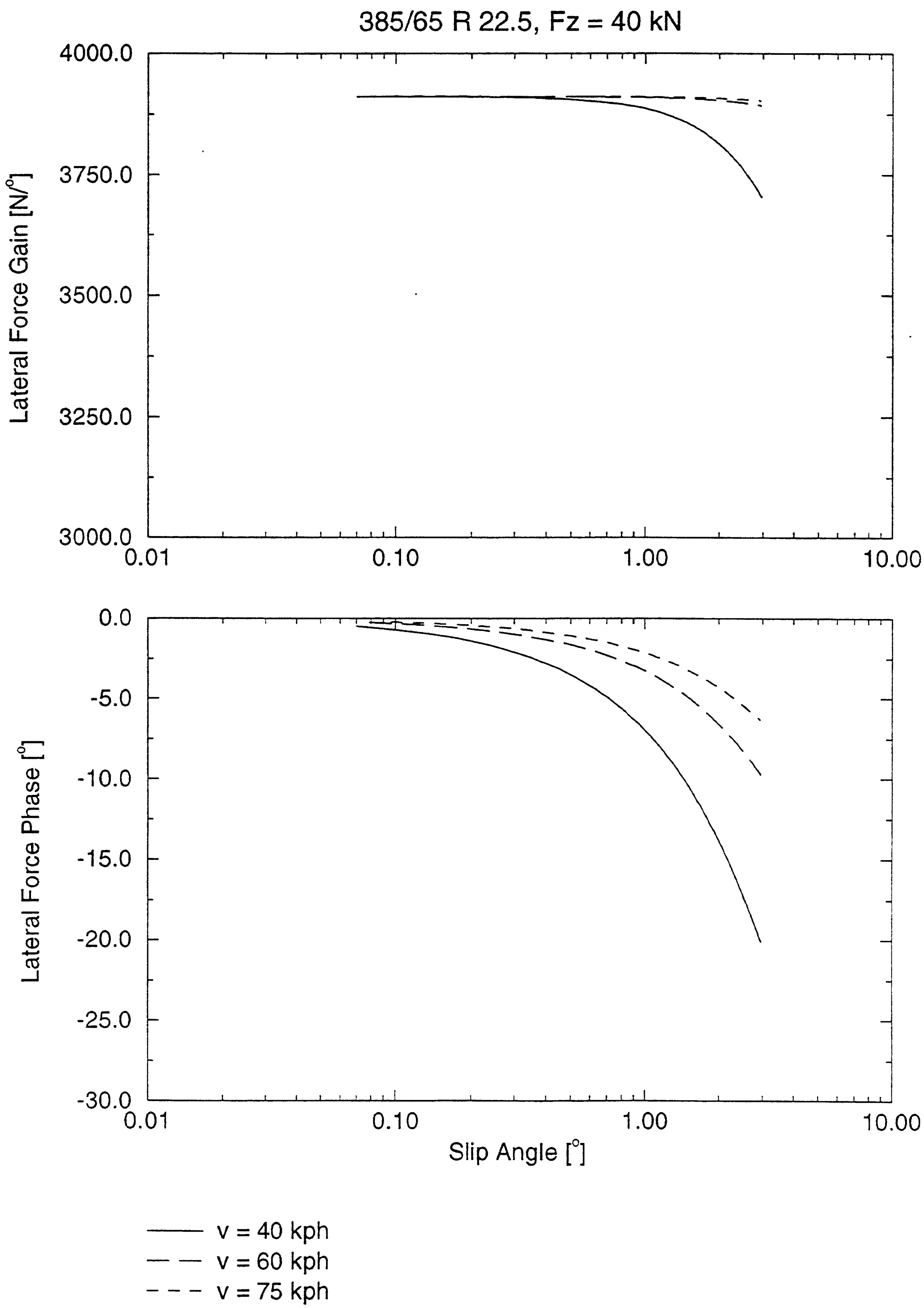

Figure 2: Lateral Force Transient Response of one of the Test Tires

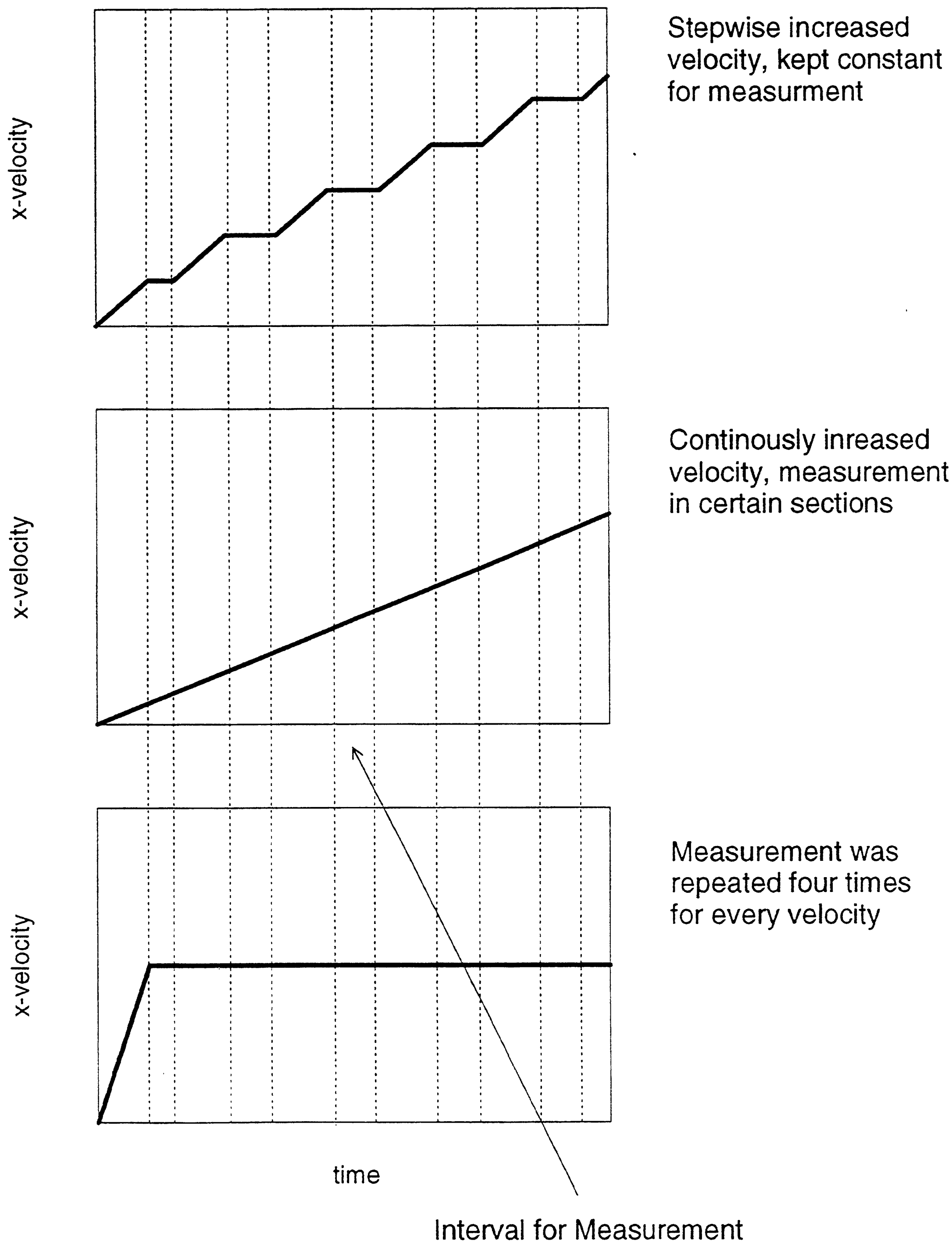

