

# WIDE-BASE SINGLE TYRES ON TRUCK DRIVE AXLES AND THE EFFECTS FOR ACTIVE SAFETY

**Dr.-Ing. Klaus-Peter Glaeser**

Federal Highway Research Institute (BAST)  
Bergisch Gladbach, FRG.

## ABSTRACT

In 2003, several European tyre manufacturers announced they would be introducing wide-base single tyres developed for the drive axles of trucks, busses and tractors. These tyres, with a size of 495/45R22,5, are optionally now available for only one type of truck from a single European truck manufacturer.

Other manufacturers will follow in the year 2004 or 2005. The aim of this project was to study the driving behaviour and active safety of various trucks and units with different tyre combinations and loading conditions. Safety demands will also be discussed.

A computer-aided simulation in ADAMS was used for this investigation. Drive tests with a 40 t unit with prototype single tyres on the drive axle were carried out to verify the simulations.

Alterations in driving behaviour and driving safety are mainly dependent on tyre cornering stiffness. The prototype wide single tyres had a higher lateral stiffness leading to a higher degree of under-steering (safer driving behaviour). The altered spring base on the drive axle had no influence on the side-tilt stability of vehicle combinations but the solo truck profited from the higher rear axle roll stiffness (less danger of roll-over accidents). As far as the driving safety is concerned there is nothing to be said against wide-base tyres on the drive axle. The simulation of a tyre defect (burst) in a bend (assuming 40% of the max. transferable side force for the flat tyre) showed no increased danger by using wide single tyres.

Later driving tests however showed the need of either tyre run flat possibilities to avoid jack-knifing of road trains or dynamic control units. Also a tyre pressure monitoring system for the trucks with wide-base single tyres on the drive axle is advised.

Other advantages and disadvantages achieved as the results of the European COST Action 334 of wide-base tyres on truck driving axles, which were presented in the year 2002 at the COST 334 workshop in Delft as part of the 7<sup>th</sup> ISHVWD Symposium, will be summarised in the paper, too.

## INTRODUCTION

It was announced by the tyre industry that in 2003 several tyre manufacturers would put wide-base single tyres for the drive axles of heavy trucks on the European market. Up to now only one wide-base single tyre system is available. It was launched in August 2003 by Michelin and the truck manufacturer MAN. Other truck manufacturers (DaimlerChrysler, Volvo etc.) and tyre manufacturers (Continental, Bridgestone etc.) are still in the developing stage and the availability will not be given before summer 2004.

The introduction of wide-base single tyres on truck drive axles calls for close cooperation between truck and tyre manufacturers due to safety philosophies, set up of vehicle dynamics control (ESP, ABS) and tyre pressure monitoring systems.

The COST<sup>1</sup> Action 334 „Effects of Wide Single Tyres and Dual Tyres“ for trucks was launched by the European Commission in 1996. It's main objective was to establish the relative effects of wide-base single

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<sup>1</sup> COST = European Cooperation in the Field of Scientific and Technical Research

tyres and dual tyre assemblies in respect of road pavement damage, vehicle operating costs, vehicle safety, vehicle comfort and environmental aspects (e. g. tyre/road noise).

This paper only describes the vehicle safety aspects and demands for vehicle dynamics control especially with reference to a tyre burst. The practical research work (mathematical simulation of the truck driving behaviour) was carried out for BAST by the former Institute of Automotive Engineering of the University of Hanover [1] and was part of the German input to the COST 334 Action, which was finished with the presentation of the results at a special workshop on the 7<sup>th</sup> Symposium on Heavy Vehicles Weights and Dimensions in Delft in June 2002 [2, 3].

## AIM OF THE STUDY

Cost-reducing aspects such as a lower purchase price and reductions in empty weight and rolling resistance encouraged the use of wide single tyres on the towed axles of trailers and semi-trailers, in Europe between 1985 and 2000.

Development work by the tyre industry together with the truck manufacturers, which could be seen e.g. at the Hanover Motor Show 2002, goes in the direction of introducing wide-base single tyres with a tyre width of nearly half a meter (size 495/45R22,5) instead of twin tyres also on the driving axle of trucks, tractors and busses, see figure 1.

The aim of the study was to look theoretically at the driving behaviour and safety of various trucks and units with different tyre combinations and loading conditions.



Figure 1. Wide-base single tyres.

