

EFFECTS OF WIDE SINGLE TYRES AND DUAL TYRES –  
A TECHNICAL AND ECONOMIC APPROACH – REPORT ON COST 334

A. F A B E R

CONTINENTAL REIFEN AG, TRUCK TYRE RESEARCH

and

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This paper deals with the comparison of technical and economic aspects for heavy commercial vehicles fitted with wide base single or dual tyres (Fig. 1). The task is a part of the European research project “COST 334: Effects of Wide Base Single Tyres and Dual Tyres” which includes pavement wear effects, vehicle operational and pavement maintenance cost models, non-pavement effects and the consequences. The paper presented here describes mainly the problems of driving behaviour and vehicle safety.

## 1. INTRODUCTION

Objectives:

COST 334 aims at establishing the relative effects of wide-base single and dual tyre assemblies with regard to road pavement damage, vehicle operating costs, vehicle safety and comfort, and the environment (particularly noise). Quantitative and reliable information on this topic will enable national governments, and the EU, to consider policies to apply regarding the use of wide-base single tyres, the recovery or distribution of any additional costs or benefits arising from their use, and any necessary harmonisation of safety or environmental standards (ADDIS [1]).

The work will also contribute strongly to the development of vehicle operating cost models and to a wider use of the whole life cost models for road pavements.

Additional significant benefits will be inputs to more effective vehicle design and network management.

Participation:

16 COST Countries: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Netherlands, Norway, Portugal, Slovenia, Sweden, Switzerland, United Kingdom.

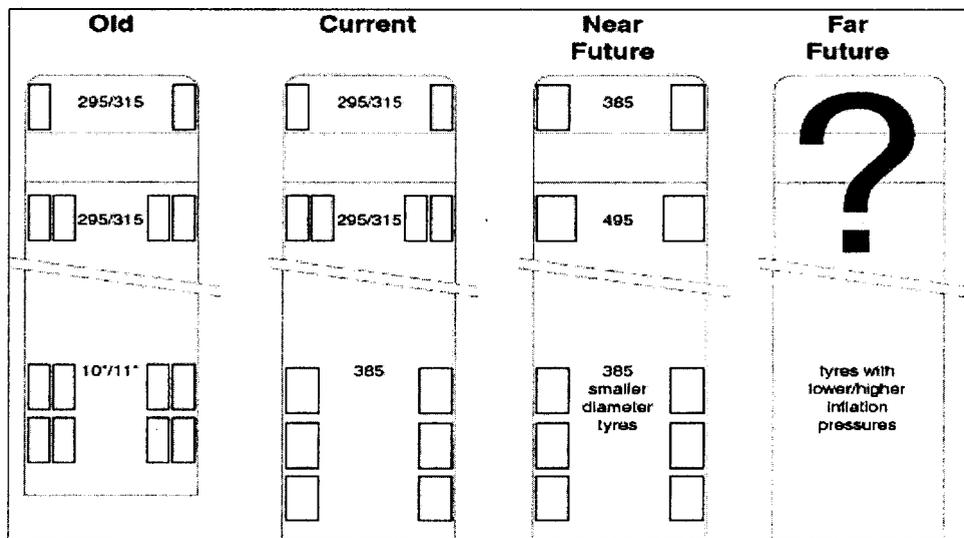


FIG. 1. Developments in tyre technology for heavy goods vehicles.

The work of the action is being carried out in seven separate tasks:

- Tasks 1 & 2 Literature review and analysis
- Task 3 Further experimental work
- Task 4 Vehicle Operating Cost models
- Task 5 Non-pavement effects
- Task 6 Assessment of overall effects
- Task 7 Case studies

## 2. TASK 1 AND 2: STATE OF THE ART

Responsible for Task 1 and 2 are C. Molzer and C. Hochreiter of Technical University Vienna, Austria.

These tasks deal with the literature survey and state-of-the-art review. The literature review contains references to different aspects of tests, evaluations and studies of the use of wide-base single tyres. More than 250 references are accessi-

ble free of cost in the form of a database via Internet, either through the COST 334 homepage

<http://www.cordis.lu/cost-transport/home.html>

or directly via the homepage of the Technical University of Vienna where the database resides and is serviced by

<http://www.istu.tuwien.ac.at/cost334/cost334.html>.

