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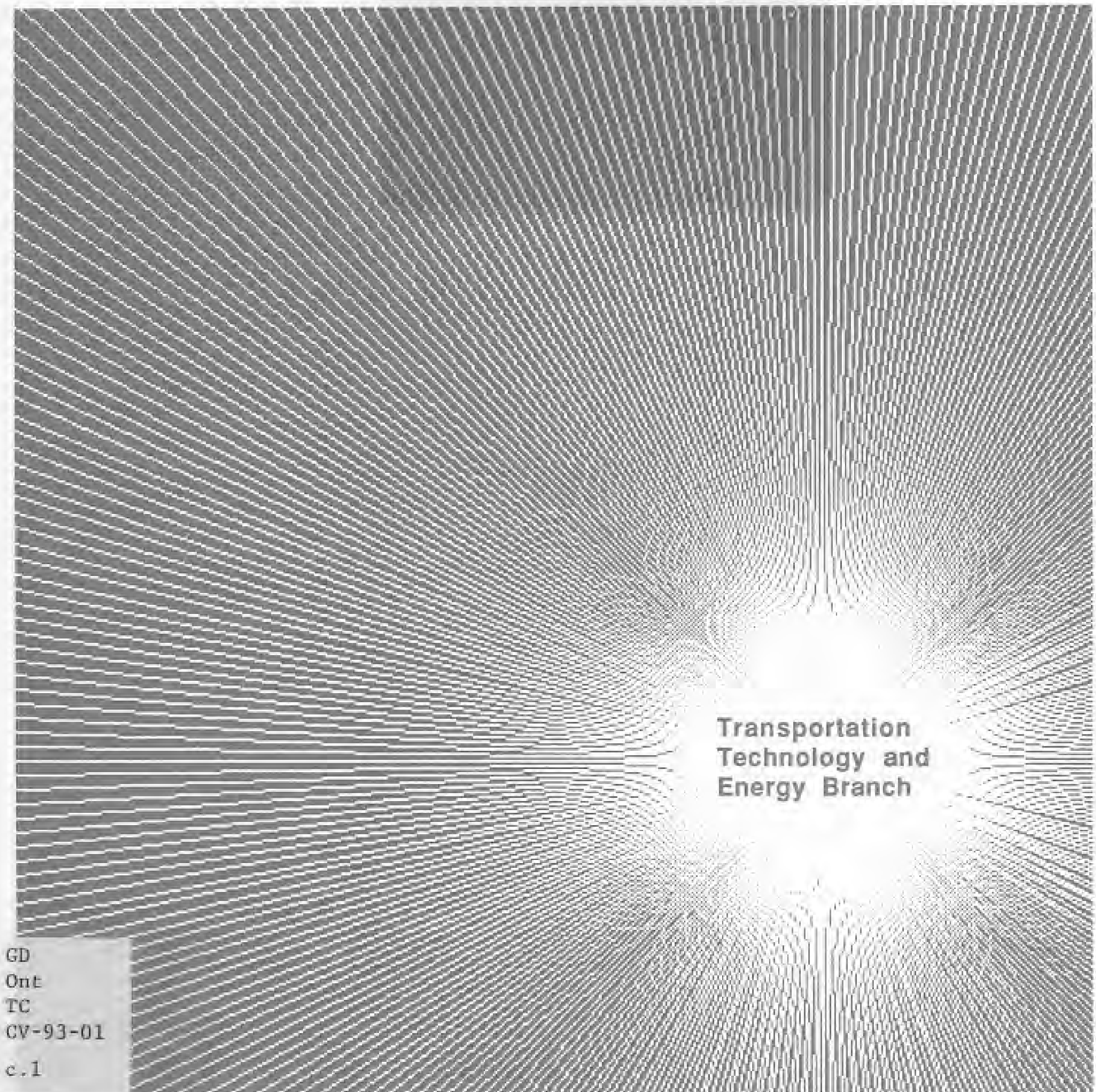
Use of Wide Base Single Tires on Heavy Trucks



Technical Report Documentation Page

Use of Wide Base Single Tires on Heavy Trucks

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Abstract:	A survey was conducted of both the manufacturers and users of wide base single tires to examine the current and future applications of these tires in central Canada. Three brands of wide base single tires were then selected to measure their side force and alignment moment characteristics.
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EXECUTIVE SUMMARY

Wide base single (WBS) tires are truck tires with an extra wide profile designed to carry the same load as two narrower tires which make up the conventional dual tire assembly found on most heavy trucks.