## METHODOLOGY

A computer-aided simulation in ADAMS<sup>2</sup> was used in this research project to investigate and compare the driving behaviour and driving safety of heavy goods vehicles with wide single tyres on their driving axles on the one hand and standard vehicles with twin tyres on the other. The different tyre widths also enabled alterations to be made to the vehicle's chassis, e.g. changes in the frame width, the spring suspension width and the stabiliser setting.

The following practically-relevant scenarios were simulated:

- keeping the same drive axle (width), while employing different tyre combinations for the drive axle (smaller rear track width for the single tyre) including alteration of tyre characteristics, tyre mass and tyre inertia moment;
- enlarged axle width (+ 0.7 m) with the same spring suspension width for the single tyre and same outer width;

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<sup>2</sup> ADAMS = AUTOMATIC DYNAMIC ANALYSIS OF MECHANICAL SYSTEMS

- enlarged axle width and alteration of the width of the spring suspension and consequent alteration to the roll stiffness while keeping the stabiliser dimensions the same;
- driving behaviour (safety) with a defect tyre (tyre burst) while driving in a bend (danger of jack knifing).

In order to cover a range of vehicles as big as possible, the simulation was used to test a solo truck (about 15% of the heavy goods truck fleet > 15 t in Germany), a truck with draw bar trailer (about 35 % of the fleet) and a tractor with semi-trailer (about 50% of the fleet). Appropriate driving manoeuvres were also selected for the simulation in order to observe driving safety with the different tyre variations.

These were in particular:

- single lane change: looking for offtracking and rearward amplification,
- J-turn (driving in a sharp bend such as a highway exit): looking for stability limits, see figure 2.

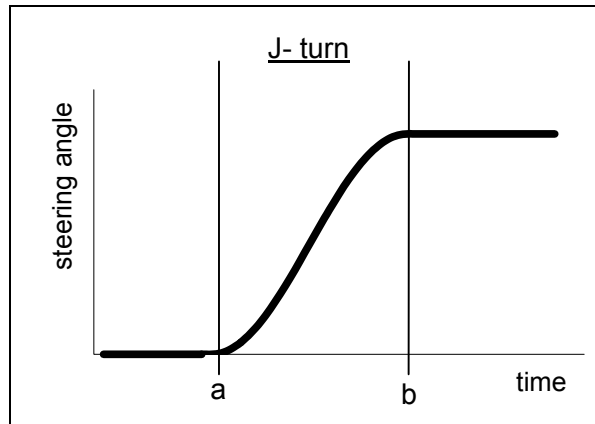


Figure 2. Steering angle vs. time in J-turn test.

In the simulation the height of the centre of gravity of the pay load was varied from 1.8 m (as in the driving tests described below), to 2.7 m (centre of volume) and additionally a swinging load hanging from the body's roof (as worst condition for driving behaviour) was simulated.

Additional driving tests (single lane change with the path following method and driving on a circular course) were carried out according to international (ISO) standards with a 40 t tractor semi-trailer combination which is the most common variant. These tests were, however, carried out without any alterations to the chassis of the tractor, see figure 3.



Figure 3. Path of single lane change for the drive tests of KTI.

The tyres chosen were:

- 315/70R22,5 on the steering axle of the tractor
- 315/70R22,5 as twins or 495/45R22,5 as single tyres on the drive axle of the tractor
- 385/65R22,5 as single tyres on the three towed axles of the semi-trailer

These driving test results – carried out by KTI in Hungary - were used to verify the computer simulations. It was assumed that, if the results of this unit were comparable with the results of the simulation of this unit, the solo truck and the truck drawbar-trailer unit would be verified, too.

The lateral stiffness (cornering stiffness) of the different tyres were measured by a special measuring truck of the University of Hanover. The wide-base 495/45R22,5 super single tyre was measured on a tyre flat-band-test facility by Michelin. The tyre characteristic curves for the single steps in the simulation were taken from calculations using the Delft Tyre Model.

## RESULTS

The cornering stiffness of the wide-base single tyre is higher than that of the dual tyres, see figure 4. This is the main reason for the increased under-steering behaviour, which usually is said to be safer than over-steering of, for instance, a single truck. This was also observed in drive tests carried out by Volvo [2]. The tendency to under-steering behaviour can also be observed for articulated vehicles.

