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# TRUCK TIRE TYPES AND ROAD CONTACT PRESSURES

by

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A Paper Prepared for Presentation
at the
Second International Symposium on
Heavy Vehicle Weights and Dimensions

Kelowna, British Columbia

June 1989

## ABSTRACT

Meeting the changing requirements of the trucking industry has resulted in the development of new tire concepts and sizes. The contact pressures developed at the interface of the tire and roadway are an important consideration in the truck tire design/development process. Critical tire performance properties affecting the economics and safety of the truck operation are impacted by the interaction between the tire and roadway. The magnitude and distribution of the tire contact pressures produced are a function of tire factors and various operational parameters. Results of a laboratory study to determine the effect of the primary operational parameters of load and inflation on tire contact pressures are presented. Key tire sizes are addressed.

## INTRODUCTION

The economic and regulatory considerations facing the trucking industry impacts the direction of truck tire development efforts. New tire concepts and tire sizes have been and are continuing to be developed to meet the changing trucking operational environment.

The first step in the truck tire development process involves identifying the tire performance properties required for the target application, examples of these performance properties are listed in TABLE 1 (1). The interaction between the truck tire and the roadway is an important design consideration as it has a direct impact on the cost and safety of the truck operation, in addition to being an issue relative to pavement life.

**PRIMARY TIRE PERFORMANCE PROPERTIES**

| MECHANICAL | ENDURANCE |
|---|---|
| • TIRE DYNAMICS | • DURABILITY |
| • TRACTION | • TREADWEAR |
| • NOISE | • BRUISE |
| • ROLLING RESISTANCE | • CUTTING, CRACKING, & TEARING |
| • TIRE CONTACT PRESSURE | |

Table 1 Truck Tire Performance Properties

Many factors, both tire related and operations related will affect this tire/roadway interaction. A laboratory study was conducted to measure vertical tire contact pressures to obtain a better understanding of the influence of these factors (2).

## TIRE/ROAD CONTACT PRESSURE

Contact pressures for this study were collected in the laboratory with the use of a specially instrumented flat bed machine, FIGURE 1. Contact data at selected tire loads/inflations were obtained by rolling the tire slowly over a strain gage imbedded in the flat bed. The bed also moves with the slow rolling tire, this enables the strain gage to collect data over the entire length of contact, FIGURE 2. Lateral positions of the strain gage are also selected to characterize the behavior of each tread element across the contact width.

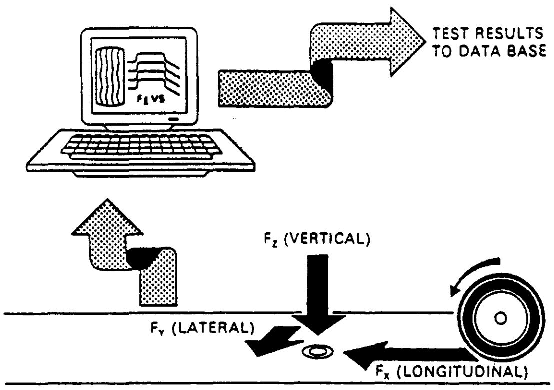



Figure 1 Tire Contact Pressure Test Machine

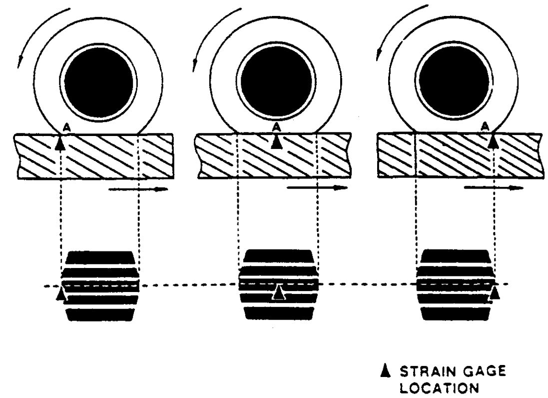



Figure 2 Contact Pressure Measurement Path

Tire load and velocity generate forces at the interface of the tire and roadway. These forces act in two planes within this interface region, called the contact area or footprint area. There is a vertical component acting in the "Z" direction, a longitudinal component acting in the "X" direction, and a lateral component acting in the "Y" direction, FIGURE 3.

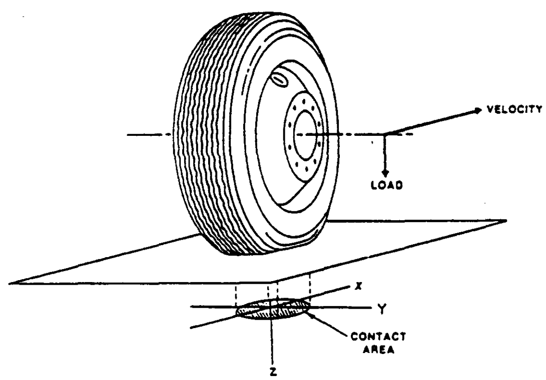



Figure 3 Tire/Road Contact Force Component Directions

Those in the lateral and longitudinal direction are termed "inplane" contact forces. They result from the bending of the tire as it is deformed from its normally toroidal shape at the tire/road interface. These inplane contact forces are generally smaller in magnitude than those developed in the vertical direction.

The lateral forces generated in the footprint tend to close the grooves of the tire. These forces (Fy) remain fairly constant through the majority of the contact length, FIGURE 4.