### 3. TASK 3: PAVEMENT WEAR EFFECTS

Responsible for task 3 is E. Vos of DWW, the Netherlands.

With regard to the possible future developments in tyre technology it was necessary to define a programme of experimental work. Additional to the state-of-the-art review, an extensive trial programme is being carried out (Fig. 2). For the future situation, the following aspects had to be taken into consideration: There is an increasing range of wide-base single tyres on towed axles, which can be used as well on steering – and driven axles. Therefore, presumably, the diameter and inflation pressure of the tyres differ.

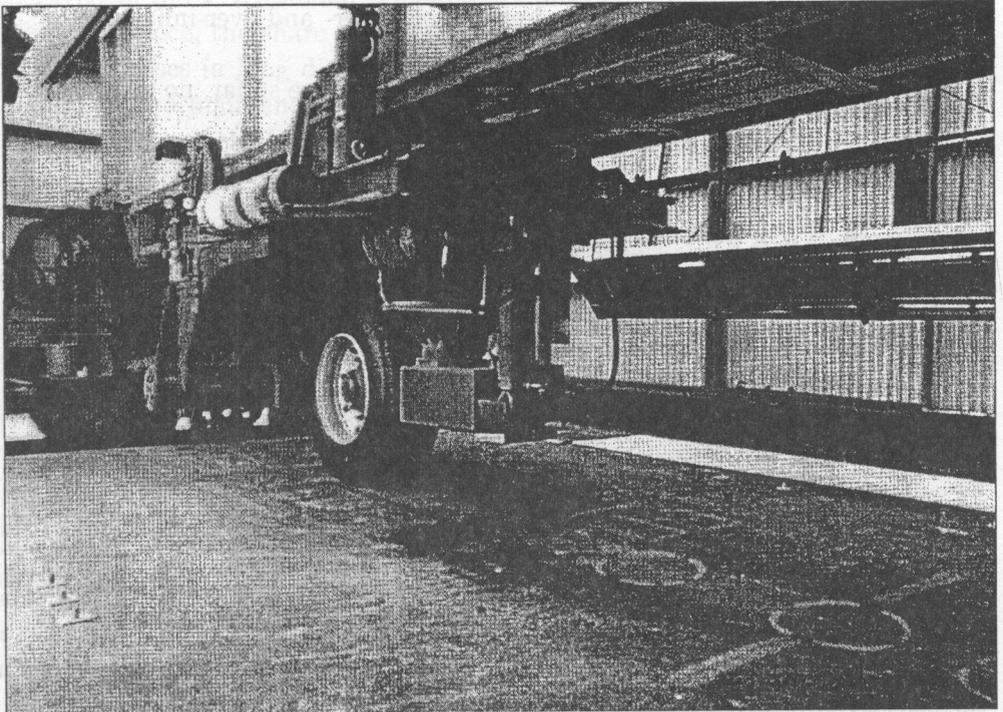


FIG. 2. Test truck for pavement wear effects, TU Delft.

In order to test the effect of the various types of tyres on the different pavement structures, tests with the following parameters are performed.

- tyres: dual: 275/80 R 22.5, 295/60 R 22.5, 295/80 R 22.5, 315/80 R 22.5  
single: 385/65 R 22.5, 495/45 R 22.5,
- inflation pressure: 6.5, 7, 8, 9 and 10 bar,
- pavements: thin [100 mm], medium [200 mm] and thick [300 mm],
- kind of damage: cracking and rutting,
- temperature: 20° C, 22° C, 40° C, 50° C,
- axle load level: 9 t and 11.5 t.

The following organisations participate in this experimental projects:

- DWW, Netherlands (Lintrak),
- Michelin/LCPC, France (Manege),
- TRL, UK (PTF),
- LNEC, Portugal (Finite-element programme),
- VTT, Finland (HVS).

Additionally, the following aspects had to be taken into consideration:

- tyre characteristics,
- translation to real world conditions of loading,
- unequal load-sharing between tyres on dual assemblies,
- different inflation pressure and effects of under- and over-inflation and
- differences in dynamic loadings.

The experimental work is still on the way. Therefore so far, no results can be offered.

