Conventional and wide base radial truck tyres

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Wide base single tires are expected to replace dual tires on long-haul heavy trucks in the United States. This paper describes recent research at Texas A&M University on operational and safety aspects of wide base and conventional radial truck tires. Field tests for dry and wet braking performance were conducted with several different trucks. Laboratory tests were made to compare the static and vibration characteristics of wide base and conventional tires. A simple model for tire force transmission is described and compared with experimental data.

1 INTRODUCTION

Wide base truck tires have long been used in the U.S. in heavy load, short-haul service. However, these tires are still seldom seen on U.S. highways—the 18 wheel tractor-trailer continues to predominate on our highways. Improvements in tire materials and the development of metric wide base radial tires aimed at long-haul highway service have made the single tire an attractive alternative to the dual tire assembly in the tandem axle suspensions of tractor-trailer combination trucks in the U.S..

Given widespread availability of wide base singles, the trucking industry will adopt them for economic reasons. The weight of a wide base single on an aluminum wheel is significantly less than the weight of two conventional tires on steel wheels (used on most trucks today). It takes more fuel to flex the four sidewalls of rolling dual tires than the two sidewalls of a single tire. Although current fuel costs are not yet high enough to make single tires attractive to the U.S. trucking industry, another increment in the price of fuel could trigger the conversion.

Converting a truck to operate on wide base singles is easily accomplished, requiring no suspension system modifications. If economic conditions make conversion attractive, it may be expected to happen with the rapidity of the switch from nylon cord bias ply tires to steel cord radial ply truck tires, which occurred in the U.S. in the early 1980's. Today most heavy highway trucks run on steel cord radial ply tires.

The conversion to radial ply truck tires, with higher inflation pressures, has been of concern to U.S. highway pavement engineers. It is now feared that the subsequent conversion to wide base single tires will exacerbate the pavement damage problem. Apart from pavement damage, operational aspects of a truck equipped with wide base tires are of concern. Some U.S. fleet drivers who have evaluated wide base tires report longer stopping distances than were necessary with dual tires. The additional tread width has led to speculation that a wide base tire would be more susceptible to hydroplaning than a conventional truck tire. Very little information on these and other operational characteristics of wide base vis-à-vis conventional truck tires is currently available.

1.1 Tires studied

Several major tire companies provided the information in Table 1, giving the most popular sizes of conventional radial ply truck tires used as duals in the United States. The inflation pressure and load limits are design values from reference 1. At present, the most likely wide base tires to replace duals are the metric wide base sizes listed in Table 2.

Table 1. Tires commonly used as duals

Tire size	Pressure (psi)	Load limit (lb)
11R22.5/G	95	5,300
11R24.5/G	95	5,640
12R22.5/G	95	5,760

Table 2. Wide base single replacement tires

Tire size	Pressure (psi)	Load limit (lb)
385/65R22.5/J	120	9,370
425/65R22.5/J	110	10,500
445/65R22.5/L	120	12,300

Heavy vehicles and roads: technology, safety and policy. Thomas Telford, London, 1992.

We decided to work with the 11R22.5/G and 425/65R22.5/J tire sizes because the load limit of the 425/65R22.5/J is close to twice the load limit of the 11R22.5/G. The 425/65R22.5 has about the same air volume as two 11R22.5 tires. An effort was made to obtain conventional and wide base tires with similiar highway-type tread patterns. The tires selected have the same groove depth (19/32 in.) and nearly the same percent footprint void (16% ratio of groove area to gross contact area). Figure 1 is a photograph of the two tires being studied.

Fig. 1. Conventional 11R22.5 (left) and a wide base 425/65R22.5 tire

2 MECHANICAL PROPERTIES

To gain a more complete understanding of how a wide base tire is different from a conventional dual tire, laboratory tests were conducted to measure basic static and dynamic properties. All laboratory testing was done with an MTS servo-hydraulic testing machine.

The test tires were mounted on standard 10-hole ball seat mounting aluminum wheels. A dual flange axle and U-shaped mounting fixture were designed and built to position either tire in the testing machine. Figure 2 shows the wide base tire mounted in the MTS machine. The U-frame, seen in Fig. 2, is bolted to a load cell which measures the resultant force on the axle. In this setup, the axle is fixed (nonrotating) and load is applied by a rigid, flat plate attached to the servo-hydraulic actuator. The rigid plate serves as the pavement, against which the tire is normally deflected. Here, the pavement plate moves and the axle is held fixed whereas on a highway, the axle moves and the pavement is fixed. Except for effects of tire rotation, these tire loading modes are equivalent. By using a fixed axle, the laboratory tests measure only the response of the tire and wheel.