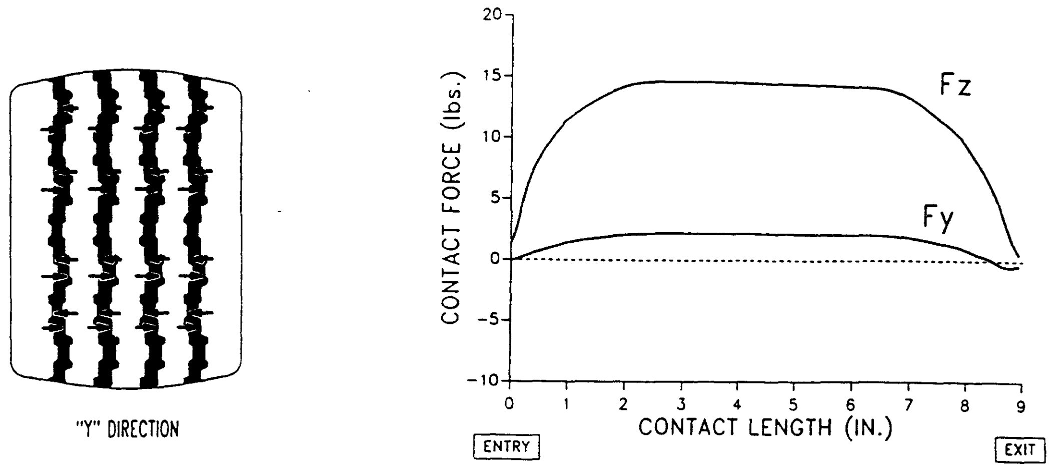



Figure 4 Lateral Contact Forces

The longitudinal forces are generally directed towards the center of the footprint. Normally there is a change in the direction of the longitudinal force (Fx) close to the midpoint of contact length and at the exit region, FIGURE 5.

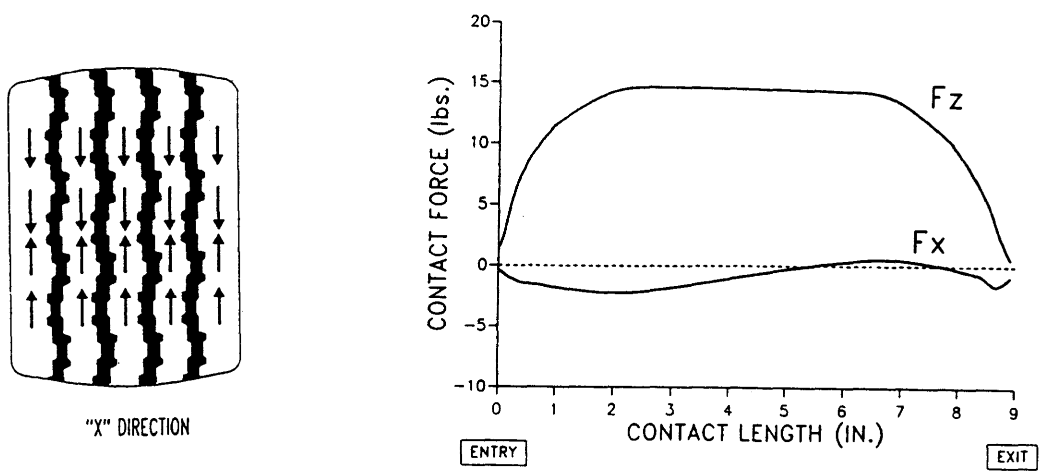



Figure 5 Longitudinal Contact Forces

There are three types of tire/road contact pressures: static, dynamic, and transient. The contact pressures addressed in this paper are quasi-dynamic because of the slow speed the test data was collected, .10 mph. Dynamic pressures are more difficult to assess, measurement of these effects are beyond the test machine capabilities. Understanding the static interaction between the tire and roadway will provide a good foundation before addressing the dynamic interaction.

## VERTICAL CONTACT PRESSURES

This study focused on the pressures exerted by the loaded tire in the vertical direction. Vertical contact pressures are generally non-uniform over both the width and length of contact, FIGURE 6. Peak vertical contact pressures are achieved in the central region of the contact area. The shape of the longitudinal pressure curve is dependent on its lateral position across the contact width, illustrated in FIGURE 7. The shoulder region pressure curve in this example exhibits a gradual rise and fall of contact pressures, the center region pressure curve exhibits a more rapid increase of pressure at the entry region of contact, a plateau at the midsection, and a rapid decrease at the exit region.