Figure 3: Comparison of different Steady State Cornering Procedures

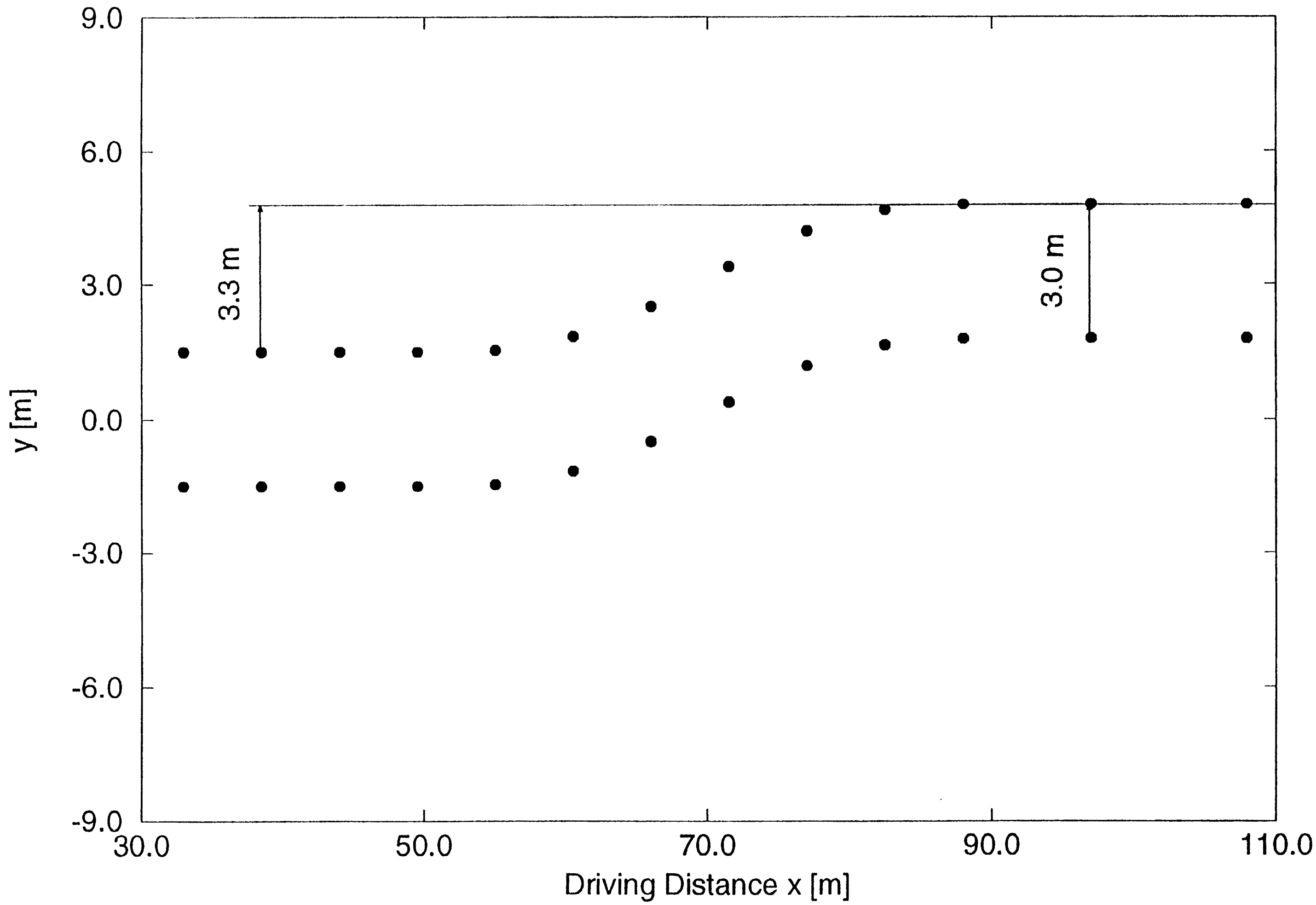