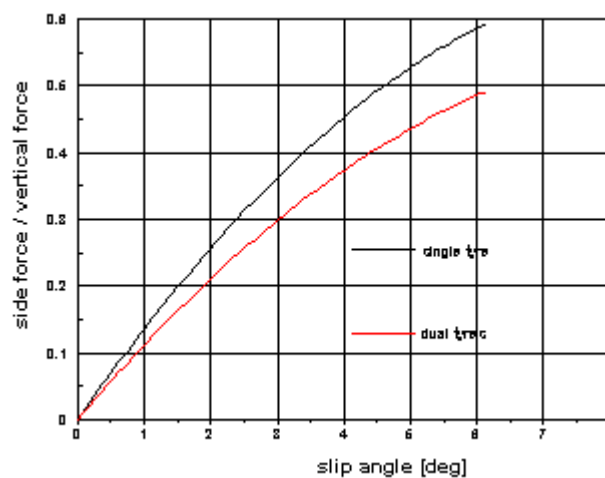


Figure 4. Cornering stiffness of wide base single and dual tyres in principal.

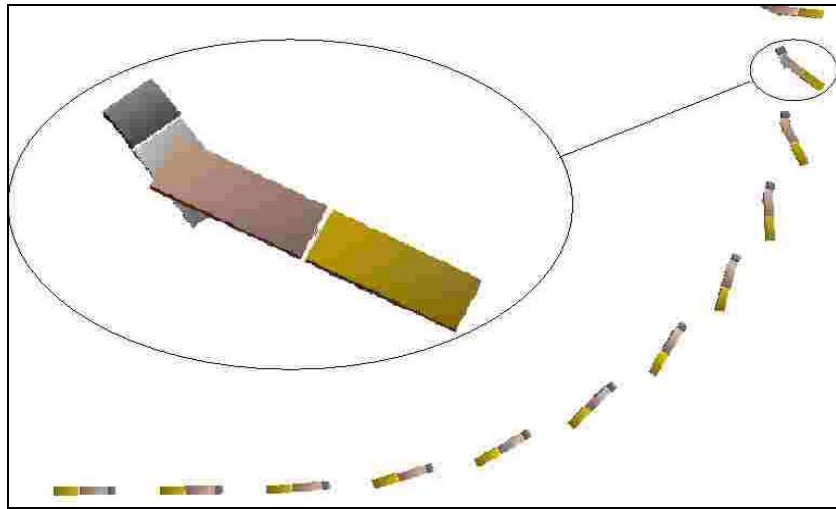
From the simulation of the single lane change manoeuvre (and from the driving tests, too) it can be seen that the rearward amplification of the yaw velocity and the lateral acceleration are somewhat lower for the single tyres compared with the dual tyres on the drive axle. The difference in the rearward amplification of the lateral acceleration on its maximum at 0.5 Hz is about 5%, the difference of the rearward amplification of the yaw velocity is much smaller and therefore may be discounted. Variations in the spring base width obviously do not have a noticeable influence on the driving behaviour. Also the height of the centre of gravity does not change the described behaviour in general.

Most information can be derived from the stability simulation of driving into the J-turn. Figure 5 shows possible vehicle reactions, which are mainly dependent on the centre of gravity height and tyre characteristics. In the simulation the velocity was increased step by step until one of the stability limits was reached. The maximum velocity and the maximum attainable lateral acceleration are the interesting parameters.

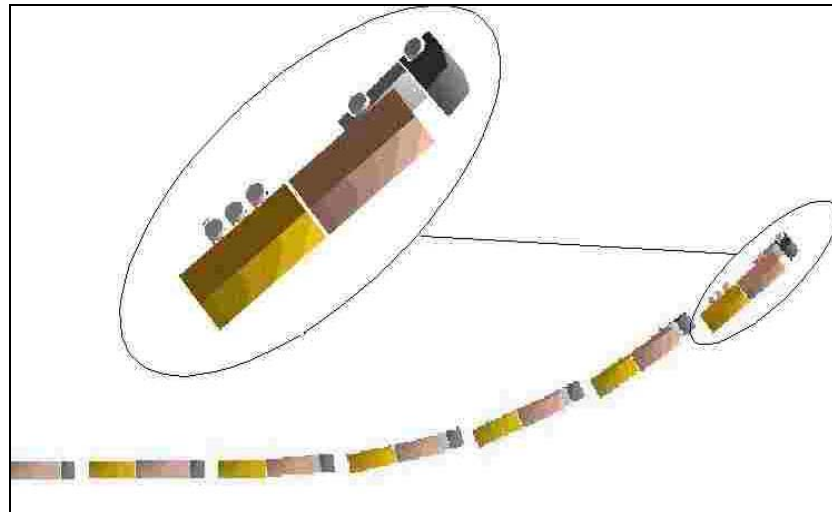
The driving radius is calculated by: square-velocity divided by centripetal acceleration.