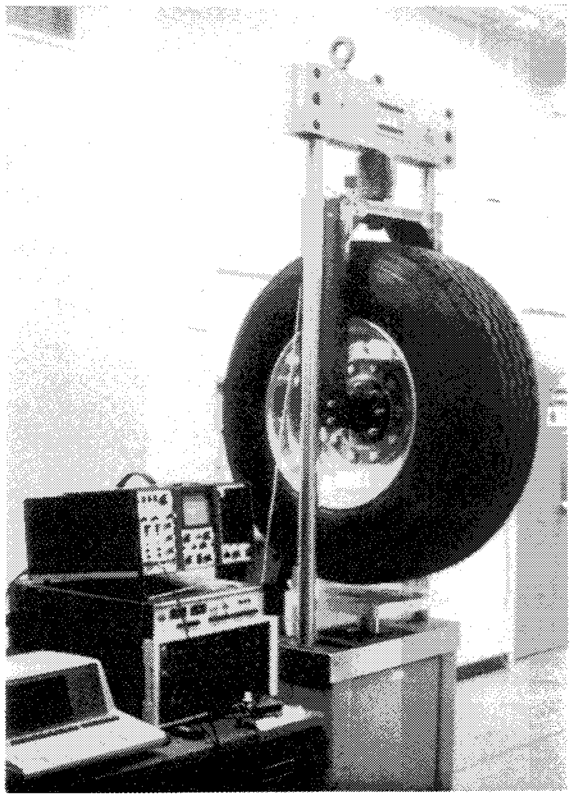


Fig. 2. Wide base tire mounted in the MTS testing machine

2.1 Load-deflection

A basic mechanical property of a tire is its deflection in response to an axle load. This response is usually plotted as a set of curves to show the influence of inflation pressure. Figures 3 and 4 show load-deflection data measured for a single 11R22.5 tire and the 425/65R22.5 wide base tire.

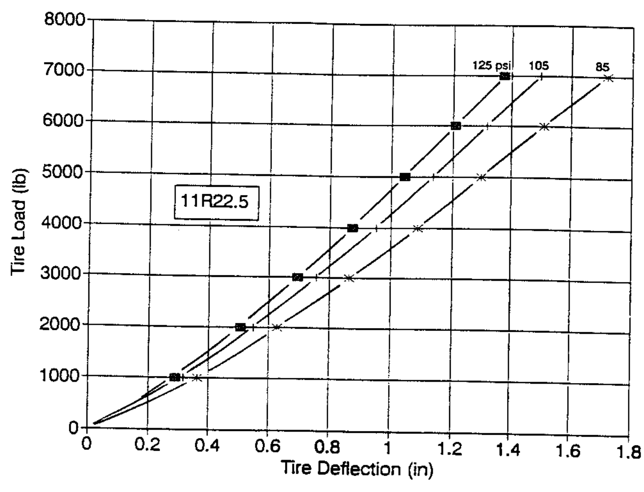


Fig. 3. Load vs. deflection, conventional tire

The slope of a load-deflection curve is the vertical spring rate of the tire. As seen in Figs 3 and 4, the spring rate is influenced by inflation pressure but is essentially constant over the operating load range of the tire. In Fig. 5, a dual tire load-deflection curve has been plotted by using twice the single tire loads. Comparing this curve with that of a single wide base tire (at the same inflation pressure, 105 psi), the spring rate of the wide base tire is seen to be considerably less than the dual tires it would replace. Figure 5 gives spring rate values (slope, K) at a typical tire load for a loaded truck. The lower spring rate of the wide base tire, about 40% lower, may account for the softer ride reported by some drivers who have compared on-the-road performance of wide base singles with dual tires.

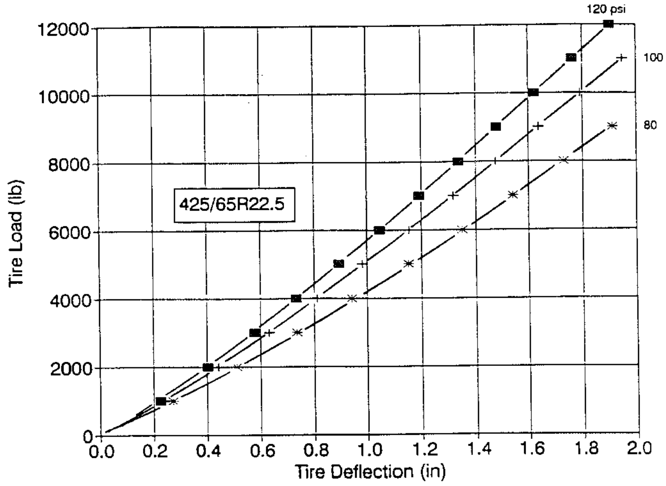


Fig. 4. Load vs. deflection - wide base tire

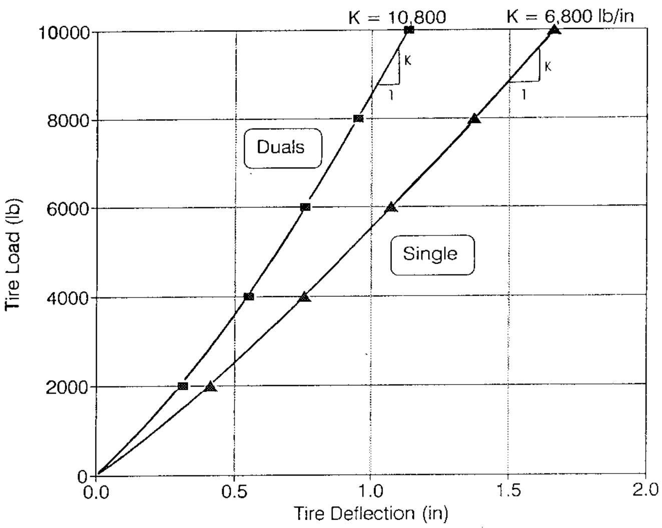


Fig. 5. Comparison of load-deflection data for dual tires and a single wide base tire

2.2 Footprint area

Many aspects of tire performance have been related to the shape and size of the area of contact between a tire and the pavement, commonly called the footprint area. For example, it is believed that the smaller footprint area of the wide base tire, compared to the combined footprint area of dual tires, will develop less frictional force during braking, thereby increasing the stopping distance of a truck equipped with wide base tires. The smaller footprint area of the wide base tire is also expected to make this tire more damaging to pavements than dual tires are.