Figure 4: Path for the Single Lane Change Maneuver

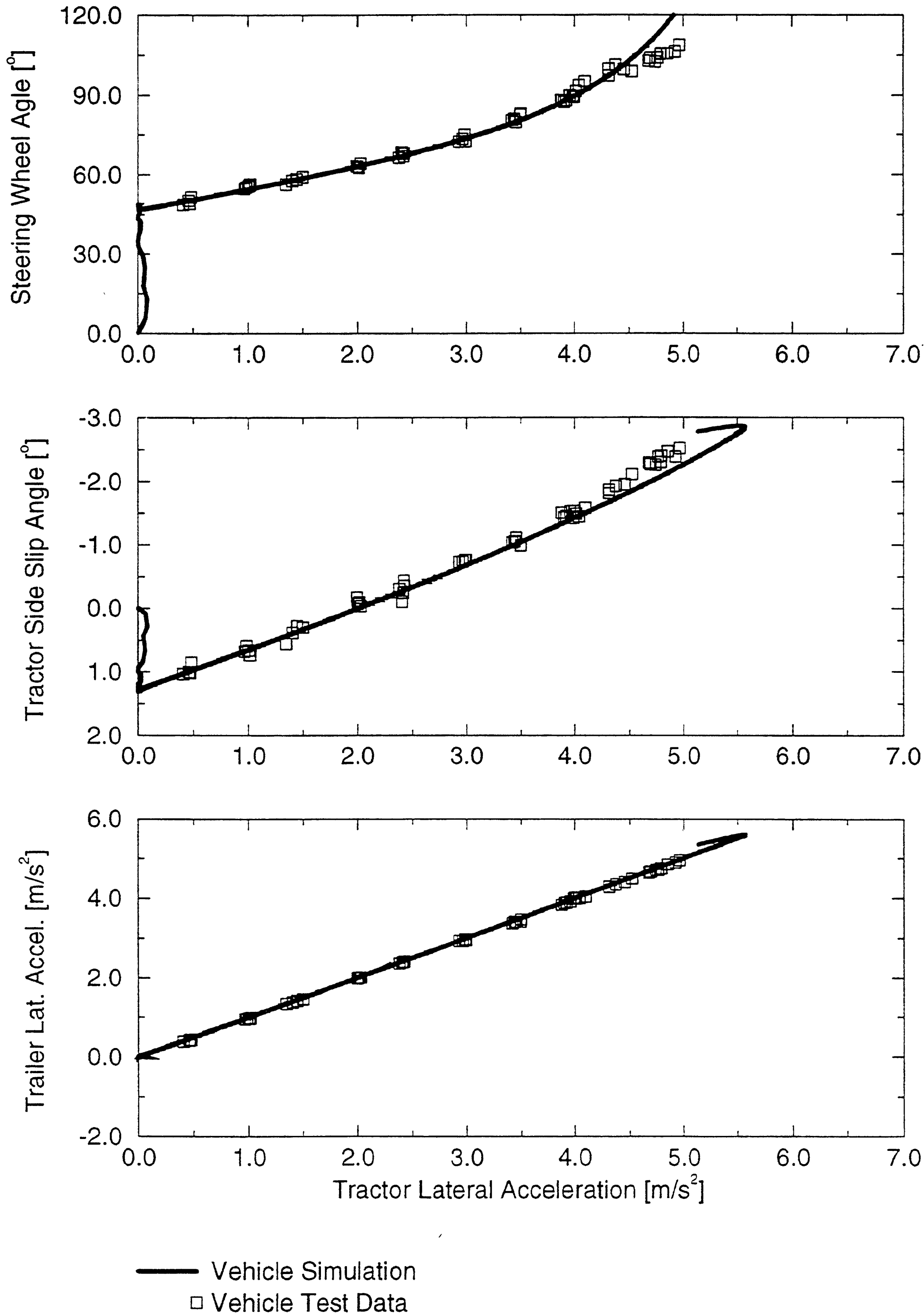

Figure 5: Comparison of simulation results to test