The actual driving behaviour can be described by comparing the actual radius relative to the radius a vehicle would follow with a given steering angle without lateral acceleration, that means driving at a speed of nearly zero. If the actual driven radius proves to be higher, the behaviour of the vehicle can be described as under-steering (safer) and if the radius gets smaller, the behaviour is called over-steering. The danger of jack-knifing is the result.

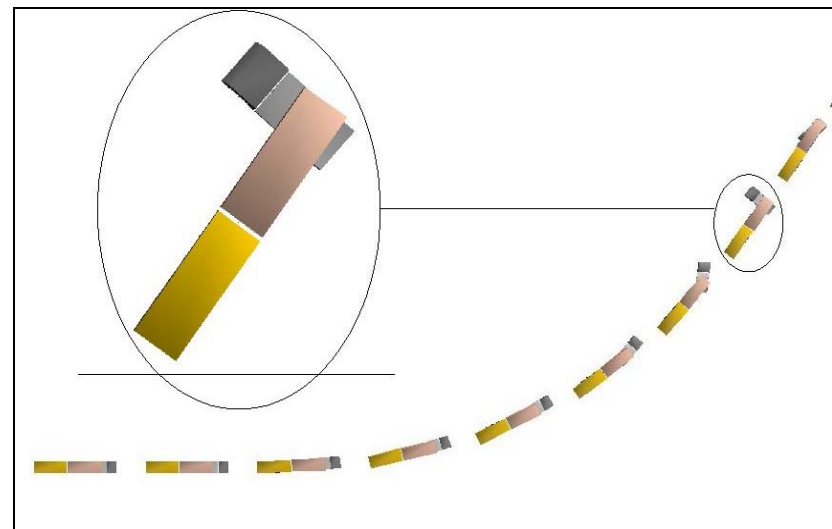
The maximum attainable lateral acceleration can be compared, too. It signifies a kind of resistance against roll-over. For road trains ( and trucks in the same kind) the following versions were examined, see figure 6. The spring base was adapted every time for the different tyres used.



Tractor semi-trailer going into skid



Tractor semi-trailer roll over



Tractor semi-trailer jackknifing

Figure 5. Unstable driving conditions for a unit (stability limits for J-turn simulation).