As very little information is available on truck tire footprint areas, the MTS testing machine was used to make footprint images that could be measured. After some experimentation, it was found that pen & pencil carbon paper will give a good tire footprint image on heavy white construction paper. Typewriter carbon paper cannot be used for this purposê as it is designed for impact copy.

The carbon paper footprint images are outlined with a black felt-tip pen and placed in front of a video camera. The video footprint image is captured in a desk-top computer and a video imaging program (NIH Image) is used to reduce the footprint image to black area in contact, white area in grooves, and an intermediate grey area surrounding the footprint. The imaging program produces a histogram with counts of the black, white, and grey pixels (picture elements) from which the gross and net footprint areas can be determined.

Figure 6 shows video footprint images of conventional and wide base tires compared in this study. Gross footprint area, the area enclosed by the outer boundary, is indicated for each tire. The percent void is the percent of white area (groove area) within the footprint. The black area is the part of the tread actually in contact with the pavement, called the net footprint area. At the inflation pressures and loads noted in Fig. 6, the footprint area of the wide base tire is 11% less than twice the footprint area of the conventional tire.

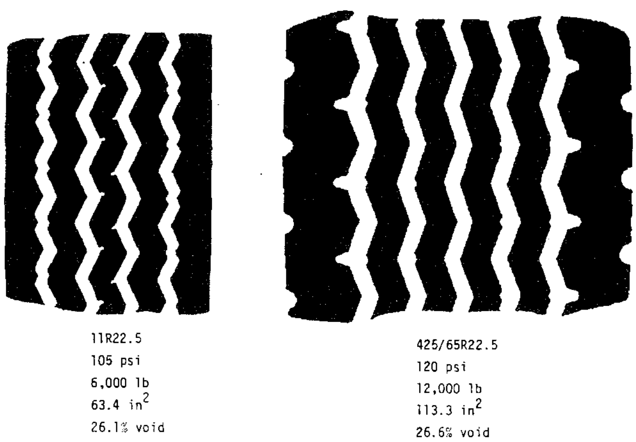


Fig. 6. Video image footprints of a conventional and a wide base tire

Figures 7 and 8 show the gross contact areas measured for a single 11R22.5 tire and a 425/65R22.5 wide base tire at the indicated inflation pressures. Since dual tires carry twice the load of a single 11R22.5 tire, and produce twice the footprint area, the data may be plotted to compare the footprint area of dual tires with that of a single wide base tire at the same load. This has been done in Fig. 9 where it is seen that the footprint area of the wide base tire is, at most, 12% less than that of the dual tires.