The use of WBS tires for intercity transport represents an extremely small market in Canada. Most operators are not aware of their potential fuel saving benefits or are unwilling to compromise allowable axle loads by using the tire. The trend to increased use of WBS tires in Canada in the 1970s ended with the reductions in allowable weight on WBS axles. The current rate of usage of WBS tires on highway combination vehicles in Central Canada is less than 0.5%. On straight trucks used in construction, which frequently go off-road, WBS tires are now widely used on the front axles and increasingly on their lift axles as original equipment.

The main advantages of WBS tires are 5% fuel savings, tare weight savings of 96 kg/axle with steel rims and 160 kg/axle with aluminum, 11% increase in roll stability, longer brake life, smoother ride, good retread life and a possible reduction in spares inventory. The disadvantages of WBS tires are increased pavement damage, longer downtime with flat tires, slightly reduced stability after a blowout and slightly shorter tire life for new tires. The life-cycle cost of the WBS tire and retreads and rims is about 10% less than dual tires.

Under current regulations, which limit axle loads on WBS tires to 9000 kg, and 11 kg/mm of tire width, the potential rate of use of WBS tires on highway trailers is estimated to be 2%. Usage would increase slowly to this level under current regulatory and economic conditions. If fuel prices were to rise substantially and remain high, then usage could increase to 10%.

In jurisdictions that allow the same axle load on WBS tires as dual tires on a particular axle group, WBS usage has gradually increased to a level of about 30% for that axle group over a period of about 10 years. This has occurred in Europe and Australia where the same axle loads are allowed on tridems equipped with either WBS or dual tires. Tandem axles generally are not permitted the same weight. In Ontario and Quebec, less than 5% of trucks are equipped with tridem axles.

If the TAC recommended load limit of 3000 kg per tire is implemented, axle loads will be limited to 6000 kg/axle on WBS tires. This would effectively eliminate any future use of the tire in Canada other than for flotation applications. Under the current and proposed regulations, the market for WBS tires in Central Canada lies with high-centre-of-gravity vehicles such as tankers, carriers who are able to consistently control axle loads, short haul carriers, and 7- and 8-axle tractor semitrailers and B-trains.

1/ BACKGROUND

Wide Base Single (WBS) or "super single" tires are truck tires with an extra wide profile designed to carry the same load as the two narrower tires which make up the conventional dual tire assembly found on most heavy trucks. Conventional tires are typically 250 mm to 280 mm wide, while WBS tires are typically 385 mm or 445 mm wide. WBS tires are now widely used on the front axles of short haul heavy carriers such as cement or aggregate trucks. Interest in long haul applications is limited in Canada but the experience of other countries and the few domestic carriers who use them is largely positive.

WBS tires were first introduced in Europe in the early 1950s and gained wide acceptance on all axle positions including steering, drive, and trailing axles. The tires offered lower tare weight, improved fuel economy, improved roll stability, and a smoother ride.

In the late 1960s and early 1970s, the Ontario government introduced a revised weight formula governing gross vehicle weights (GVW) in the province. At the same time carriers began using WBS tires on all axles in order to realize some of the economic benefits of the tires.

After operators started using these tires, pavement design engineers began to oppose their use due to their higher load equivalency factors and potentially damaging effect on pavements. New weight regulations were then introduced in the early 1970s, reducing the maximum allowable gross weight on axles with WBS by 1000 kg, which effectively limited their widespread use.

Today, as deregulation has caused many trucking firms to take a second look at their operations, WBS tires may be reconsidered for certain applications.

This report outlines some of the potential applications, economic benefits, and future trends in the use of WBS tires.

2/ PROFILE OF CURRENT USERS AND APPLICATIONS

2.1/ Summary of Interviews

To assess the level of interest in WBS tires in the industry, approximately 20 interviews were conducted with tire manufacturers and fleet operators. The primary conclusion from the interviews is that there is little or no interest in WBS tires from manufacturers or from fleet operators. The primary reason for the lack of interest is the weight restrictions imposed on this tire through regulation.

Several other conclusions were also evident from the interviews:

- Fuel savings attributable to the WBS tire are not great enough to overcome the load restrictions.
- Few carriers showed any interest in having the regulations changed to allow more weight on WBS tires.
- Few manufacturers showed any interest in research and development of WBS tires, because of the small market for them in Canada.
- Because the first introduction of WBS tires came so long ago, the original test data used to substantiate decisions on WBS tires are difficult to find.