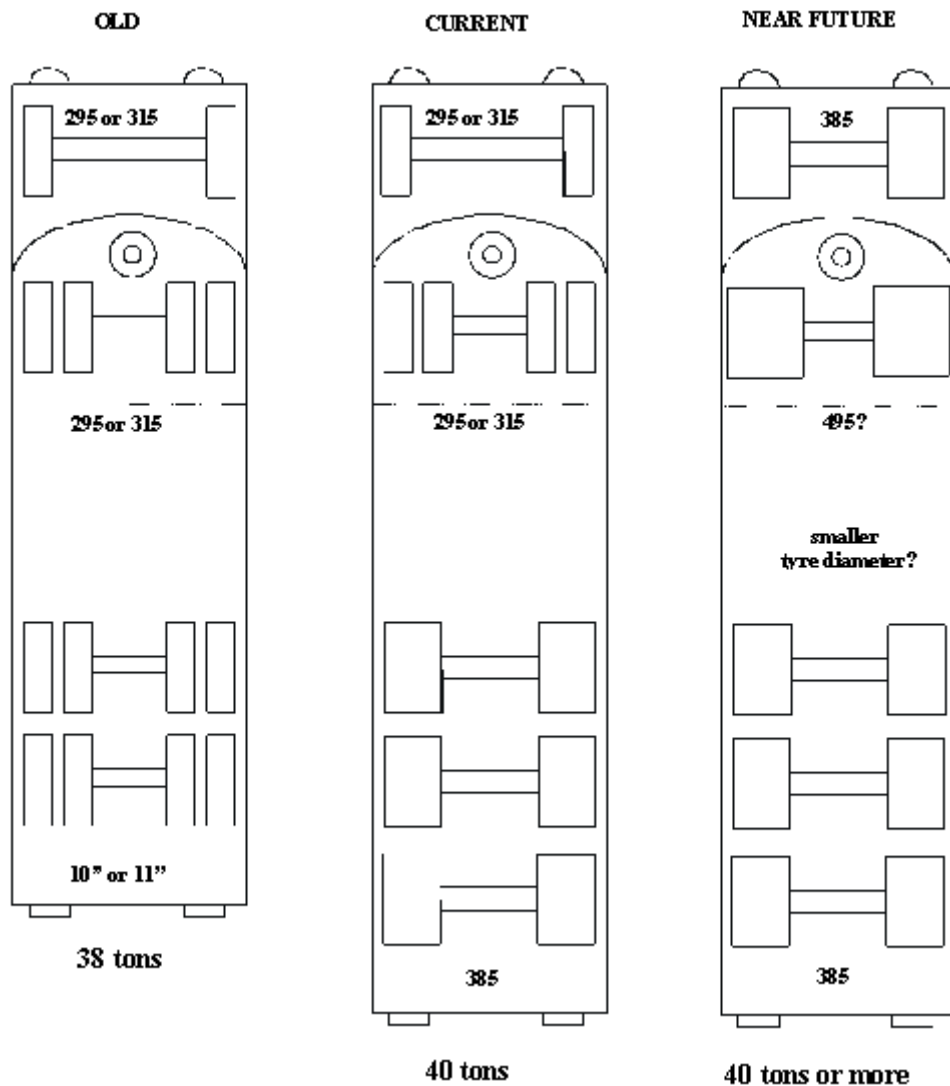


Figure 6. Old, current and future tyre combinations used for tractor semi-trailer combinations.

For articulated vehicles there is no difference in the maximum attainable lateral acceleration. The attainable max. lateral acceleration is strongly dependent on the height of the centre of gravity. Increasing the height of the centre of gravity by 70 cm reduces the max. lateral acceleration to about 40%. The most dangerous loading condition is swinging loads hanging from the roof. The attainable max. lateral acceleration is reduced to more than half of that attainable by the vehicle with low centre of gravity. The max. lateral acceleration is improved for the solo truck using wide-base single tyres by about 10 %. This means a higher roll-over stability can be achieved, see figure 7.

Figure 8 shows the results of the critical (max.) speed of trucks and units going into a J-turn. Trucks and units reach a higher critical speed with the same lateral acceleration, if they are equipped with wide-base single tyres. This means more under-steering which is safer. This advantage is higher with the trucks and units having a lower centre of gravity. The critical speed for a single truck is about 10 % higher in the simulation of wide-base single tyres on the drive axle.

Another safety aspect involves the vehicle behaviour in case of sudden tyre burst, especially in a bend. This was studied by simulation, too. Most dangerous is a sudden tyre defect of the outer tyre of the drive axle.

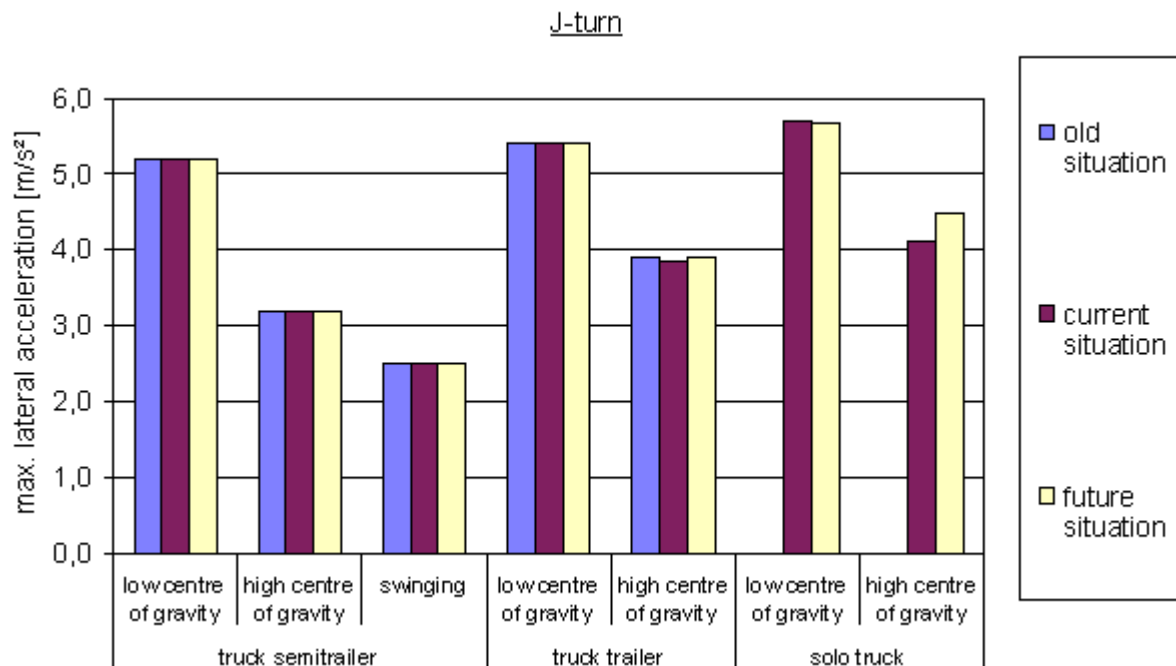


Figure 7. Maximum lateral acceleration for different trucks and articulated vehicles with different CG heights.