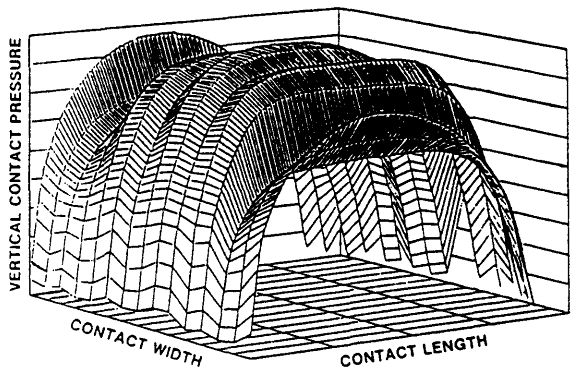



Figure 6 Vertical Tire Contact Pressure

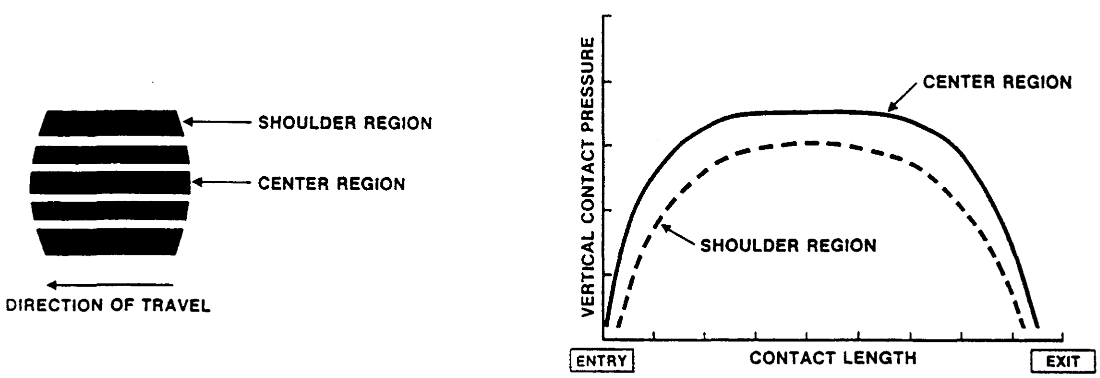



Figure 7 Contact Pressures Along Contact Length

Vertical contact pressures are a function of tire factors and operational factors. It is these factors which determine how the tire distributes contact pressures across its tread width and the peak contact pressure achieved, FIGURE 8. Any number of pressures distributions across the contact width are possible, depending on the tire's state of loading and its particular tire construction,

FIGURE 9 (3). This is the reason why for the same tire size, contact pressure distributions may differ from tire manufacturer to manufacturer and even within the same manufacturer.

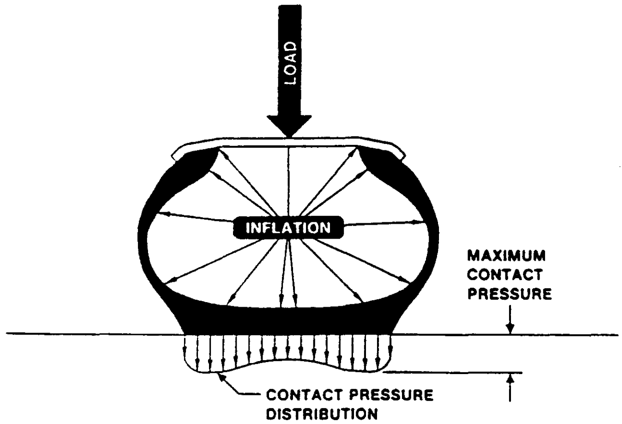



Figure 8 Vertical Contact Pressure Distribution

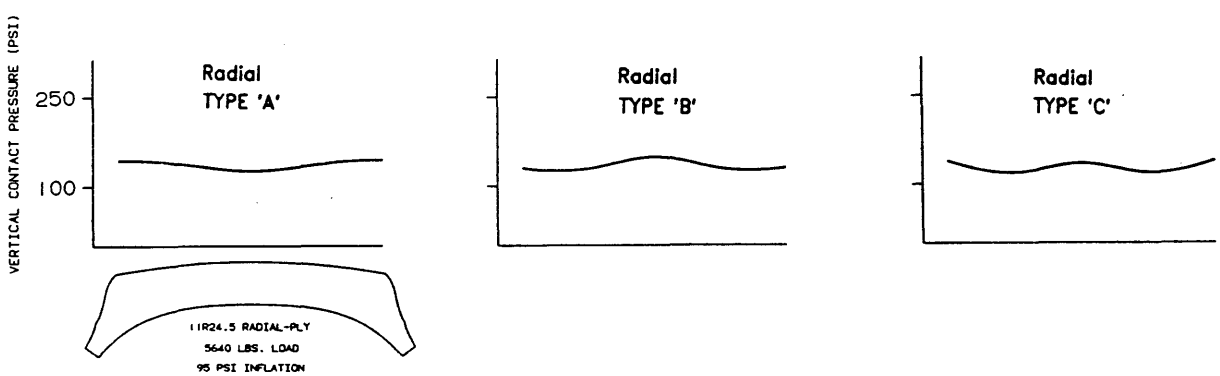



Figure 9 Typical Radial Tire Contact Pressure Distributions

## Tire Factors Affecting Contact Pressures

Tire construction and tire design are the two key tire factors which influence how a truck tire distributes vertical contact pressures and the peak level achieved, FIGURE 10. Tire construction consists of the materials and their orientation within both the crown and carcass structure of the truck tire. Tire design consists of parameters such as tire shape, tread pattern, and tire dimensions.

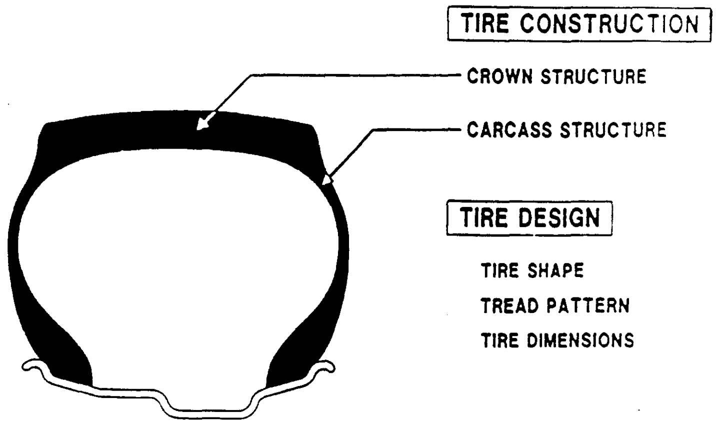



Figure 10 Tire Factors Affecting Contact Pressure

One of the major developments in terms of tire construction has been the radial-ply truck tire. Since its introduction during the late 1960's the radial-ply truck tire has continued to increase its market share over its predecessor, the bias-ply truck tire, FIGURE 11. It offers improved tread life in addition to improved fuel economy. The bias-ply truck tire has a fairly stiff carcass structure, due to it multiple cross-angled fabric body plies. The crown structure has multiple cross-angled fabric breakers in addition to the fabric body plies. The radial-ply truck tire on the other hand has a fairly soft carcass structure but a relatively stiff crown structure. This is a result of the carcass construction having a single radially oriented steel body ply. The crown structure is constructed of multiple angled steel belts. These construction differences result in a marked difference in the way the two tires respond to load. The softer carcass structure of the radial- ply tire produces a greater amount of vertical deflection, FIGURE 12. This is also an indication of the damping characteristics of the tire.