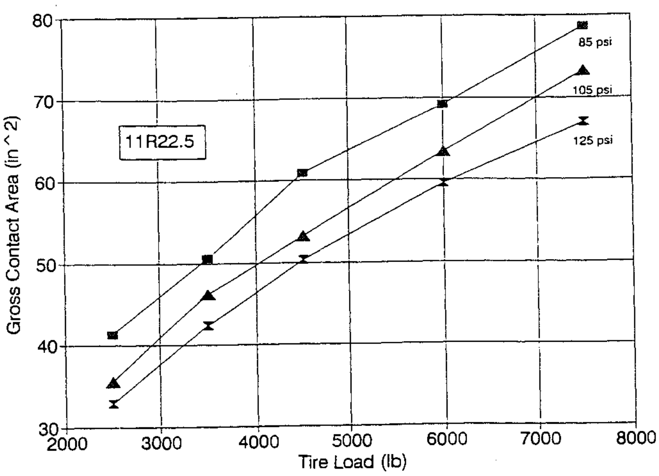


Fig. 7. Effect of tire load on footprint area of the conventional truck tire

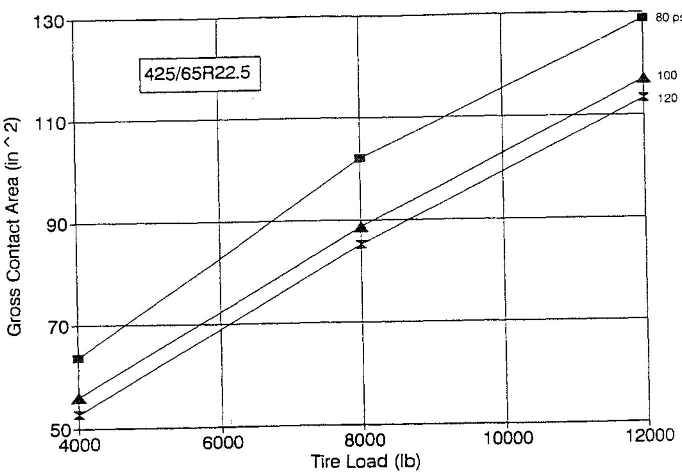


Fig. 8. Effect of tire load on footprint area of the wide base truck tire

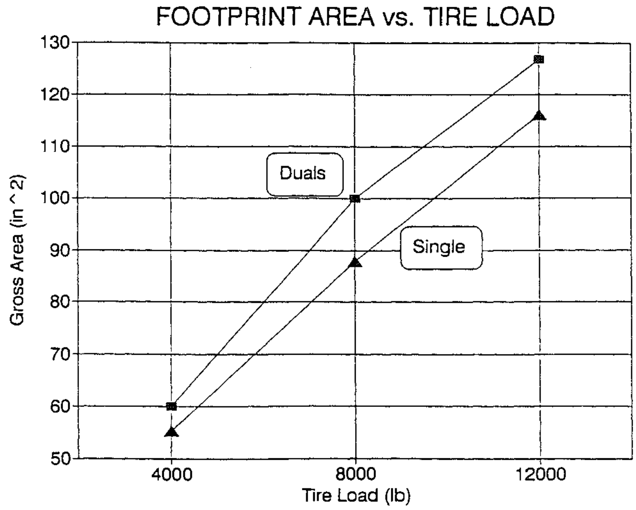


Fig. 9. Comparison of the footprint area of dual tires and a wide base single tire at the same inflation pressure

2.3 Vibration transmission

The vibration of heavy trucks, transmitted through the tires to the pavement, is the major cause of pavement damage. A basic dynamic characteristic of the pneumatic tire is the manner in which it transmits force from the axle to the pavement. Force transmission through a tire depends on the vibration frequency and is somewhat influenced by damping in the tire structure. Transmissibility in passenger car tires has been extensively studied in efforts to improve vehicle ride. Truck tire transmissibility has not yet been studied, although it is now recognized that tire construction can have a measurable influence on pavement damage (ref. 2).

Since the force transmissibility of the wide base tire could be significantly different from that of a conventional truck tire, a comparative study was conducted in the laboratory. The transmissibility test is made by vibrating the tire footprint at a single frequency and measuring the force transmitted to the fixed axle. This is equivalent to the highway situation, where vehicle dynamics causes the axle to vibrate and the tire transmits the dynamic axle load to the fixed pavement. Transmissibility, T is here defined as

$$T = \frac{\textit{axle force amplitude}}{\textit{footprint displacement amplitude}}$$

where the footprint displacement is a single frequency sine wave, maintained by the servo-hydraulic testing machine controller. The axle force varies as a phase-shifted sine wave, seen in the load cell output signal. A fast Fourier transform (FFT) signal analysis program was used to confirm the test frequency and extract the amplitudes from the input (displacement) and output (force) signals.

Tire transmissibility was measured for a range of frequencies that includes the fundamental resonant frequency of the tire. This was done for both the conventional and the wide base tire. Typical results are shown in Fig. 10, where it is seen that the resonant frequency of the wide base tire (32 Hz) is only slightly less than the resonant frequency of the conventional truck tire (33 Hz).* It is also noted in Fig. 10, that, except near the resonant frequency, the transmissibility of the wide base tire is less than twice that of the conventional tire. This would indicate that the dynamic component of pavement load from a wide base tire is somewhat less than the dynamic component of pavement load from dual tires.

Transmissibility tests were conducted for a range of tire inflation pressures and at various tire loads. It was found that inflation pressure and tire load have little effect on tire transmissibility, for the range of pressures and loads at which the tire can be safely operated.

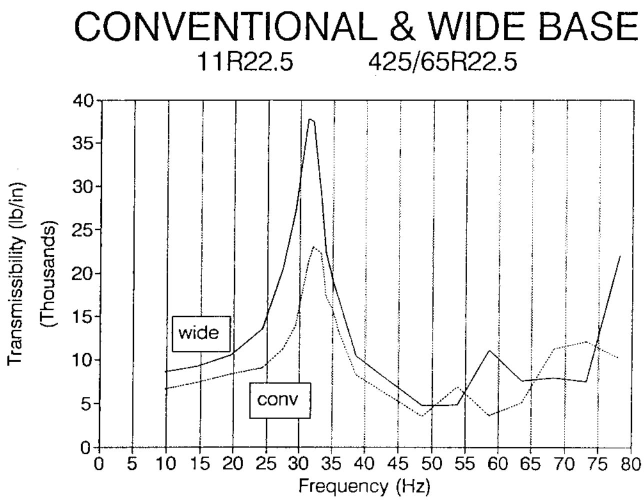


Fig. 10. Comparison of transmissibility data measured for the conventional and the wide base tire

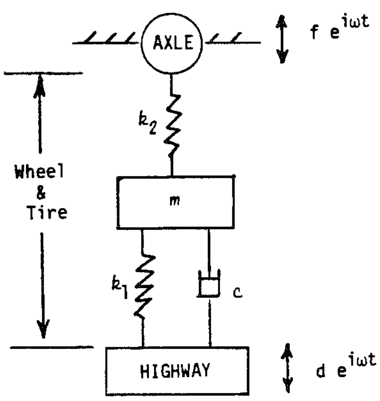
2.4 Dynamic tire model

The weak link in comprehensive simulations of the dynamic behavior of a vehicle has usually been the tire model. This has not been a serious deficiency for purposes of vehicle design. However, as pavement design analyses become more sophisticated, the demand for realistic pavement load information is increasing. A good tire model is now important for pavement design work. A tire model can also be used to deduce certain information about the tire itself.