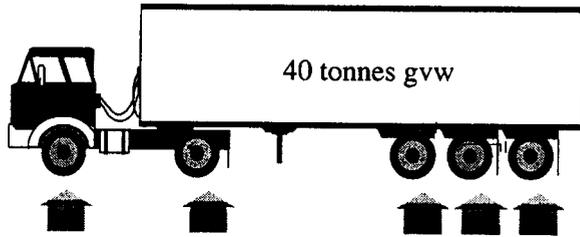
#### 4. TASK 4: VOC – VEHICLE OPERATING COST MODELS

Responsible for Task 4 is R. R. Addis of TRL, United Kingdom.

Vehicle Operating Cost Models have to fulfil different demands:

- Requirement to assess benefits to operators;
- Requirement to apply to European conditions;
- Sensitivity of the cost model to various input parameters;
- Availability of the cost model (commercial, public domain, *etc*).

A sensitivity study was made by K. P. Glaeser from “Bundesanstalt für Straßenwesen” (BAST), Germany. He used the so-called Mercedes Benz VOC-Model which is widespread in the management of many vehicle fleets. Calculations were made for the most common vehicle in Europe, which is the tractor semitrailer configuration. The wheel and tyre assemblies used for calculations in the sensitivity study are listed in Fig. 3.



1. Old case:	S	T	T	T	T
	11R22.5	2 X 11R22.5	3 AXLES X 11R22.5		
2. Recent case:	S	T	T	T	T
	295/80R22.5	2 X 295/80R22.5	3 X 295/80R22.5		
3. Current (Base) case:	S	T	W	S	W
	295/80R22.5	2 X 295/80R22.5	3 AXLES X 385/65R22.5		
4. New case:	S	W	S	W	S
	315/70R22.5	495/45R22.5	3 AXLES X 385/65R22.5		

FIG. 3. Scenarios for the sensitivity study.

In the sensitivity study, the so-called current (base) case and the new case of tyre use were compared. In the first place it was necessary to check the sensitivity of the VOC-Model. A number of preconditions had to be set, e.g. the rolling resistance, the share of rolling loss on different axles, the share of rolling loss on all losses in long distance transport, the changes in pay-load, the costs for fuel, oil and maintenance, etc. The model proved to be sensitive enough to respond to variations of wheel and tyre types. For example the differences in fuel consumption for the current case and the new case could be calculated in this way.

Additional VOC-Models and different truck types still have to be checked. Furthermore the variable costs within the different countries of the EU will have to be considered.

## 5. TASK 5: NON-PAVEMENT EFFECTS

Responsible for Task 5 is W. Hahn of University of Hanover, Germany.

Task 5 has got two main parts. Part one relates to the vehicle driving behaviour and the vehicle safety. Following aspects are important here:

- Lateral Stability (e.g. Manoeuvrings, Roll Over),
- Safety (e.g. in case of Tyre Failure),
- Vertical Stability (e.g. Axle Load, Load Distribution) and
- Longitudinal Stability (e.g. Stopping Distance).

The second part relates to the environmental effects and deals with:

- Tyre Noise,
- Rolling Resistance,
- Economy and Ecology.

Full-scale driving tests and computer simulation tests with different types of heavy vehicles were made to study the driving behaviour and vehicle safety. The study was ordered by BAST, FABER [4]. It was coordinated and/or carried out by the IKH, University of Hanover. The driving tests on the one hand were made in order to obtain the first results concerning the driving behaviour of a vehicle, that was fitted with the various tyre types and on the other hand, to validate the computer model. For the validation of the simulation model additional tests were made by the IKH. The full-scale tests for comparing the tyre types were made with a rigid truck<sup>1</sup> and a tractor-semitrailer combination<sup>2</sup>. So far the tyres are the only parameters tested. The following tests were carried out:

a) Rigid truck <sup>1</sup> (18.8 t), carried out by VOLVO Truck Cooperation.

- ISO/DIS 14791 pseudo-random input (lateral transient response – yaw velocity and lateral acceleration – were determined),
- ISO/TC22/SC9/WG6 N56 Steady state (the coherence between the steering-wheel angle and the lateral acceleration was determined).

b) Tractor semitrailer combination<sup>2</sup> (Tractor: Iveco 440 E 38, trailer: Schwarzmüller, three axles, air spring), carried out by TÜV Hanover – KTI Kft. and IKH, University of Hanover).