2.2/ Observed Rates of Use in Central Canada

Based on observations of approximately 1500 trucks on Highways 417, 401, 11, 7, and 16 between Montreal, Toronto, Ottawa, and North Bay the rate of usage within the following vehicle groups is:

Combination vehicles	0.5%
Aggregate trucks (straight trucks only)	
Front axle	95%
Lift axle	6%

WBS tires are popular on the front axles of construction vehicles due to their extra flotation capability for off-road use. For intercity transport, observations show that there are very few combination trucks equipped with WBS tires on the road. Generally the only vehicles observed were Labatts and Manitoulin Transport.

The observations were conducted from a moving vehicle and were carried out over 10 different days over a period of six months from January to August 1991.

2.3/ Tire Size

The two most popular WBS tire sizes are the 445-mm tires, used widely on construction vehicles and some Canadian highway trucks, and a 385-mm tire used on highway-only vehicles (mostly in the U.S.). At present the 445-mm WBS tires are most frequently used on the front axles of straight dump trucks, ready mix concrete trucks, tandem steer and tandem steer/tandem drive concrete mixer trucks, and mobile cranes. The extra tire width provides better flotation for off-road use, which is often encountered by these vehicles, and they can be used effectively to carry the heavier front axle loads on these vehicles.

In the U.S., the 385-mm tire is the most popular WBS tire for strictly highway use. U.S. regulations typically limit tire loading on WBS tires to 10.7 kg/mm and axle loads to 7700 kg/axle on a tandem assembly. In Ontario and Quebec, where the maximum axle load on WBS tires is 9000 kg and maximum tire loading is 11 kg/mm, maximum axle loads can only be achieved with the wider 445-mm tire. The RTAC Memorandum [1] proposes to limit loads to a maximum of 3000 kg per tire, or 6000 kg per axle for WBS equipped axles. On combination vehicles, this restriction would cut payload capability nearly in half, effectively ruling out any future use of WBS tires except for cases where load capacity is not a factor.

2.4/ Applications in Central Canada

Current Ontario regulations effectively reduce the load capabilities of most truck combinations using WBS tires in Central Canada. These regulations have been largely responsible for the low rate of market penetration of these tires.

In the few cases where WBS tires are being used on combination vehicles, they are used for reasons related to tare weight and fuel economy. Interviews with operators and survey observations indicate there is little interest in these tires, mostly due to their weight limits and partly due to the small base of knowledge about them. Where they are used, the most frequent truck configurations are 7- and 8-axle B-trains and tractor semitrailers where maximum GVW can be achieved using WBS tires instead of duals. In Central Canada, trucks equipped with WBS tires include mostly tankers, bulk carriers, and van trailers for carriers who consistently haul the same payload and do not operate across provincial borders.

Generally, operators are still experimenting with the tire and there is not yet any consensus on where they can best be used. On 7- or 8-axle tractor semitrailers or B-trains where maximum GVW can be achieved with or without WBS tires, the WBS tire is used to improve fuel economy and increase payload capability by reducing tare weight. The tire is not favoured on other combinations where GVW must be reduced when WBS tires are used.

WBS tires are used in the U.S., Europe, and Australia on trailers with a high centre of gravity such as tankers, bulk carriers, hopper bottom trailers, grain trucks, stock carriers, and furniture vans. The wider spread between WBS tires provides greater roll stability and, with an integrated design, allows the payload to be dropped slightly lower resulting in a lower centre of gravity.

For bulk haulers and refrigerated service, in which trucks are often weight limited, WBS tires may be used effectively on truck configurations where they would not result in a lower GVW. In these cases, the reduced tare weight of WBS tires allows them to carry greater payload. There is still some reluctance to use them in heavy long haul operation. One U.S. refrigerated carrier equipped with WBS tires on 70 tractors and 97 trailers in 1987 ended up removing them in 1989 [2]. Over long distances at high speeds with heavy loads, the tires would overheat and separate the treads from the tire. The carrier reported that it would go back to WBS due to their weight saving if tire durability improved.

Volume carriers who carry cube limited cargo could potentially use WBS tires in order to increase the volume available for payload by utilizing the wider spread between the axles. It is more likely, however, that volume haulers will follow the current trend toward low profile tires which increase payload space while retaining the advantages of a dual tire. WBS tires would offer some reduction in tare weight which would result in fuel savings.