data - empty vehicle

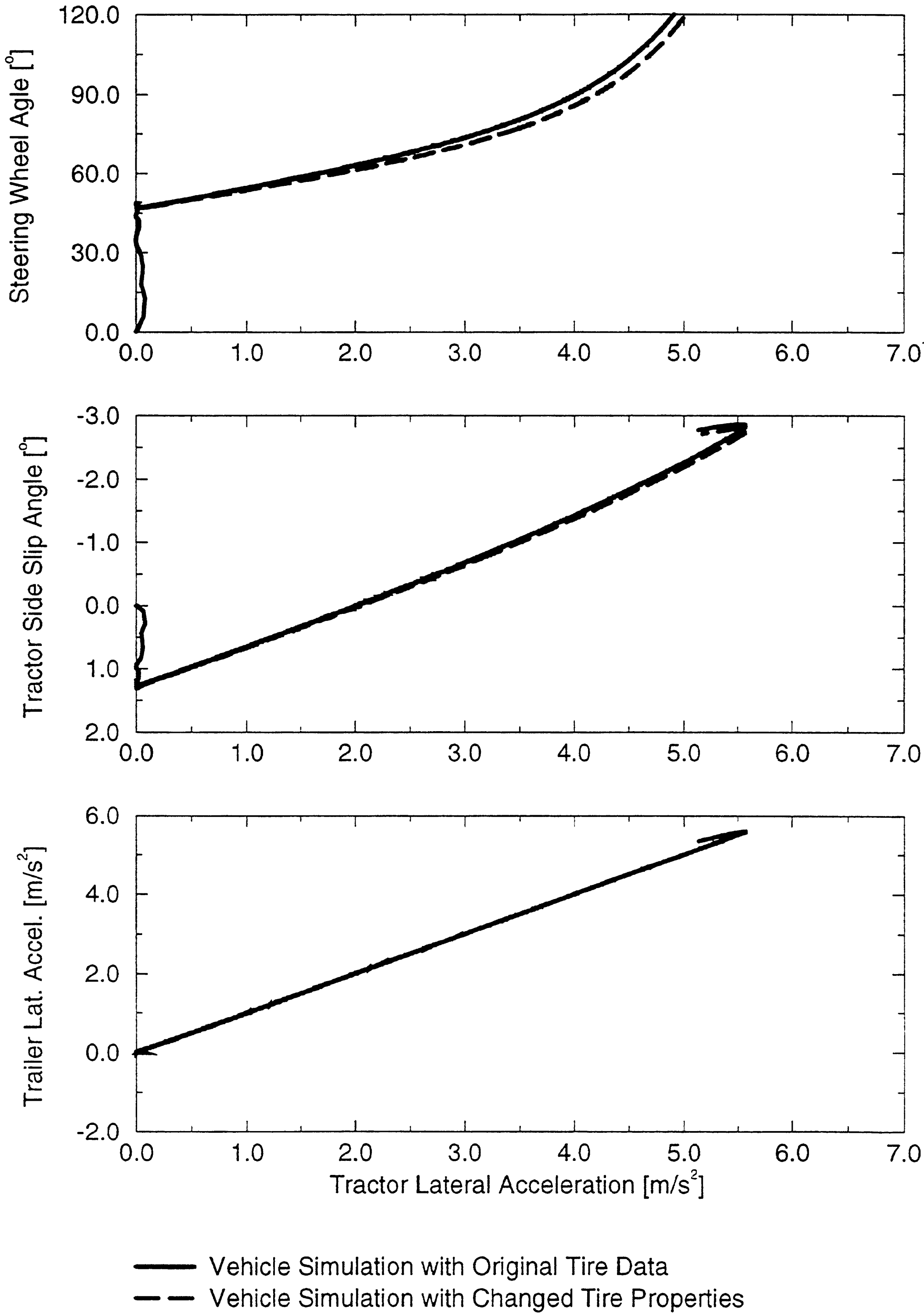

Figure 6: Comparison of simulation results with changes tire properties