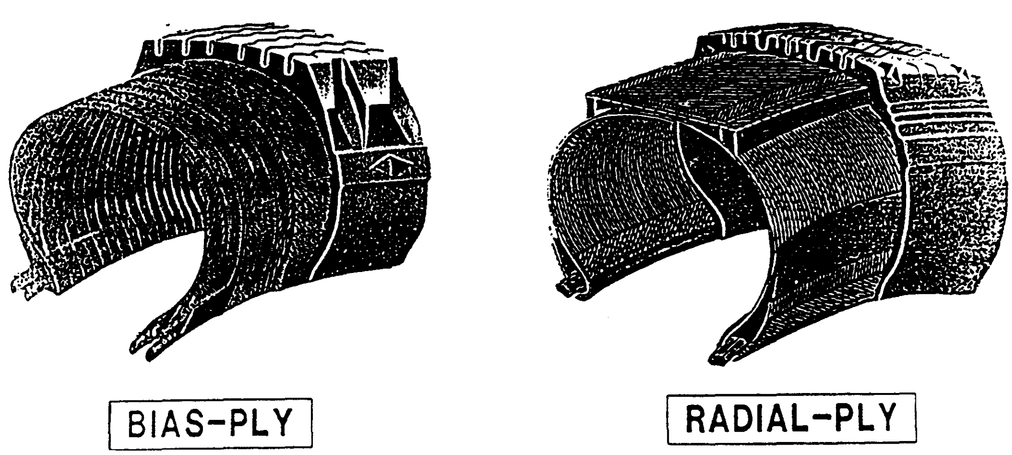



Figure 11 Truck Tire Constructions

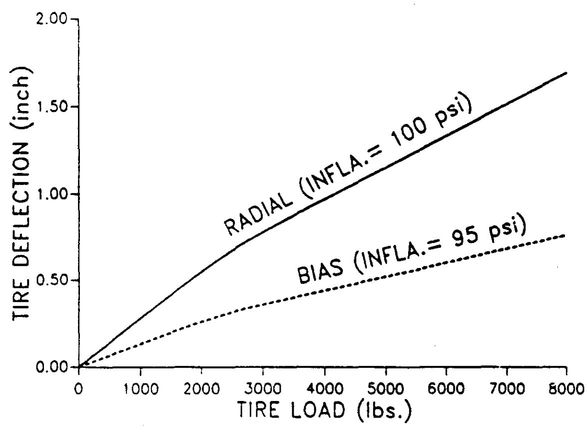



Figure 12 Tire Deflection Versus Tire Load

Maximum vertical contact pressure of these two tire types at their typical steer and drive/trailer axle loads/inflations are shown in FIGURE 13. The bias-ply tire generates lower peak pressures than the radial-ply tire, in the order of about 12% less at the steer tire load and about 26% at the drive/trailer loads. Average contact pressures at these same loading conditions are about equal to inflation pressure, the bias-ply tire still is less than the radial-ply tire, FIGURE 14.

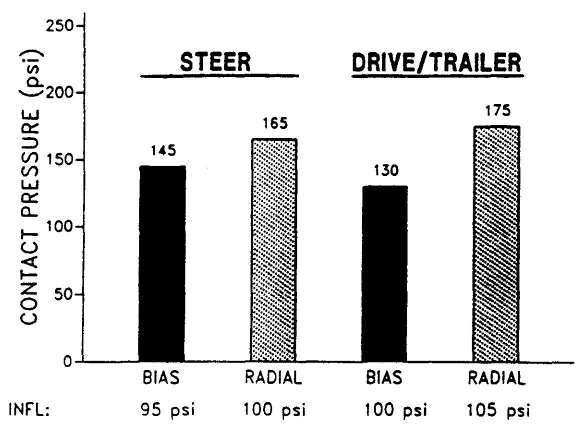



Figure 13 Maximum Vertical Contact Pressure

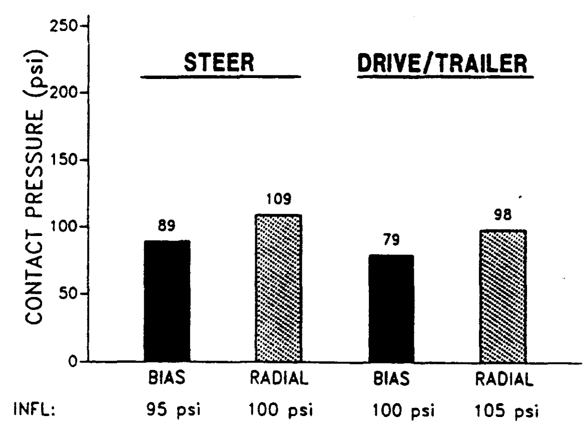



Figure 14 Average Vertical Contact Pressure

The second of the two tire factors affecting contact pressure is tire design. Three tire parameters fall within this category: tire shape, tread pattern, and tire size.