- ISO/DIS 14791 single lane change, path following method (Fig. 4)<sup>3</sup>,
- ISO/DIS 14791 pseudo random and puls input,
- Steady state.

Compared Tyre dimensions were in both cases (Fig. 5):

Single: 495/45 R22.5,

Dual: 315/70 R22.5.

When these tyre dimensions are compared, a different width shows up. The wide base single tyre is about 15 cm smaller than the dual assemblies. The tyre dimension 315/70 R 22.5 for the dual tyre was chosen instead of the more common 315/80 R 22.5 tyre in order to be able to use the same diameter as the single tyre has. The use of this tyre is increasing compared to the use of the standard tyre with a higher diameter. If the dual tyres are replaced by single tyres, there are two ways to place them on the axle:

- the same overall width, implies a different track on ground, used in b) and

<sup>1</sup>rigid truck: a commercial vehicle according to ISO 3833.

<sup>2</sup>tractor-semitrailer combination: an articulated road train according to ISO 3833.

<sup>3</sup>The co-ordinates, longitudinal  $x$  [m] and lateral  $y$  [m], of the manoeuvring section of the test course for a given maximum lateral acceleration  $a_y$  [m/s<sup>2</sup>], test speed  $v$  [m/s], and investigated frequency of the lateral acceleration  $f$  [Hz], are given by this equation.

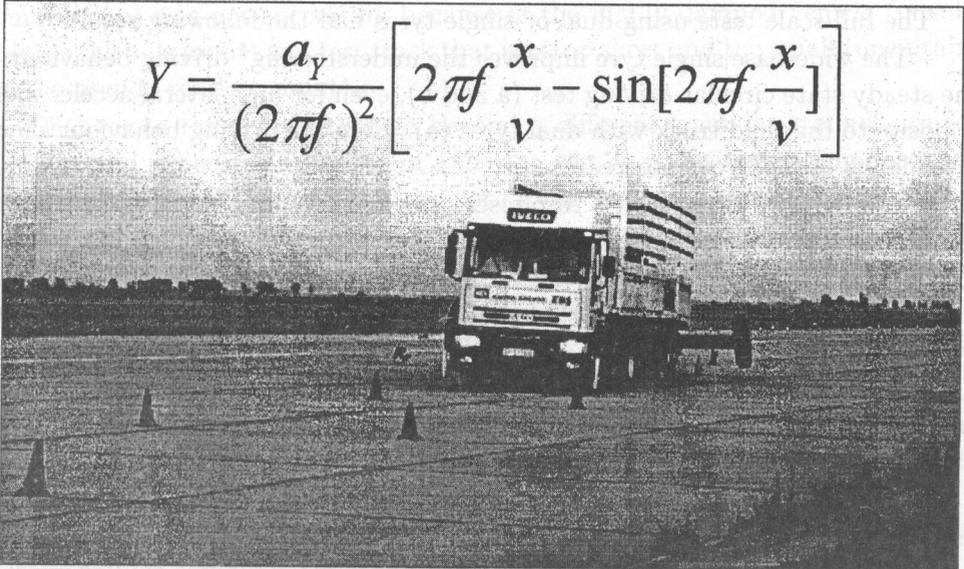


FIG. 4. Single Lane Change, path following method.