Carriers such as breweries who always carry the same payload are able to control axle loads precisely, thereby avoiding accidental overloading of any individual axle. Since there is less chance of an overload, these carriers are able to utilize the advantages of WBS tires while minimizing the impact of their lower axle limits.

Various axle combinations of WBS tires are being used on 7- and 8-axle semitrailers. Some operators use duals on the lift axles and WBS tires on the fixed axles in order to take advantage of the lower rolling resistance of the WBS tires when the trailer is empty and use the higher capacity dual tire lift axles when loaded. Other operators use WBS tires on the lift axles only, allowing the axle to be lifted in the event of a flat tire and making the truck more suitable for long haul. Still other operators use WBS tires on all trailer axles in order to realize the full benefits of the tire.

On B-trains, WBS tires may be used on all trailer axles, only on the centre tridem, or only on the back axles of the pup trailer. Some concern was expressed about using WBS tires on the centre bogie for safety reasons. The centre bogie supports both the front trailer and the pup trailer and a flat tire could potentially have more severe consequences than a flat tire on the rear pup trailer only. Some bulk liquid carriers are also using WBS tires on all trailer axles on 7-axle B-trains with a tandem centre bogie.

The variation among provinces in regulations governing WBS tires can make interprovincial operation difficult. An axle loaded to 9000 kg in Ontario for example, would be overweight in Manitoba (the most restrictive province) where the same axle is permitted only 6000 kg.

2.5/ United States

Twenty-eight U.S. states have "inch width" regulations varying from 8.9 to 14.3 kg/mm (500 to 800 lb/in) with the most common limit being 10.7 kg/mm (600 lb/in). This results in individual axle loads of 8200 kg on WBS tire axles, which is less than the 9000 kg allowed on dual tire axles. Overall GVW limits of 36 287 kg can still be achieved with WBS tires, however, (385 mm/tire x 10.7 kg/mm x 2 tires/axle x 4 axles + front axle) and this has led to the situation where WBS tires are widely favoured by operators who are weight limited. Within a fixed GVW, any decrease in tare weight such as offered by WBS tires means a corresponding increase in payload. This situation reflects what would probably happen in Canada if weight limits on axles equipped with WBS were the same as duals.

WBS tires are now widely used in the Western U.S., where over 100 fleets are committed to using these tires or are now evaluating them, primarily on tandem trailer axles and some tandem drive axles [3]. The tires are typically used on tandem axles, since most U.S. regulations concentrate on GVW (typically 36.3 tonnes on a 5-axle truck) and there is little advantage to the use of tridem axles in order to increase GVW. The tires are most popular among bulk trailers and tankers due to the extra roll stability and greater payload capability resulting from reduced tare weight.

A survey conducted for this study in Washington state shows that between 10% and 15% of all combination vehicles on Interstate 5, which is the main north-south corridor, are using either WBS or single[1] conventional tires on some trailing axles. Allowable tire loads are 10.7 kg/mm (600 lb/in) of tire width and axle loads are 9072 kg on a single axle, 15 422 kg on a tandem axle, and 36 287 kg maximum GVW. WBS tires generally appeared on:

- A-train hopper bottom carriers
- A-train tankers
- straight truck tankers with a trailer
- Pup trailers often towed by straight dump trucks.

The typical axle configuration would include dual tires on single and drive axle groups and WBS tires on tandem or tridem groups.

Of the combination trucks using WBS or conventional singles, about 75% are running dual wheel assemblies with the inner tire of the dual assembly removed. This is often done in the western states in order to save weight [4] when the full load capability of dual tires is not required. These "outer tire only" combinations typically appear on:

[1] one tire of dual assembly is removed.

- 6- and 7-axle tractor van semitrailer combinations (usually wood chip trucks) with one tire removed on the leading or trailing axle of the trailer axle group;
- A-train vans, tankers, and some flatbeds with one tire removed from the dual assemblies of both axles in the tandem axle groups.