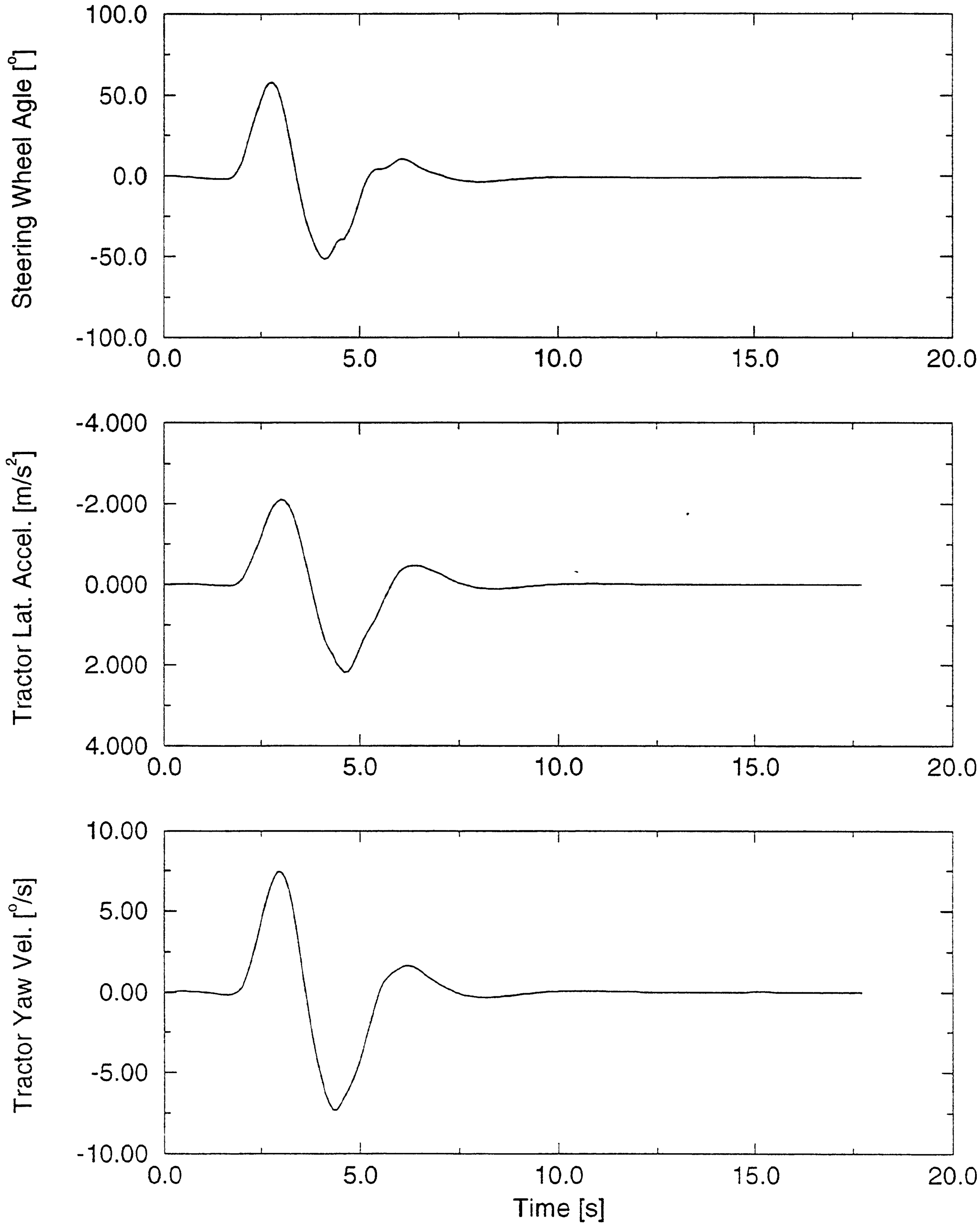

Figure 7: Steer characteristics of the tractor at v=75 kph single lane change