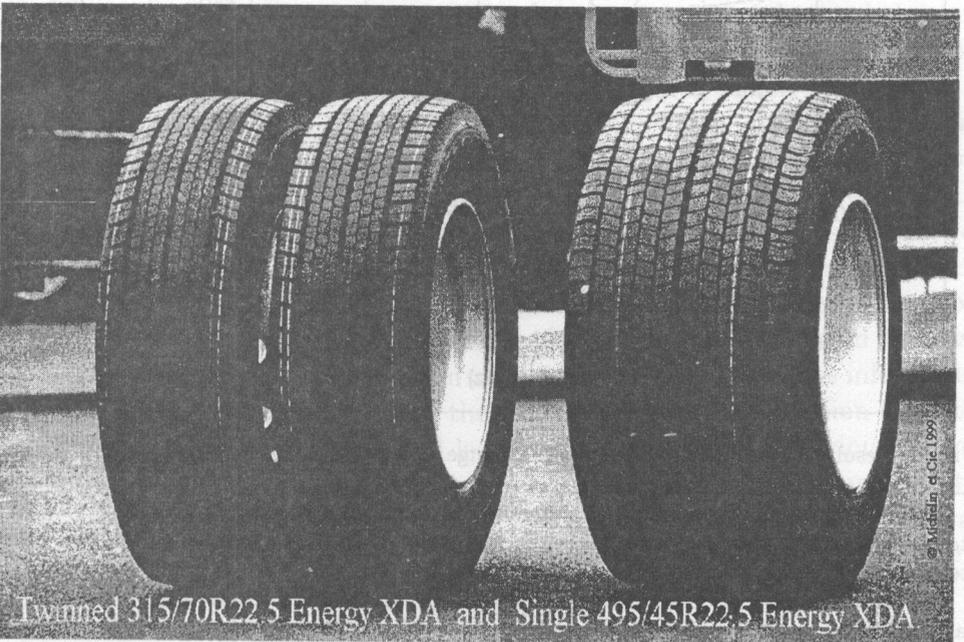


FIG. 5. Compared Tyres for the driven axle.

– the same track on ground, implies a different overall width, used in a).

The full-scale tests using dual or single tyres had the following results:

– The wide-base single tyre improves the understeering<sup>4</sup> driving behaviour in the steady state circular driving test (a and b), even for high lateral acceleration, opposite to the rigid truck with dual tyres (a). Here the driving behaviour shows a tendency of being oversteered.

– The delay of the vehicle's responses (yaw velocity and lateral acceleration) relating to the steering movement is smaller in the frequency range below 1 Hz, if single tyres are used (a).

– The rearward amplification<sup>5</sup> of the lateral acceleration is a little bit smaller with single tyres (b).

– The offtracking<sup>6</sup> is smaller in the frequency range, where the rearward amplification of lateral acceleration becomes maximum (Fig. 6).

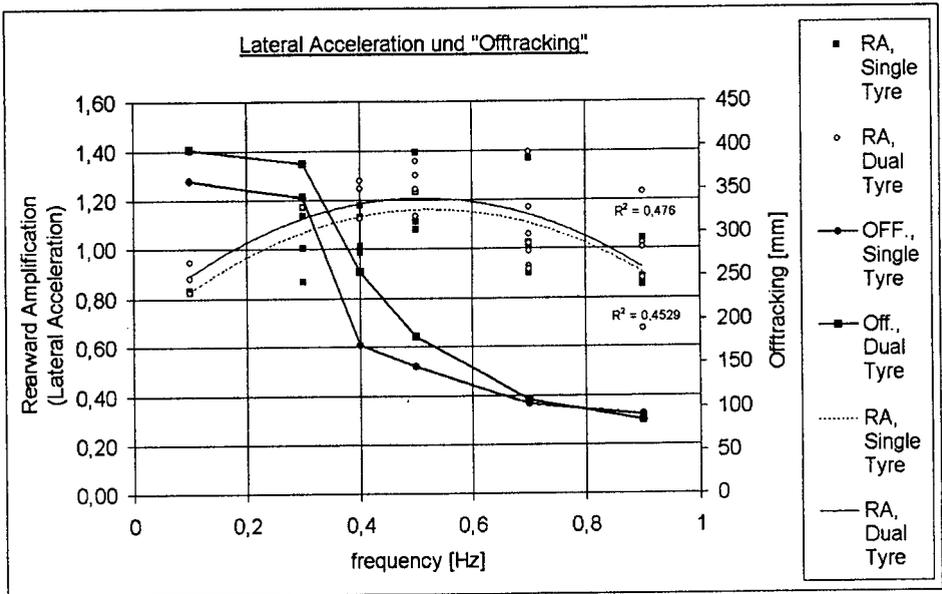


FIG. 6. Results full scale test: Single Lane Change, Rearward Amplification<sup>5</sup> and Offtracking<sup>6</sup>.