In the short term, the practice of removing a single tire from a dual assembly allows operators some leeway in reducing tare weight and tire cost on axle groups which do not need the full load capacity of dual tires. In the longer term this practice is not likely to continue. There is a higher possibility of pavement damage since tire load distribution on axle groups designed for duals is poor when there is a mix of dual and single tire axles within the same axle group. Inch width regulations are also difficult to enforce on axle groups with a mix of dual and conventional single tires. Single tires mixed with dual tires within the same axle group are most likely the main cause of pavement damage attributed to single tire use in the western states. This practice is also less than optimal for operators in the long term since the weight of the second wheel hub of a dual assembly is still being carried. One of the complaints of operators using WBS tires is that they are being unfairly blamed for pavement damage which is most likely being caused by overloaded conventional single tires on axle groups designed for duals.

The future outlook in the U.S. is for the use of WBS tires to continue to increase slowly due to the weight and fuel savings unless weight restrictions on WBS tires become more widespread. The future users among line haulers will most likely be the bulk liquid and gasoline carriers who make use of the greater stability and increased payload capacity [2].

2.6/ Europe

WBS tires are widely used accounting for 30% of new tri-axle trailer sales in Europe and nearly 100% in France [5]. In the European Economic Community (EEC) the standard intercity transport is a 38-tonne, 5-axle tractor semitrailer unit with a 2-axle tractor and 3-axle trailer. Typically it is the 3-axle trailers which are equipped with WBS tires while most tractors and 2-axle trailers use dual tires. The tridem trailer is the most frequent configuration using WBS tires due to the greater safety and reduced downtime associated with tire blowouts in a 3-axle group. The tridem with a 24-tonne load limit imposes a load of 4 tonnes per wheel which is within the rated capability of available WBS tires.

WBS tires on tandems may become even more popular in Europe if manufacturers' tire load ratings are increased. The legal load on tandem axles (dual or WBS) is 20-tonnes or 5-tonnes per wheel, which generally exceeds the load capability of 385-mm WBS tire and is near the limit of most 445-mm tires. There is some concern that if tire capabilities increase, leading to fully loaded WBS tandems, this will result in pavement damage.

As in Canada, GVW depends on wheelbase, number of axles, and axle spread. Axle loads are slightly higher on tandems and slightly lower on tridems but regulations do not require a reduction in axle weight when WBS tires are used, so long as tire load ratings are not exceeded. There are variations in GVW among EEC countries but axle loads for Great Britain are typical. These are compared with Ontario axle loads in Table 1.

Table 1/ Comparison of Load Limits on Dual and WBS Tires for Ontario and Great Britain

Axle	Ontario			Great Britain	
	Spacing (m)	Dual Tires (kg/axle)	WBS (kg/axle)	Spacing (m)	Dual or WBS (kg/axle)
Steering			9 000		6 830
Single		10 000	9 000		10 170
Tandem (1.8 m)	1.8	19 100	18 000	1.8	20 000
Tandem + single	1.8 + 2.54	29 100	27 000	4.6	24 390
Maximum GVW*		(kg)	(kg)		(kg)
4-axle		34 600	n/a		37 000
5-axle		43 700	41 500		38 000
6-axle		53 200	50 500		38 000

*Assumes 5500 kg on front axle

2.7/ Australia

Growth in WBS usage has flattened out now in Australia after operators began converting around 1982. About 15% of tri-axles on semitrailers and trains are now equipped with WBS tires. Weight limits are structured to allow the full 20-tonne (3.33 tonnes/wheel) weight on a tri-axle to be achieved using WBS tires. The allowable weight of 16 tonnes (4.0 tonnes/wheel) on tandems cannot be achieved with WBS tires and consequently there are very few of these configurations.

In its "Review of Road Vehicle Limits" report [6] Australia acknowledged the greater pavement damage attributable to WBS tires. It justifies the decision to allow tridems the same axle load on WBS as duals with the statement "As it is expected that only a small portion of industry would use wide-base single tires, we consider that they should be allowed the same loading as duals on the tri-axle group to encourage the higher safety standards and assist industry to improve operating efficiency."

The primary users are semitrailers and trains with a high centre of gravity such as tankers and refrigerated trucks. They are taking advantage of wider spread between tires to increase roll stability and the reduced tare weight to increase payload. The roll stability aspect may be more important in Australia since roads are typically designed with a greater pavement crossfall.

Users are generally having good success with the tires but are still learning how to operate with them. Yokohama Tire in Australia is undertaking a 12-month field study equipping up to 100 fleets with various new tire designs including trailer mounted WBS tires. The trial started in February 1991 and results are not yet available. The testing will include such details as ride, handling, steering response, rolling resistance, and tread wear.