*In general, resonant frequency increases as tire size decreases. The first resonant frequency of a passenger car tire is approximately 100 Hz.

A relatively simple single-degree-of-freedom tire model was developed to extract tire damping information from the transmissibility data measured for the conventional and wide base truck tires. Figure 11 shows the configuration of mass, springs, and damping element in the tire model, which is activated in the same manner as a real tire in the laboratory transmissibility test. The block marked HIGHWAY in Fig. 11 is the flat plate on the servo-hydraulic actuator that vibrates with a single frequency, ω, during a test. This dynamic footprint load is transmitted through the tire model to the fixed element marked AXLE where the resultant force is measured. The complex amplitude ratio, f/d, is the transmissibility, which has both amplitude and phase (due to the damping element). The transmissibility amplitude, $|T|$, is calculated from the model parameters by the expression given in Fig. 11, and is compared with the measured transmissibility amplitude to validate the model.

In working with the tire model, it was found that the best results are obtained when m is the mass of the tire and wheel together, obtained by weighing the mounted tire before putting it in the testing machine. The two springs in the tire model, k_1, and k_2, behave as springs in series. The laboratory data are best reproduced when the spring constants are taken as $k_1 = k_2 = 2K$, where K is the vertical spring constant measured for the tire (taken



Transmissibility $T = f/d$ (Amplitude, Phase)

$$|T| = k_2 \sqrt{\frac{k_1^2 + \omega^2 c^2}{(k_1 + k_2 - \omega^2 m)^2 + \omega^2 c^2}}$$

m = total mass of wheel and tire

$k_1 = k_2 = 2K$ where K = static spring constant

c = damping calculated as function of frequency ω

Fig. 11. Dynamic tire model

from the load-deflection data). Finally, the damping coefficient, *c*, is obtained as a function of frequency by matching the tire model transmissibility to the transmissibility measured at the discrete test frequencies. Figure 12 shows the damping coefficient obtained in this manner. The minimum value of *c* is found at the resonant frequency. When the minimum *c* is used as a constant in the tire model, the predicted transmissibility (dashed curve) is fairly close to the measured transmissibility at frequencies above and below the resonant peak, in the range 10-50 Hz.

The tire model provides a simple mechanism to quantify tire damping, which is directly related to the efficiency of the tire. The values found for the two tires in this study are *c* = 27.4 lb-s/in for the wide base tire and *c* = 22.4 lb-s/in for the conventional tire. The wide base tire may thus be expected to be more fuel efficient than dual tires, which has proved to be true on the highway.

There is now a large amount of truck axle vibration data available in the literature. The tire model developed here provides a realistic mechanism for converting the axle vibration data to the dynamic pavement load data needed by pavement design engineers.

3 PERFORMANCE CHARACTERISTICS

Two aspects of truck tire performance were evaluated: the stopping distances of commercial combination vehicles; and dynamic hydroplaning. In these evaluations, a series of field tests were conducted that provide a means to assess the relative performance of conventional and wide base radial truck tires.

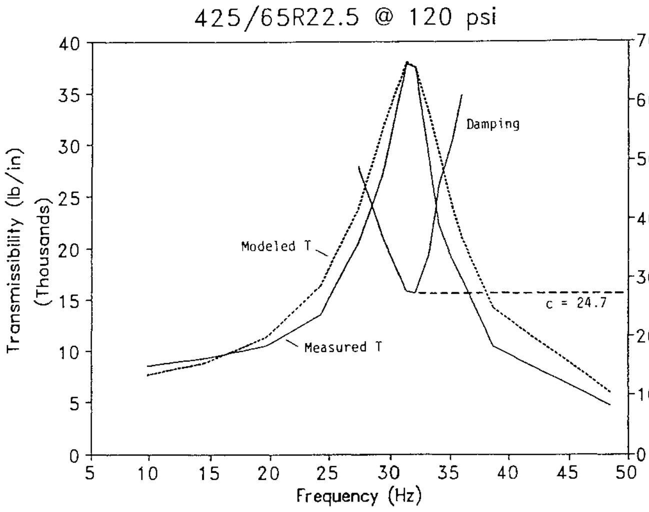


Fig. 12. Comparison of transmissibility predicted by the tire model with measured transmissibility. Damping coefficient, c, as a function of frequency.

3.1 Stopping distance

The stopping distance tests were conducted with three representative 18-wheel tractor/trailer combination trucks. After testing with conventional tires, the 16 dual tires were replaced with 8 wide base single tires and the stopping distance test runs were repeated. All tests were conducted on an asphaltic concrete pavement at the Texas

Table 3. Test vehicle weights (GVW) and approximate tire loads (lb)

Vehicle 1: Kenworth 6X4 Conventional with PennCo Tank Trailer

	Empty				Loaded			
	Wide base Tires GVW = 28,240		Conventional Tires GVW = 29,520		Wide base Tires GVW = 77,140		Conventional Tires GVW = 76,860	
Axle	Wt./Axle	Mean/Tire	Wt./Axle	Mean/Tire	Wt./Axle	Mean/Tire	Wt./Axle	Mean/Tire
Steer	11,180	5,590	11,230	5,615	11,160	5,580	11,620	5,810
Drive	10,220	2,555	10,980	1,373	32,780	8,195	32,760	4,095
Trailer	6,840	1,710	7,310	914	33,200	8,300	32,480	4,060