With respect to tire shape, the area of interest is the crown region and the dimensions of tread width and tread radius, FIGURE 15. The maximum width of the contact patch or footprint is determined by the tire's tread width. Tread radius is the curvature of the tread, shoulder to shoulder. The amount of curvature will affect the distribution of pressures across the tread.

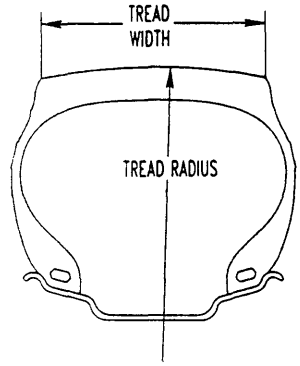



**Figure 15 Tire Shape Factors Affecting Contact Pressure**

The second tire design parameter is that of tread pattern. A tire's tread pattern can be characterized by its tread design, its non-skid depth, and its net-to-gross. Non-skid depth refers to the depth of the grooves. Net-to-gross is the percentage of void area in the tread design. Four basic tread patterns are illustrated in FIGURE 16 (1). The tread pattern will affect the tire's crown area stiffness, which in turn will influence the contact pressure distribution. The greater percentage of void area as found for example in traction tread patterns result in higher contact contact pressure levels since the effective contact area is smaller.

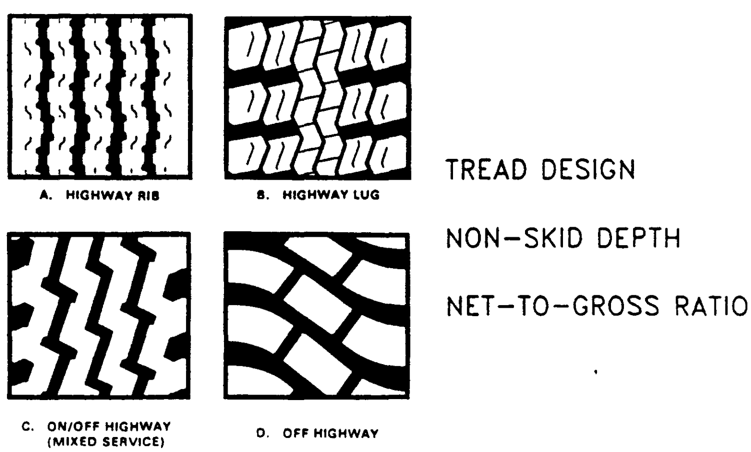



Figure 16 Tire Tread Pattern Factors Affecting Contact Pressure

The third tire design parameter is that of tire size. This design parameter is defined by the tire's overall diameter, its section width, and the wheel rim diameter, FIGURE 17 (4). With these tire and wheel dimensions, load and inflations are calculated using formulas standardized by the Tire and Rim Association. Two tire size concepts differing dimensionally in section width are illustrated in FIGURE 18. The wide base tire features a greater section width than the conventional tire, it also has a greater load carrying capability. One application is replacing a dual tire assembly with a single wide base tire. This offers a number of potential benefits affecting operating cost. It also results in the axle end load being transferred through a smaller contact area than with a dual tire assembly. The average and the maximum vertical contact pressures of the single wide base tire are higher, FIGURE 19. A larger size wide base tire is directionally better with respect to both average and maximum contact pressures.

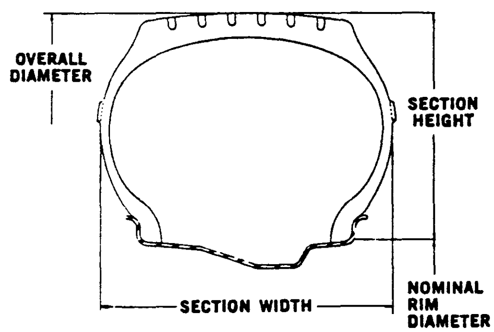
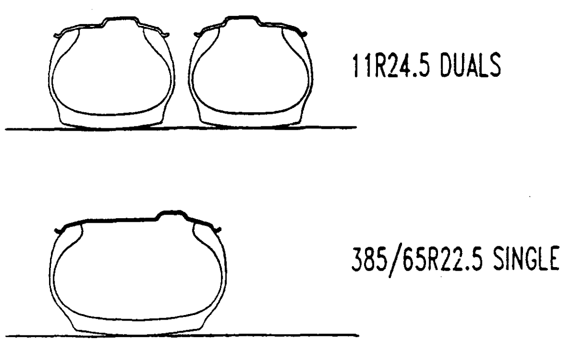



Figure 17 Tire Size Factors Affecting Contact Pressure




| SIZE | AIR VOLUME | HOT INFLATION | LOAD | CONTACT AREA |
|---|---|---|---|---|
| | $(inch^3)$ | (psi) | (lbs.) | $(inch^2)$ |
| 11R24.5 | 13,613 | 105 | 4,250 | 114 (*) |
| 385/65R22.5 | 9,644 | 130 | 8,500 | 87 |
| 425/65R22.5 | 12,359 | 120 | 8,500 | 90 |