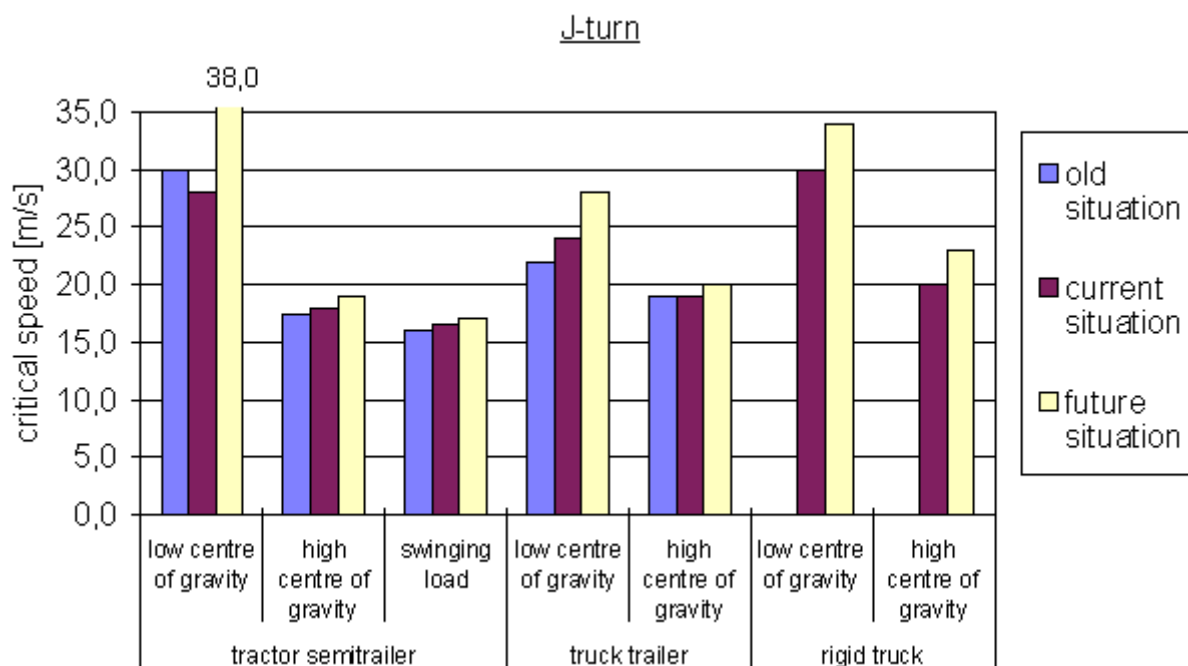


Figure 8. Critical speed of trucks and units with different tyre combinations and CG heights.

Only the 40 t tractor with semi-trailer was analysed. As soon as the tyre loses its pressure two effects take place:

- The maximum transferable side force of a defective single tyre decreases rapidly, for a twin assembly only one tyre can transfer side forces.
- With a flat single the car body sags onto the rim, for a twin assembly one tyre has to carry half of the axle load alone, but sagging is negligible.

Both effects were part of the simulation. The loss of tyre pressure was assumed to occur within one second. The max. transferable side force for the single tyre was assumed to be 40 % relative to the intact tyre. No experimental data were available. The critical speed and maximum lateral acceleration in case of the J-turn manoeuvre were calculated for these parameters, see figure 9.

The over-steering driving behaviour, caused by a puncture damage of one of the dual tyres, changes into an (safer) under-steering behaviour, if a wide-base single is used (the change to higher lateral acceleration values for twin tyres indicates a smaller radius in the path). It has to be considered that a wide-base single tyre has the disadvantage, that the roll over limit is considerably lower, for both low and high centre of gravity, if a tyre burst happens.