Vehicle 2: Ford CL9000 6X4 COE with Lufkin Van Trailer

	Wide base Tires GVW = 29,320		Conventional Tires GVW = 29,660	
Axle	Wt./Axle	Mean/Tire	Wt./Axle	Mean/Tire
Steer	8,860	4,430	8,460	4,230
Drive	11,700	2,925	12,160	1,520
Trailer	8,760	2,190	9,040	1,130

Vehicle 3: Navistar International 9700 6X4 COE with Flatbed Trailer

	Wide base Tires GVW = 28,900		Conventional Tires GVW = 30,040	
Axle	Wt./Axle	Mean/Tire	Wt./Axle	Mean/Tire
Steer	10,120	5,060	10,900	5,450
Drive	10,660	2,665	10,520	1,315
Trailer	8,120	2,030	8,620	1,077.5

Vehicle 3: Navistar International 9700 6X4 COE Tractor only (Bobtail)

Wide base Tires	Conventional Tires
GVW = 16,316	GVW = 16,900

Transportation Institute's vehicle proving ground. The friction numbers (FN) of the test pavement are the following

Speed	Wet FN	Dry FN
20 mph	50	
30	40	
40	38	72

3.1.1 Test vehicles. Three basically different tractor/trailer combination trucks were used. Vehicle 1 is a 1983 Kenworth long-nose conventional tractor with a 40 foot tank trailer. Vehicle 2, shown in Fig. 13, is a Ford CL9000 cab-over-engine (COE) tractor with a 45 foot van trailer. Vehicle 3 was a 1989 Navistar International 9700 COE tractor with a 48 foot flatbed trailer. Test runs were also made with the tractor of vehicle 3 as shown in Fig. 14 without a trailer, the 'bobtail' configuration.

Vehicle 1 was tested both empty and loaded. The other vehicles were tested only empty. Table 3 gives gross vehicle weights, axle loads and approximate tire loads.

Fig. 13. Vehicle 2: COE tractor with van trailer

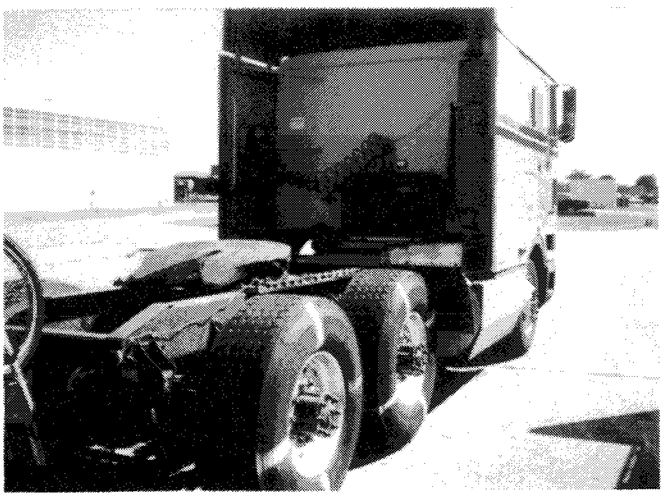


Fig. 14. Vehicle 3: Bobtail configuration with wide base tires

3.1.2 Test procedures. All test tires were new. After a tire change, the test vehicle was driven 60 miles to condition the tires prior to the braking test runs. All tire pressures (duals and wide base) were maintained at 100 psi.

The steering axle brakes were disabled during the tests. All drive and trailer brake systems were operational, confirmed by video tapes made of both sides of the truck during each test run. Brake slack adjustments were inspected before and during each test session and adjusted as necessary to maintain proper stroke travel.

Most of the stopping distance tests were made under straight ahead locked-wheel conditions. Although this braking technique, commonly referred to as a 'panic stop', does not represent the majority of highway stops, it does provide a consistant measure of longitudinal traction capability, eliminating driver variability. Some tests were conducted with modulated braking, in which the driver attempted to bring the vehicle to a stop in the shortest possible distance without locking the wheels. The stopping distances in modulated braking are significantly longer than locked wheel distances (for the same initial speed), and much more variable.

The results reported here are locked-wheel stopping distances on wet pavement. The pavement was kept wet by a trickle pipe along the 400 foot length of the skid pad. The water flow was adjusted to maintain a consistantly wetted surface for all test sessions.

3.1.3 Results. Stopping distances were measured for locked-wheel braking applied at 20, 30 and 40 mph for vehicles 1 and 2. Typically, five test runs were made at each speed. The plots here show the average stopping distances. Figures 15 and 16 give the results found with vehicles 1 and 2.