(*) Dual Tires

Figure 18 Single Wide-Base Tire versus Dual Tire Assembly

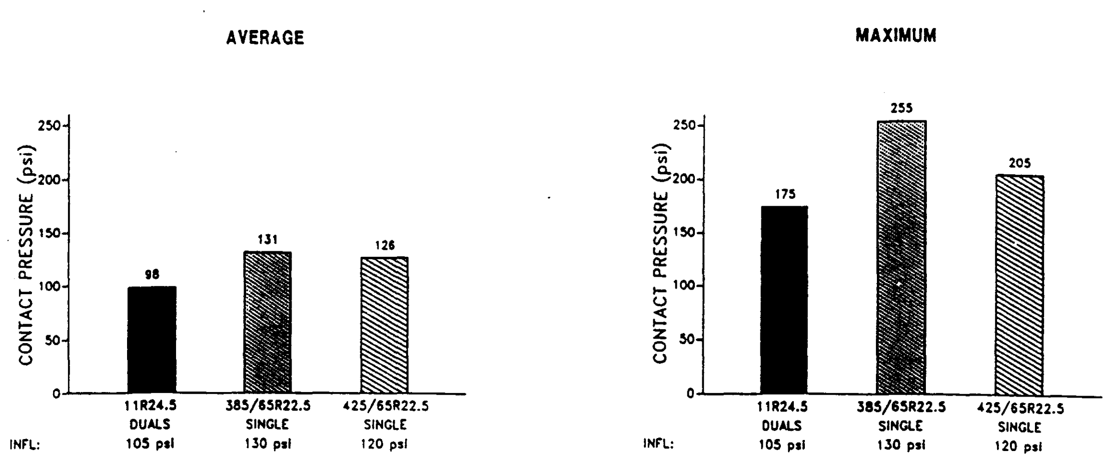
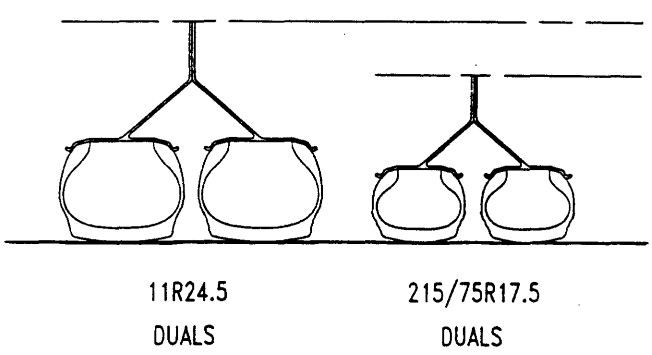



Figure 19  Average & Maximum Contact Pressures-
Dual Tire Versus Single Wide Base Tire

Another possible tire size concept is down-sized duals, FIGURE 20. The smaller wheel rim diameter reduces axle height, which in turn allows the trailer floor to be lowered, providing increased trailer cube capacity. Because air volume is lower, these down-sized duals require a higher level of inflation pressure to carry the equivalent load of a conventional size dual tire. These tires also have smaller contact patches. Average contact pressure for the down-sized dual tire was greater than the conventional size dual and the wide base single tire. Down-size dual tire maximum contact pressure fell between the conventional dual and the wide base single pressure levels, FIGURE 21.




| SIZE | AIR VOLUME | HOT INFLATION | LOAD | CONTACT AREA |
|---|---|---|---|---|
| | (inch$^3$) | (psi) | (lbs.) | (inch$^2$) |
| 11R24.5 | 13,613 | 105 | 4,250 | 114 (*) |
| 215/75R17.5 | 5,593 | 135 | 4,250 | 74 (*) |

(*) Dual Tires

Figure 20  Down-Size Dual Assembly Versus Conventional
Dual Tire Assembly

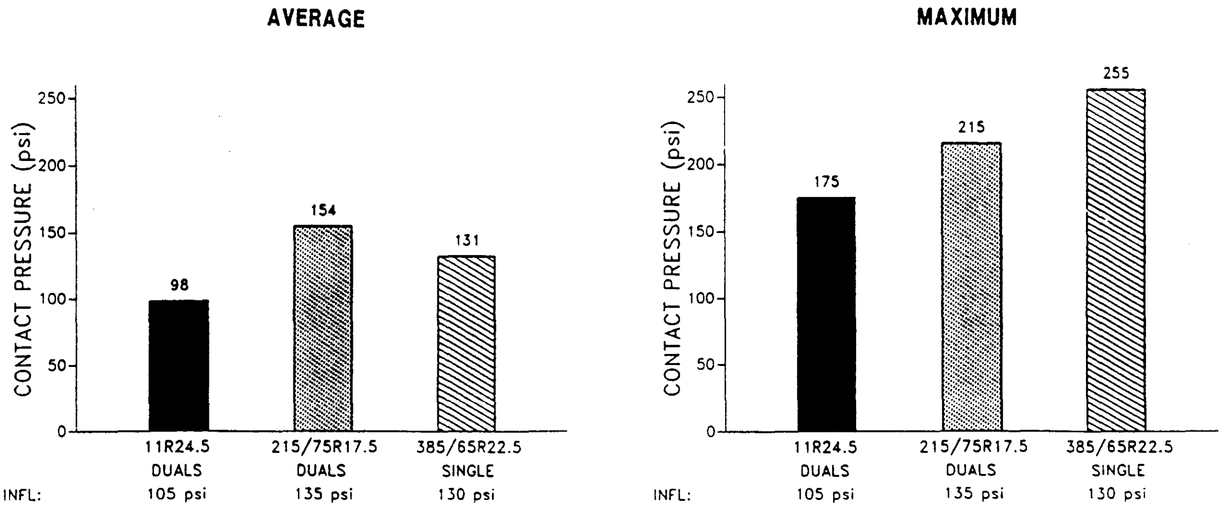



Figure 21 Average & Maximum Contact Pressures-
Conventional Dual & Single Wide-Base
Versus Down-Size Duals

## Operational Factors Affecting Contact Pressures

Operational factors such as inflation pressure, tire load, wheel alignment, vehicle speed, and vehicle suspension type will influence contact pressure distribution and maximum contact pressure levels. Alignment effects is an area of on-going study, its influence on the development of irregular tire wear is critical to maximize tread life. Vehicle speed and vehicle suspension type are dynamic considerations which were not part of this quasi-dynamic study. The dynamic effect though is an important consideration. The focus of this laboratory study was to address the impact of load and inflation on the average and maximum contact pressures and the distribution across the width of contact.