3/ ECONOMIC AND OPERATIONAL FACTORS

3.1/ Introduction

The main advantages of WBS tires are:

- Reduced tare weight
- Reduced rolling resistance
- Potential increases in roll stability
- Improved ride
- Reduced brake wear

and the main disadvantages are:

- Increased pavement damage
- Increased downtime with flat tires
- Reduced vehicle control in the event of tire blowouts
- More complex inventory for trucking firms

Tire life-cycle costs and inventory requirements do not change significantly.

3.2/ Weight Savings

Replacing conventional dual tires on steel rims with WBS tires saves 96 kg/axle when wide steel rims are used and 160 kg per axle when wide aluminum rims are used [7]. On a 5-axle tractor semitrailer unit, replacing the four drive and trailer axles with WBS steel rims would save 384 kg, with WBS aluminum rims would save 640 kg. Weight savings per axle are summarized in Table 2.

3.3/ Fuel Savings

The theory and fleet experience with fuel savings associated with WBS tires is presented more fully in Chapter 4 and 5.

Fuel savings reported by users have been as high as 10% but typically average around 5%. The fuel saving is due primarily to the lower vertical stiffness of the tire resulting in up to 25% less rolling resistance. The lower vertical stiffness is the result of reduced sidewall flexing when four sidewalls on a dual are replaced with two sidewalls on a WBS. In most applications where WBS tires are now being used, further fuel savings attributable to lower tare weight are generally offset by higher payload.

Table 2/ Weight Savings per Single Axle WBS Tires vs Duals

Wheel Type	Dual Tire Double Cap Nut Steel Disc	WBS Steel Wide Base Wheel	WBS Aluminum Wide Base Wheel
No. of Wheels and Tires	4	2	2
No. of Nuts	40	20	20
Weight of Wheels	82 kg/pair	56 kg	28 kg
Weight of Tires	107 kg/pr size 11R22.5 14 ply	81 kg 15R22.5 18 ply	81 kg 15R22.5 18 ply
Weight of Wheels and Tires	377 kg	274 kg	218 kg
Saving	0	103 kg	159 kg

Laboratory and controlled tests conducted by the Ministry of Transportation of Ontario (MTO) [8] indicate fuel savings of 5% in summer and 13% in winter with WBS tires. However, in truck fleet applications included in the same test program, there was no significant fuel savings. This may be attributable to the fact that the reduced rolling resistance power is being used as additional speed and acceleration performance.

Manitoulin Transport, which has been using WBS tires consistently since 1981, has reported fuel savings of about 4% and Labatts has reported 8% to 10% savings.

3.4/ Stability and Tire Stiffness

The reduced vertical stiffness of WBS tires, which leads to their reduced rolling resistance, also reduces their resistance to rollover. While tire stiffness is less than that of dual tires, this factor is more than compensated for when the tires are used in conjunction with increased track and spring mount width. The net effect is greater roll stability. The standard axle width is 1.83 m while the wider axles used with WBS tires is 1.96 m.

Tests conducted on a tilt table [9] showed no significant change in vehicle roll stability when WBS tires were fitted to a standard axle. When axle and spring mount width was increased by 152 mm, roll stability increased by 11%. This is approximately equal to the increase in roll stability which could be expected with WBS singles mounted on an axle designed for WBS tires. The WBS axle is 127 mm wider than a conventional axle and on vehicles designed to use WBS tires, spring centres are 250 mm wider [10]. A further stability increase is possible on bulk trailers if the trailer body is mounted lower between the wider wheel spacing, thereby lowering its centre of gravity. Axles and trailers with these specifications are now being manufactured in regions where there is a demand for the product. These configurations are less likely to be available in Canada since there is not enough demand here to warrant production by Canadian manufacturers.

The increased stability is a potential safety benefit for bulk liquid carriers, refrigerated vans, furniture vans, livestock carriers, or other trucks with a high-centre-of-gravity payload.

As part of this study, three WBS tires were selected and tested on a flat bed tire test apparatus to measure cornering force and aligning moment at various slip angles and tread depths. The tires tested included:

Michelin	XZY	445/65 R22.5 L
Bridgestone	M747	445/65 R22.5 L
Goodyear	G165	445/65 R22.5 L

The lateral force and aligning movement tables generated by the tests are presented in the appendix of this report. The full test results are available under separate cover from MTO Transportation Technology and Energy Branch [11].