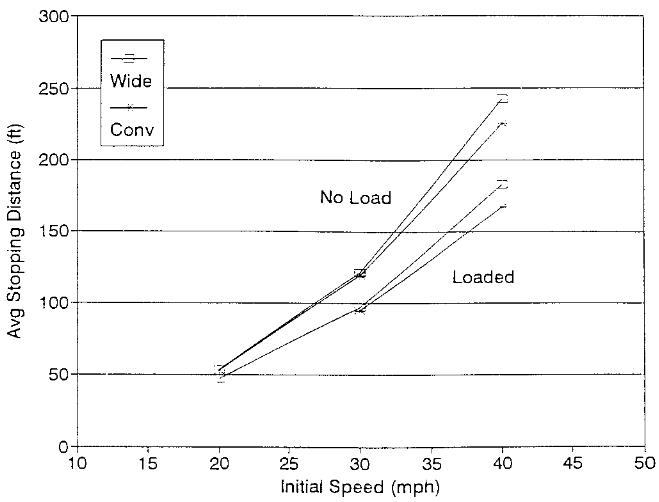


Fig. 15. Test vehicle 1 results

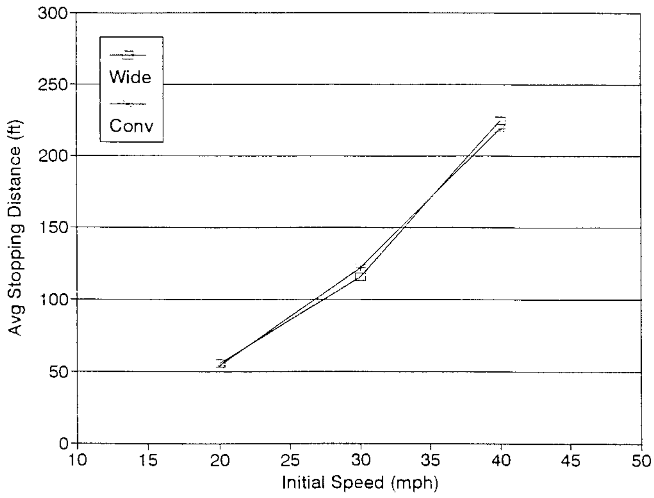


Fig. 16. Test vehicle 2 results

Differences between conventional and wide base tires are evident only at 40 mph with vehicle 1. At 40 mph, without load, this vehicle required an average of 18 feet (8%) more to stop with wide base tires. Essentially no difference in stopping distances were found with vehicle 2 (cf. Fig. 16).

With vehicle 3, we were able to increase initial speed to 45 mph. Also, conventional and wide base tires from two major manufacturers were tested on this vehicle. No significant difference in stopping distance was found in comparing conventional, or wide base, tires from the two manufacturers. The tractor of vehicle 3 was tested without a trailer (bobtail). Figure 17 shows the results. With the trailer, a slight difference is seen only at 45 mph. Without the trailer, a distinct (but still slight) difference is seen at all three test speeds. As expected, significantly longer stopping distances are required for the bobtail, a very unsafe configuration.

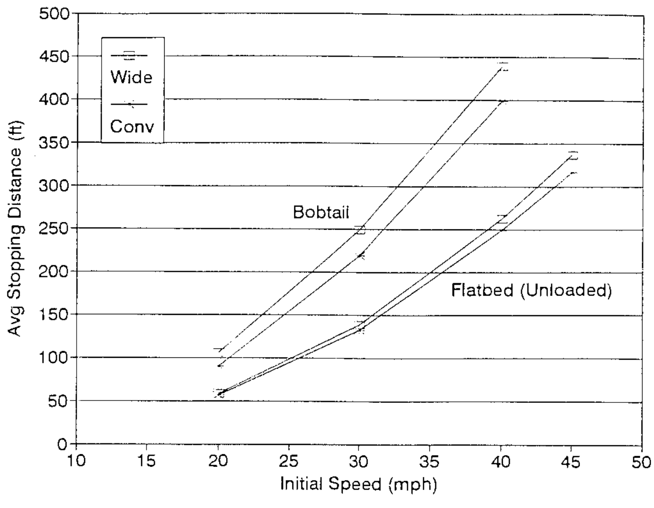


Fig. 17. Test vehicle 3 results

To gain a perspective on the tractor/trailer stopping distances, test runs were made with a passenger car on the same pavement. The car was a 1979 Pontiac Grand Am with steel belted radial tires. Figure 18 compares the average stopping distances found with the passenger car to the average stopping distances of all of the unloaded tractor/trailer combinations tested. Although our data suggest wide base tires may degrade high speed truck stopping distances, the differences are minor when truck and passenger car stopping distances are compared.

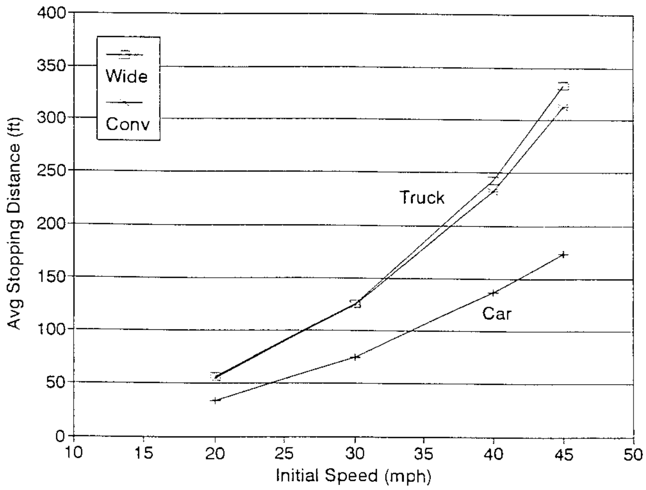


Fig. 18. Comparison of tractor/trailer and passenger car stopping distances

3.2 Hydroplaning

The hydroplaning tests were conducted by towing a single test tire in a water trough. The trough is 800 feet long and 30 inches wide, and will maintain uniform water depths up to 0.75 inches. This depth permits new tires to be tested with the grooves completely flooded. Flooding the grooves minimizes tread pattern influence on hydroplaning, insuring that test results will mainly measure the effect of tire carcass design (wide vs. narrow).