## Inflation Effect

Conventional size bias and radial ply tires were tested at various inflation pressures to determine how these different tire types respond with respect to contact pressure (2). Tire load was held constant at the typical drive/trailer load of 4,250 pounds.. Inflation pressures were varied approximately +/-20 psi from their rated T&RA condition. Both tires exhibited an increase in average contact pressure resulting from the reduction in contact area as inflation pressure increased FIGURE 22.

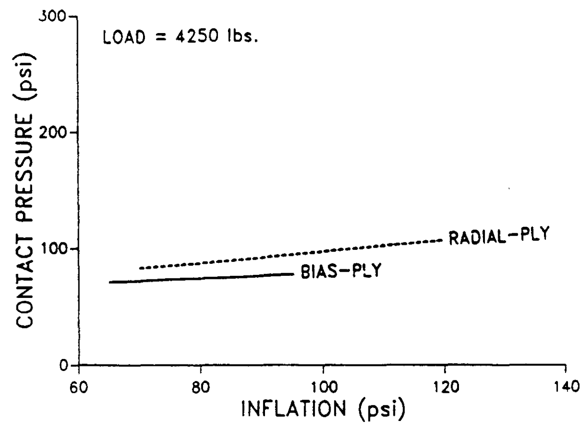



Figure 22 Effect of Inflation on Average Vertical Contact Pressure

The distribution of pressures across the contact width also varied with inflation; the area affected was mainly the central region of the tire, FIGURE 23. Increased inflation pressure resulted in an increase in the center region contact pressures. The bias-ply tire didn't exhibit a change in maximum contact pressure within the range of inflations tested, FIGURE 24. The maximum contact pressure sensitivity with respect to inflation variation for a radial-ply tire is dependent on its characteristic contact pressure distribution. Examples of these distributions were shown earlier, FIGURE 9. The radial-ply tire illustrated in FIGURE 23, exhibited a steady increase in maximum contact pressure with increased inflation. A radial-ply tire having a concave pressure distribution like that of a TYPE 'A' distribution rather than the convex like the TYPE 'B' distribution, will tend to exhibit less sensitivity to inflation pressure variation. The greater the shoulder region contact pressures are relative to the center region, the less sensitive the tire's maximum contact pressure will be to inflation pressure.

Average contact pressures for either the bias or radial ply tires did not exceed inflation pressure. Measured maximum contact pressures were between 1 to 2 times the inflation.

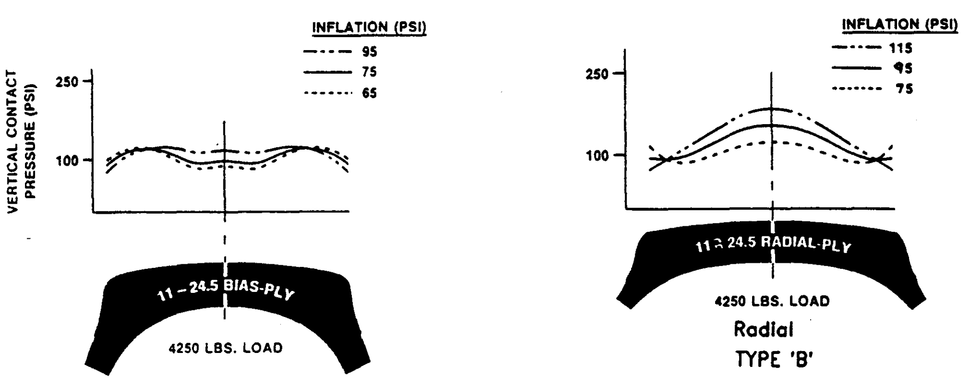



Figure 23 Effect of Inflation Pressure on Vertical Contact Pressure Distribution

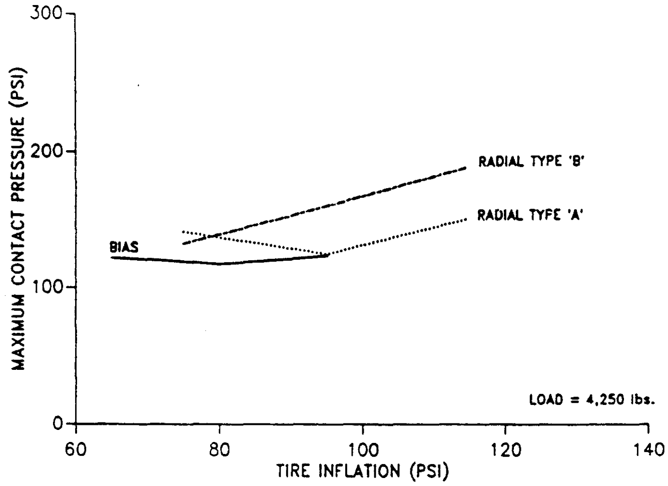



Figure 24 Effect of Inflation Pressure on Maximum Vertical Contact Pressure

## Load Effect

A similar test was conducted to determine how the two tire types responded to load variation (2). Tire inflation was held constant at their rated T&RA condition, this did result in a 20 psi difference between the two tires. Load was varied approximately +/-2,000 pounds, to simulate empty, fully-loaded, and over-loaded conditions. Both tires exhibited an increase in average contact pressure with increased tire load, FIGURE 25.