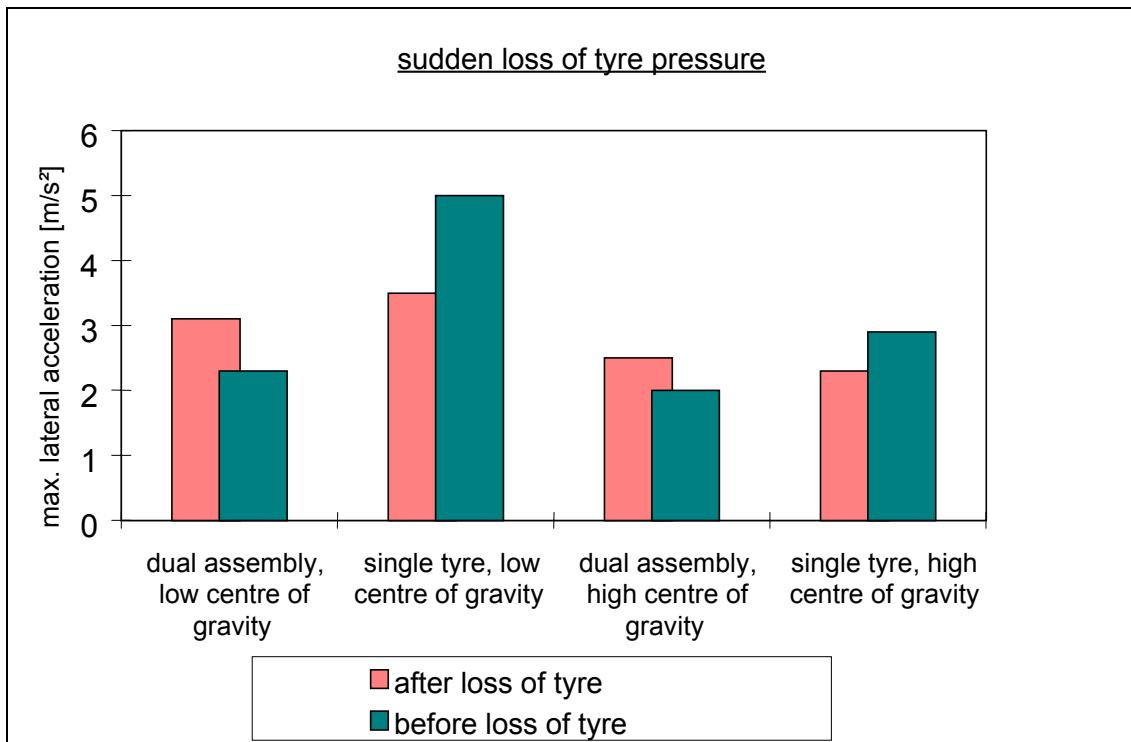


Figure 9. Maximum lateral acceleration for a 40 t unit having a sudden tyre burst on drive axle in a J-turn.

## SAFETY STRATEGIES

From the European legislative side tyre manufactures have to fulfil the Regulation ECE R. 54 or 92/23/EWG respectively. This means they have to prove the tyre endurance strength of the wide-base tyre in a durability drum test.

A further aspect in Germany is the national Motor Vehicle Traffic Regulation for axle loads. A single drive axle may be loaded to a maximum of 11,5 t and a double axle to 18 t, except twin tyres are mounted and the truck is equipped with road friendly suspensions, then 19 t for the double axle are allowed.

The current development of wide-base tyres for drive axles is mainly aimed at tractors of tractor-semi-trailer units and in Germany these are mostly equipped with only one single drive axle. Vehicle dynamic control systems (ESP in combination with ABS) are much more easy to handle for those units than for truck-drawbar-trailer units.

Different developments by vehicle electronic suppliers and different demands regarding safety on the part of the truck manufacturers must be brought together with the possibilities of the tyre manufacturers.

All truck manufacturers demand and will equip their trucks with a tyre pressure monitoring system. Several suppliers are on the market.

One German truck manufacturer demands a tyre self support in case of a tyre burst. This can be achieved by mounting an inner supporting ring on the rim (first development by Continental but connected with the loss of the benefit “weight reduction”) or by the AIRCEPT System developed by Bridgestone.