<sup>4</sup>The vocabulary oversteering and understeering are used according to ISO 8855; Oversteer: steer property at a steady-state equilibrium where the understeer gradient is negative. Understeer: steer property at a steady-state equilibrium where the understeer gradient is positive.

<sup>5</sup>Rearward amplification according to ISO/DIS 14791: The RA is the ratio of the maximum value of the quantity of interest of a following vehicle unit to that of the first vehicle unit during some kind of manoeuvre.

<sup>6</sup>Offtracking according to ISO/DIS 14791: The O. is the lateral deviation between the path of the centre-line point of the front axle of the vehicle and the path of the centre-line point of some other part of the vehicle.

The pseudo-random tests and pulse input (carried out with the tractor trailer combination) was not successful, because of the highly damped vehicle (unsuitable for the pulse input) and test track that was too short and too small (unsuitable for the pseudo random input).

Changes to the vehicle that go beyond a different track on ground, are too complex and expensive to realize in a driving test (e.g. a wider spring base, and therefore a different frame). A wider spring base would mean a higher roll-over stiffness for the vehicle. To make the necessary changes of the chassis possible, a computer simulation model was used. The chosen programme was ADAMS, a widespread simulation tool (multi-body system). The constructed models were validated by the driving tests in Hungary and tests from the IKH in Hanover. The following models were simulated:

- Rigid truck 1 (MAN F 90; 19FL);
- Truck trailer combination<sup>7</sup> (Göbel company, three axles (incl. one lifting), air spring);
- Tractor semitrailer combination<sup>2</sup>, (tractor: Iveco 440 E 38, semitrailer: Schwarzmüller company, three axles, air spring).

In addition to the ISO/DIS 14791 (Road Vehicles – Heavy commercial vehicle combinations and articulated buses – Lateral stability test procedures) a J-turn<sup>8</sup> was simulated, because it has a higher sensitivity to the altered driving behaviour that is caused by the effects of little changes, e.g. in the chassis. Furthermore the J-turn is appropriate to simulate the situation that a vehicle comes close to the stability limit. Apart from that it is a very common driving manoeuvre, that causes accidents, e.g. on slippery roads and exits. The simulated test was an Open Loop Test which means that a steering movement is given and the reaction of the vehicle is measured. The J-turn was realized with a step-function of the steering movement. The lateral acceleration and the maximum speed is measured for this manoeuvre (Fig. 7), when the vehicle combination is just about to become unstable (no rolling over, jack knifing or run into a skid). In this case, the combination of lateral acceleration and maximum speed provides information about the driving behaviour. If e.g. the maximum lateral acceleration stays the same, but a higher maximum speed is obtained, the driving behaviour is more understeering, and the circle of the driven track is bigger. So you can assess the driving behaviour and the lateral stability of the combination. In the full scale test, the centre of gravity was very low. That is why a higher (normal) centre of gravity is simulated, too.

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<sup>7</sup>Truck trailer combination: a road train according to ISO 3833.

<sup>8</sup>The J-turn is an open loop test with a special steering angle law. First the vehicle has to run a course straight ahead, then with a step-function steering law into a circle, and finally to keep a constant steer angle. No international standard for this kind of manoeuvre exists.

In addition, a puncture (total air pressure loss within one second) on the driven axle is simulated during the J-turn. The defect is arranged for the static phase (some seconds after the steering movement). In this case the effects of a puncture were tested on a tyre in an outward position. In order to imitate a puncture, the radius of the tyre was reduced to the same radius that the rim has. Furthermore the transmittable side force was divided into halves.