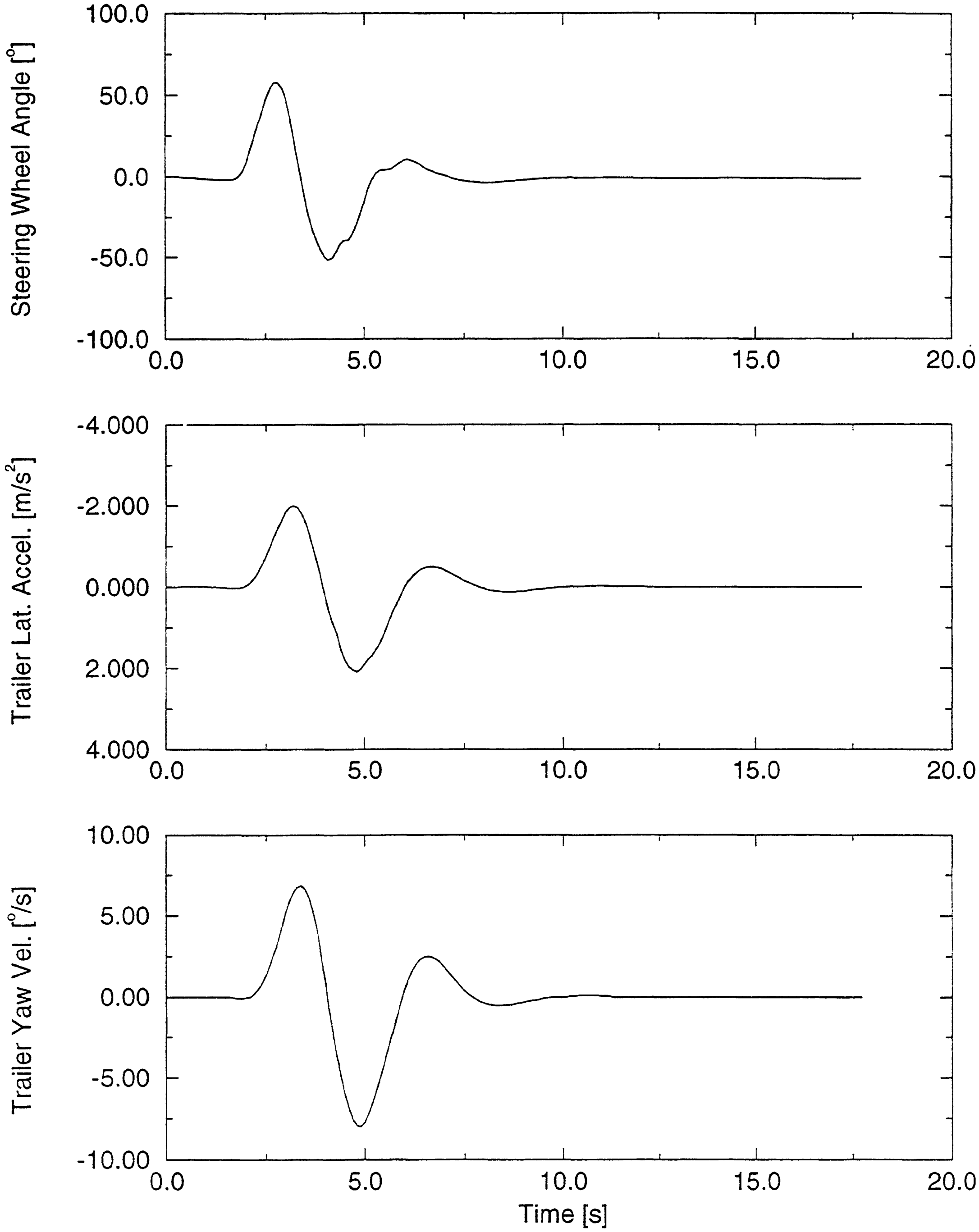

Figure 8: Steer characteristics of the trailer at v=75kph lane change

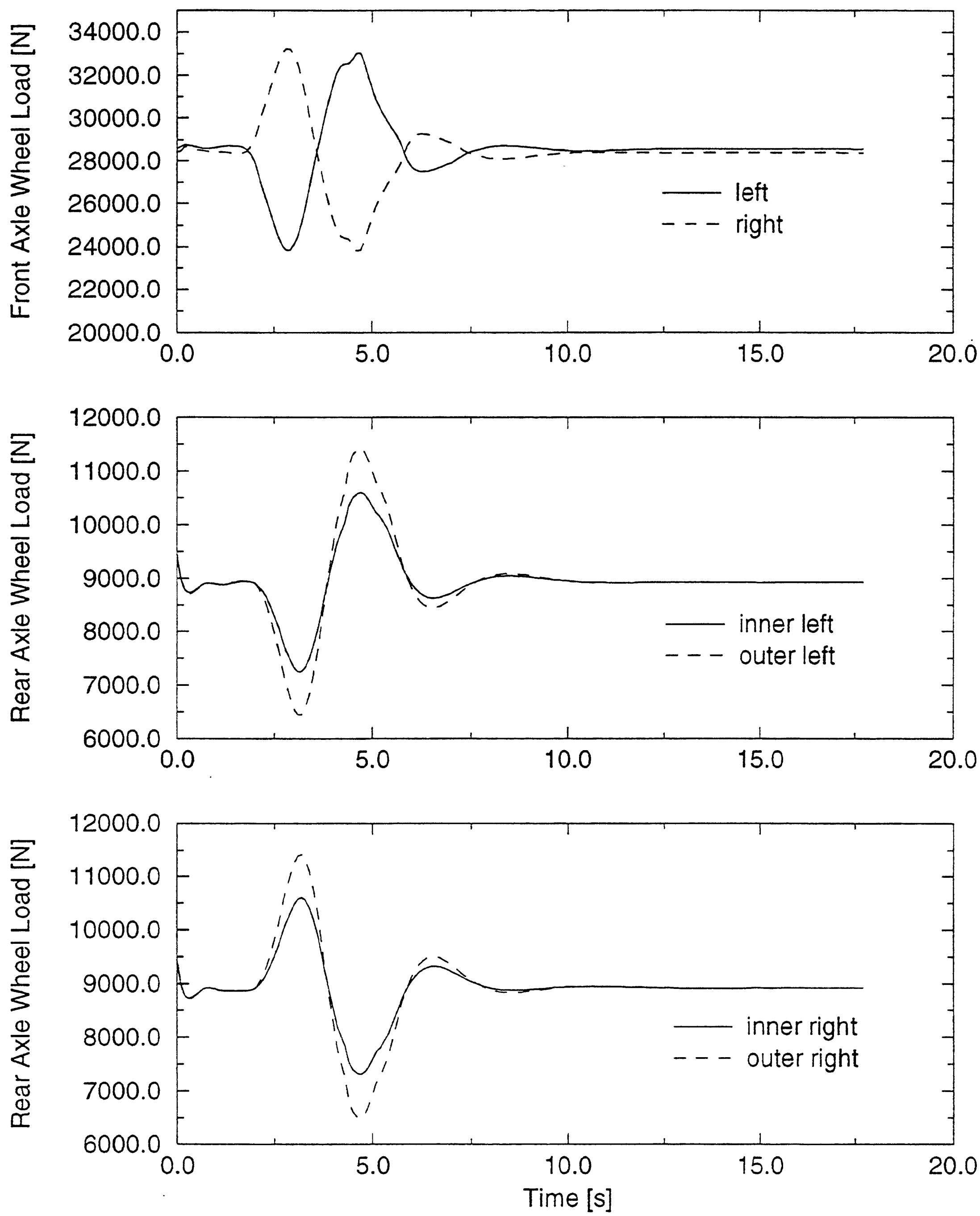