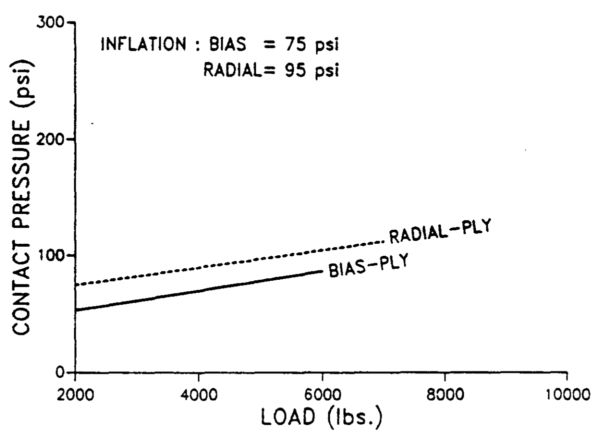



Figure 25 Effect of Load on Average Vertical Contact Pressure

Load affected mainly the contact pressure distribution in the shoulder region. Higher shoulder region contact pressures were produced as tire loading increased, FIGURE 26. The bias-ply tire exhibited a steady increase in maximum contact pressure as tire load increased, FIGURE 27. The radial-ply tire's sensitivity to load variation is dependent on its characteristic pressure profile, as it was for inflation pressure variation. The radial tire featuring higher center region contact pressures, TYPE 'B' distribution, exhibited a decrease in peak contact pressure as load increased from the initial 2,500 lbs. load. Once the pressure distribution shifted from a center loaded to a shoulder loaded one, the maximum contact pressure increased with load at a rate similar to the bias-ply tire. For a radial-ply tire featuring higher shoulder region contact pressures, TYPE 'A' distribution, the sensitivity to load variation is similar to the bias-ply tire.

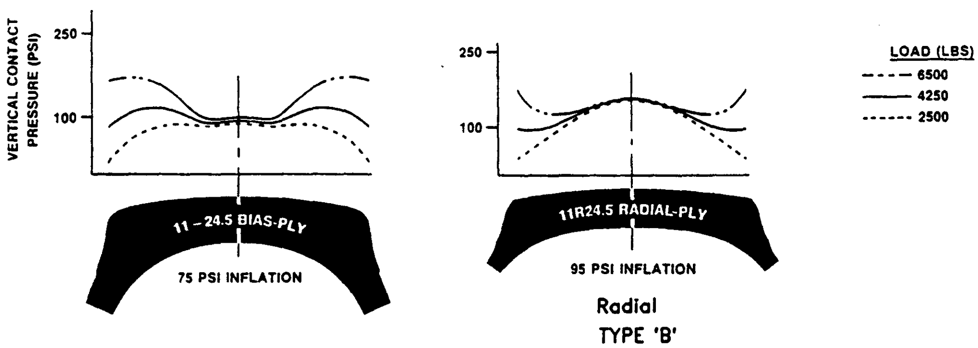



Figure 26 Effect of Load on Vertical Contact Pressure Distribution

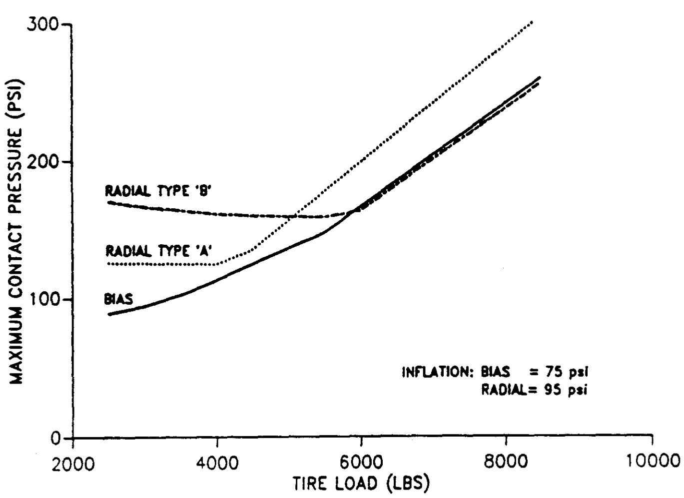



Figure 27 Effect of Load on Maximum Vertical Contact Pressure

## SUMMARY

Truck tire contact pressures are affected by many factors, tire related and operations related. It is the combination of these factors that determine how contact pressures are distributed within the contact patch and the peak level achieved. Major tire factor considerations are internal construction and size. Just as important are the operational factors of inflation pressure and tire load.

Regardless of its particular tire factors, all responded to load and inflation variation in a similar manner. Inflation variation with constant load affected the contact pressures in the central region of the footprint. Load variation at constant inflation affected the contact pressures in the shoulder regions of the footprint. Higher contact pressures will result from either an increase in inflation pressure or an increase in tire load. Whether a radial tire's characteristic contact pressure distribution is concave, convex, flat, or a combination of these, will affect its maximum contact pressure sensitivity to either inflation or load variation. Differences exist between the various radial-ply tire manufacturers and even within the same manufacturer, with respect to the tire construction materials utilized, tire component placement/geometry within the tire structure, and tire design. This results in differences in the contact pressure distributions/sensitivity for the same tire size.

Average contact pressures generally did not exceed the tire's inflation pressure. Peak pressures though, were found to be as high as twice the inflation pressure. Within the range of loads and inflation pressures tested, load variation produced the greater change in tire contact pressures.

Dynamic effects were not addressed in this study due to test equipment limitations. Dynamic tire contact pressures/loads need to be quantified as part of an integrated tire/suspension system.

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