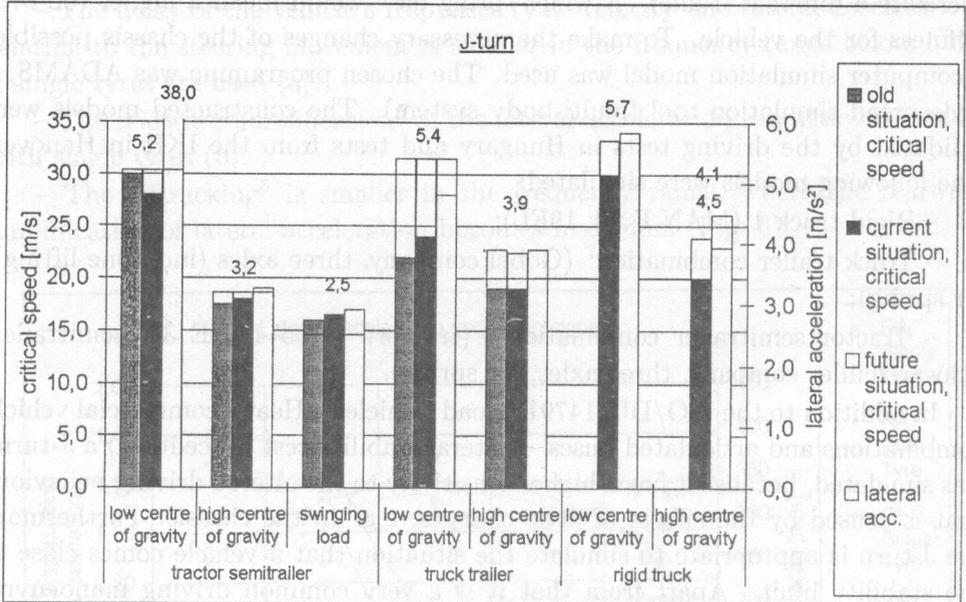


FIG. 7. Results computer simulation: J-turn<sup>8</sup>, critical speed and lateral acceleration.

#### Results:

Using the wide-base single tyres (with the wider spring base), the critical speed is cooperatively higher than the speed of the vehicle combination fitted with dual tyres (Fig. 7). The maximum lateral acceleration is the same within the compared vehicle combination. Only the rigid truck achieves a higher lateral acceleration. These results can be explained as follows:

- All vehicle combinations fitted with wide-base single tyres show a more understeering driving behaviour. That means that the vehicle has a tendency to run out of circle. An understeering driving behaviour is considered to be easier to handle for the driver, because the oversteering driving behaviour leads to unstable driving conditions.

- Only the rigid truck profits from the wider spring base (and therefore from the higher torsional stiffness) on the driven axle. The other combinations don't get a higher roll-over stability.

– The lateral stiffness of the tyres has a higher influence on the driving behaviour as the changed spring base.

– Compared to other parameters, like variation of the centre of gravity, the tyres have less influence.

– The oversteering driving behaviour, caused by a puncture of one of the dual tyres, changes to an understeering driving behaviour, if a single tyre is used. It has to be considered that a defect single tyre has the disadvantage, that the roll-over limit is lower for vehicles with a high centre of gravity.

The other important aspects of Task 5 are tyre noise and rolling resistance as part of the problems of environmental effects.

Tyre noise depends on several factors. Some measurements have already been done by ETRTO (European Tyre and Rim Technical Organisation). Results obtained so far show that main influences on tyre noise come from tread design, tyre design, rubber components and speed. Less influence have the tyre size and single/dual equipment which is looked for in COST 334. Additional tests are planned using prescriptions of the EC-Proposal 92/23/EWG (Tyres) to quantify the differences between a wide-base single equipment and a dual equipment as exact as possible.

Also some rolling resistance measurements have already be done by ETRTO. Results so far show a significant decrease of rolling resistance for the wid- base single equipment. The results are used for VOC-Calculations made in Task 4. Additional measurements on a flat bed test stand still are planned.

## 6. TASK 6, 7 AND 8: ASSESSMENT OF OVERALL EFFECTS, CASE STUDIES AND DEVELOPMENT OF GUIDELINES

Responsible for Task 6 is C. Penant of Michelin, France and for Task 7 M. Huhtala of VTT, Finland. Task 8 will be worked out by all members.

These tasks are in treatment and revision. In Task 6 the relevant information of the tasks 1 – 5 can be used to evaluate the overall effects of the use of wide single or dual tyres. The results will be basically based on mathematical tools, in order to obtain the total financial consequences. But still a consideration of the non-pavement effects (e.g. safety, noise) is included. Task 7 prepares the case studies for selected countries, which are based on the results of Task 6. All participants work together to develop the guidelines.

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More than 250 references are accessible in form of a database (see Task 1 and 2: State of the Art).

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