Figure 9: Wheel loads at the tractor, v=75kph lane change

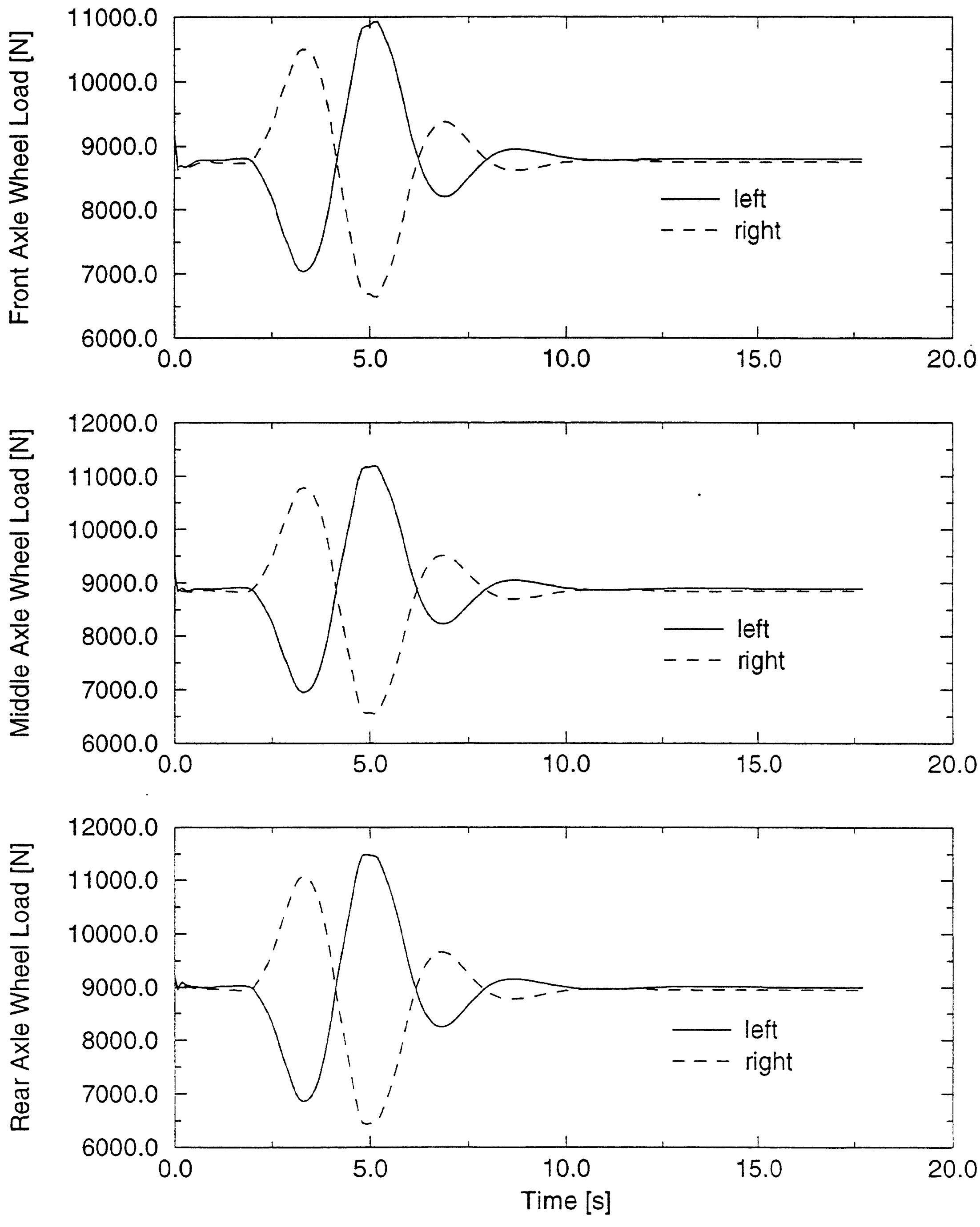

Figure 10: Trailer wheel loads, v=75kph lane change