Figure 19 shows the two-wheel trailer on which the test tire is mounted. The trailer has an offset hitch to put the test tire track between the drive wheels of the tow vehicle.

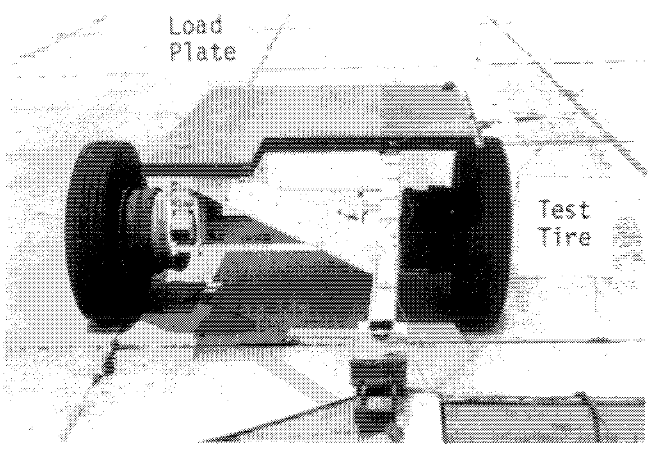


Fig. 19. Hydroplaning tire test trailer viewed from towing vehicle

The trailer is loaded with one or two steel plates (2.5 inches thick) each weighing 2,700 lbs. The towing speed is monitored by a fifth wheel on the tow vehicle and the test wheel speed is measured by an axle tachometer.

Tire hydroplaning is detected here by spin-down of the test wheel. As the test wheel is free-rolling, the spin-down usually stabilizes at about 2 mph below the tow speed. Confirmation that hydroplaning occurred is given by an abrupt spin-up when the test tire exits onto dry pavement. Testing is begun at 45 mph and the tow speed is gradually increased until hydroplaning occurs.

The wide base 425/65R22.5 and conventional 11R22.5 tires were each tested with 100 psi inflation pressure and at two tire loads. Both tires were found to hydroplane at highway speeds. The hydroplaning speeds found at the test loads are plotted in Fig. 20. The dual tire data in Fig. 20 are the single 11R22.5 tire speeds plotted at twice the single tire load. The wide base data in Fig. 20 are extrapolated to the dual tire loads to permit dual and wide base tire hydroplaning speeds to be compared at the same axle end loads. This comparison is shown in Fig. 21.

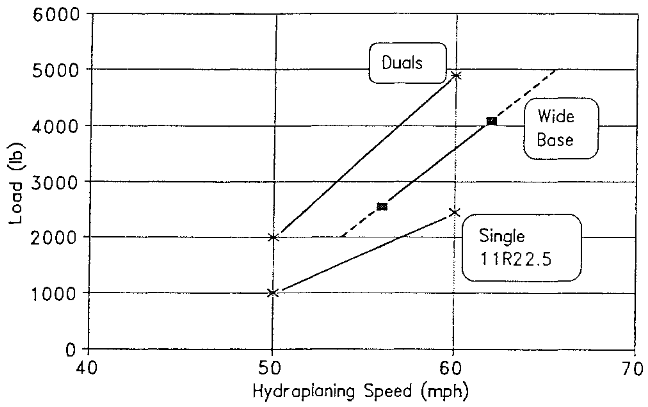


Fig. 20. Effect of load on hydroplaning speed

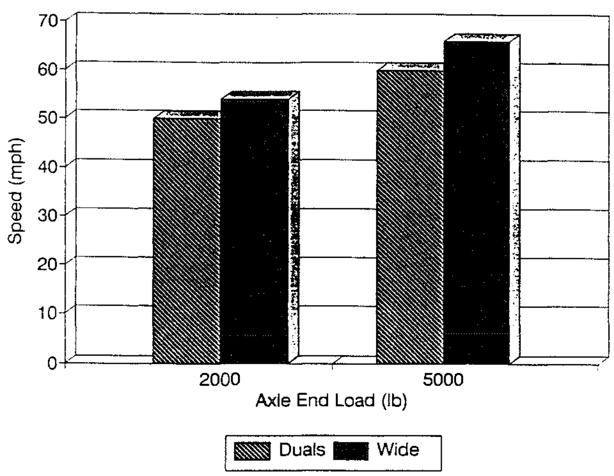


Fig. 21. Hydroplaning speed comparison

The 2000 and 5000 lb axle end loads are realistic for empty trucks. It has previously been recognized that tire load, as well as inflation pressure, has a significant influence on the hydroplaning speed of truck tires (ref. 3). The limited data we have obtained indicate the wide base tire is not more susceptible to hydroplaning than dual tires are.

4 ACKNOWLEDGMENTS

The tire research described here was sponsored by the AAA Foundation for Traffic Safety during 1990 and 1991. Further details are given in the research report (ref. 4) available from the Foundation at 1730 M St., N.W., Suite 401, Washington DC 20036. Val Pezoldt was responsible for the field tests, and statistical analyses. Laboratory testing was conducted by Mansoor Wasti and Nathan Tielking. We are indebted to the Alcoa Co. for aluminum wheels, and to Bridgestone and Goodyear for providing all of the tires.

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