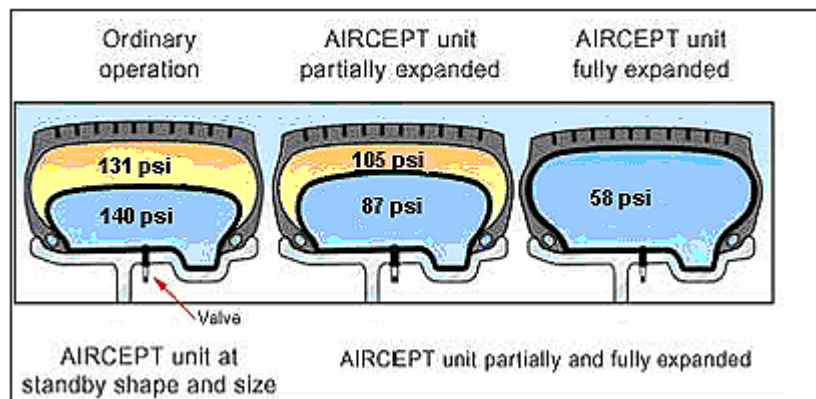


Figure 10. The AIRCEPT configuration.

Figure 10 shows how the system works:

- The AIRCEPT systems is installed inside the tyre flush against the wheel. In that position, the AIRCEPT components are protect from nearly any kind of damage. If the tyre loses pressure suddenly, the AIRCEPT unit expands virtually instantaneously to support the load.
- A specially developed valve permits inflating the tyre and AIRCEPT unit to different pressures simultaneously through a single valve.

Other truck manufacturers do not demand any special running flat technology for the wide-base tyres. To achieve the aim of meeting the truck manufacturer's internal safety specifications (e.g. tyre burst at 80 km/h in a highway exit bend without danger) an active vehicle stability assist system is needed. This system has to activate the semi-trailer brakes first to stretch the unit. The tractor's brakes equipped with ABS are activated separately (front/rear, left/right) to avoid a breakaway. The lateral acceleration is sensed and an intervention in the engine management and brakes is possible. The 495 Michelin X-one XDA2 Energy and the Continental SuSi Tyres have no self supporting technology.

Another problem is, that it is not possible to have a wide-base tyre as spare wheel on board, but the tyre manufacturers have built up in the last years special service teams in Europe to assist truck operators in case of a tyre defect day and night.

## CONCLUSIONS AND FURTHER NON SAFETY EFFECTS

Wide-base single tyres for drive axles of different manufacturers will be in future introduced into the market and they will probably replace the twin tyres used today. The driving behaviour of trucks and articulated vehicles was studied by computer simulation. Drive tests with a 40 t unit with prototype single tyres on the drive axle were carried out to verify the simulation.

The following results were derived from the simulation: Alterations in driving behaviour and driving safety are mainly dependent on the tyre characteristics (cornering stiffness) of the tyre itself. The wide single tyres showed a higher level of lateral stiffness which was reflected in a higher degree of under-steering i.e. safer driving behaviour. This tendency is beneficial with regards to the steerability of a vehicle combination. The altered width of the spring suspension on the drive axle had no influence on the side-tilt stability of the vehicle combination. Only the solo truck profited from the higher roll stiffness of the rear axle, which means a lower danger for a roll-over accident. As far as the driving safety is concerned there can be no objection to use wide-base tyres on the drive axle.

The investigation into the driving stability with defective tyres on the drive axle showed for the very seldom case of tyre defect in a bend (assuming 40% of the max. transferable side force for the flat tyre) that no increased danger could be observed in the mathematical simulation when using wide-base single tyres.

Later driving tests [2, 5] showed however the need of tyre run flat properties (e.g. supporting ring on the rim or AIRCEPT system) or other features of dynamic vehicle control to avoid jack-knifing of road trains. Also tyre pressure monitoring systems for trucks and units are advised.

In addition to the described safety aspects some more advantages and disadvantages of wide-base single tyres should be mentioned but without further explanations [4]:

- The rolling resistance of a single tyre is about 20 % less compared to twins. This leads to lower fuel consumption (about 2 % for a 40 t unit) and lower CO<sub>2</sub> emissions.
- A higher payload (130-150 kg) can be achieved.
- In busses the aisle width can be increased.
- The tyre road noise is nearly equal for both tyre combinations.
- The road wear (rutting) is higher for single tyre equipped trucks, especially on secondary roads. This can be nearly compensated if the wider 385 size tyres are used on steering axles instead of the common 315 or 295 size.

## **ACKNOWLEDGEMENT**

Special thanks to Dr. Andreas Faber, who made the ADAMS calculations and to Dr. Wolf Hahn of the former Institute of Automotive Engineering of the University Hanover, who supervised the project.

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