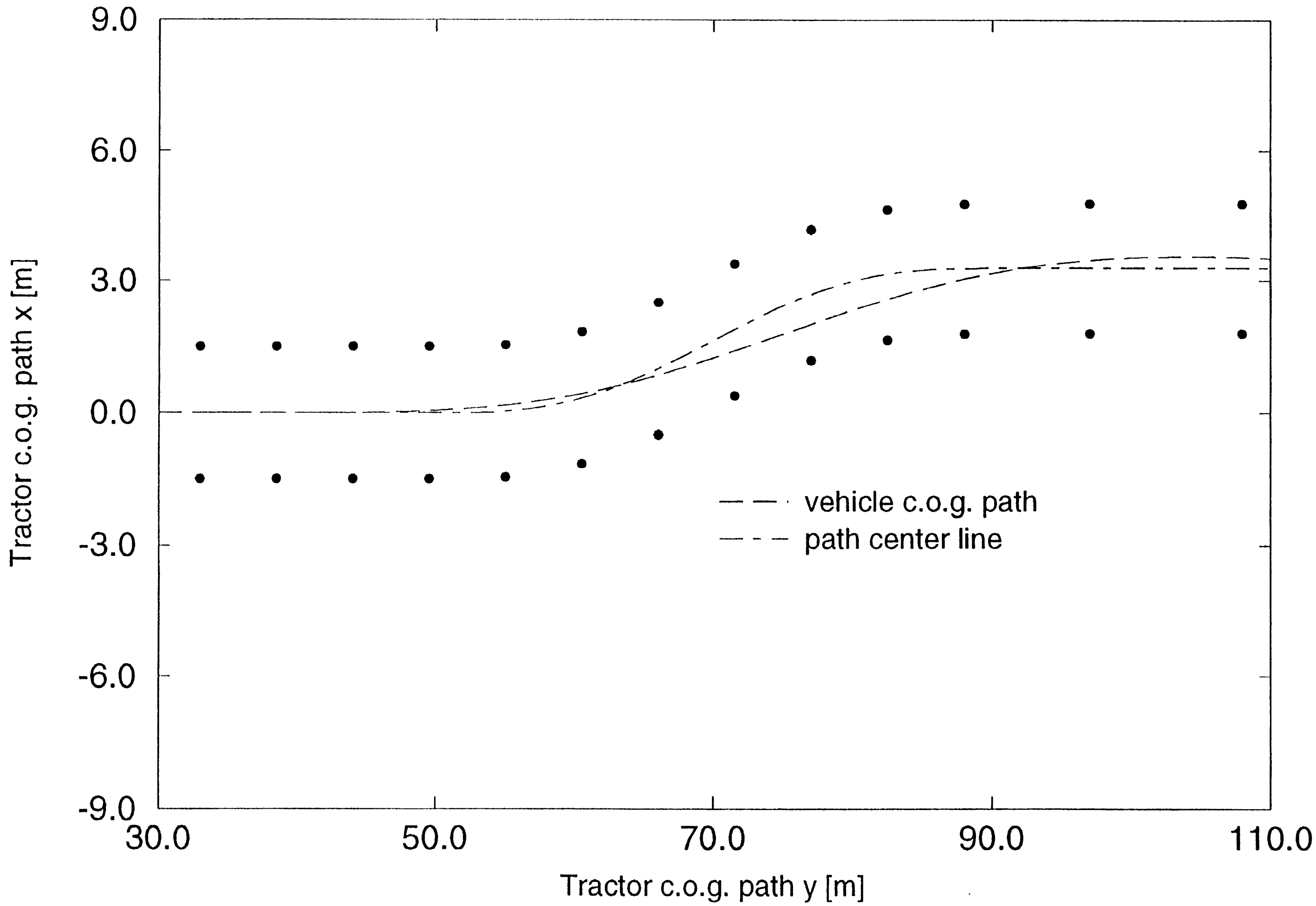

Figure 11: Tractor c.o.g path and desired path, v=75 kph single lane change