3.5/ Tire and Wheel Costs

When tire life, number of retreads, tire cost, and rim cost are taken into account, the cost per kilometre of WBS tires is about 10% less than conventional tires. This is due mainly to the longer life of retread WBS tires and the greater percent of tires that can be recapped. Recapping costs are about 15% less than the comparable cost for two conventional tires. The original life of the WBS tire is often shorter because the tire is loaded to a higher percent of its rated capacity than a comparable dual tire assembly. The higher sidewall strain in WBS tires is more likely to result in tread separation at higher loads and temperatures.

The tire life-cycle costs are calculated in Table 3. The calculations do not take into account the cost of mounting rings (about $100/tire) which must be added if WBS tires are being retrofitted to standard width axles. This can also have negative effects on axle end durability by changing the moment arm of the axle on the bearing.

Table 3/ Tire and Wheel Costs

Item	Cost (1991 $)	Component Life (km)	Cost/km ($/km)
1 WBS tire	$600	100 000	0.0060
1 Wide Base Aluminum Wheel	$440	5 000 000	0.0001
Retread	$350	80 000	
No. of retreads/tire	1.3		
% retreadable	70%		0.0048 *
Total			0.0109
2 Conventional Tires	$700	110 000	0.0064
2 Conventional Aluminum wheels	$560	5 000 000	0.0001
Retread	$400	70 000	
No. of retreads/tire	1.6		
% retreadable	60%		0.0060 *
Total			0.0124

*Retread cost/km = retread cost/(retread life x retreads per tire x % retreadable)

3.6/ Brakes

WBS tires allow more room around the wheel, exposing the brakes to a greater flow of air around the wheel, which results in better brake cooling and longer brake life. This helps to offset braking power requirements that have been increasing steadily over the years, as aerodynamic and rolling resistance drag are reduced through modern truck design and lower rolling resistance radial and WBS tires. To the extent that drag is reduced, braking power must be increased proportionately. The added room around the wheel also allows for more efficient air disk brakes.

3.7/ Pavement Damage

A review of relative pavement effects of WBS versus conventional tires is outside the scope of this report. It is worth mentioning, however, since this is the main impediment to relaxing weight restrictions and realizing the economic advantages of WBS tires. There are numerous reports on the subject that estimate anywhere from 4% to 400% greater pavement damage resulting from the use of these tires. Both theoretical and practical experience show that WBS tires result in increased pavement rutting and some increase in fatigue in the upper pavement layers due to the more concentrated load imposed by WBS tires. This remains true even when compared to dual tires which are not evenly inflated [12] as is often the case in practice. The contact area of the WBS is often 15% less than a dual under the same load.

3.8/ Flat Tires

One of the main operational problems cited by users is flat tires. With dual tires, a truck can usually continue on to its destination or to a repair facility, depending on the load, distance, and severity of the blowout. Generally drivers will continue on with the flat by travelling at a reduced speed in order to keep the remaining tires from overheating.

When a WBS tire goes flat, the driver is less likely to continue, particularly if the truck is loaded, since there is no secondary dual tire to absorb the load. This problem is less severe on tri-axle groups, depending on which tire is flat and how badly the tire is blown. In many cases, the only solution is to replace the tire at the side of the road or to chain up the suspension below the flat tire, both of which are time-consuming procedures. This is one reason why some operators favour using WBS tires only on lift axles.

Trucks on a long haul generally will have to carry a spare WBS until such time as WBS tires become widely available at truck stops and repair facilities. Without a spare available, operators have reported long waits for a replacement tires. Drivers are also faced with a tire and rim assembly that is about 40 kg heavier than a single conventional tire and rim, which may cause problems while changing a tire.

Trucks equipped with WBS tires usually experience greater lateral movement and yaw angles after a blowout than comparable trucks equipped with dual tires. This has been confirmed in tests conducted jointly by Alcoa Wheels and Bridgestone [13] on 5-axle twin trailer and semitrailer configurations loaded to 36 300 kg. Typically the WBS equipped truck requires more steering effort to bring it to a halt. Interviews and a review of literature did not indicate WBS tire blowout has been a safety problem.

U.S. experience with these tires has shown them to have shorter life than duals, particularly under heavy loads over long trips. At a typical axle load of 6500 kg on a U.S. truck, the 385-mm WBS singles would be operating at about 75% of the manufacturer's rated capacity, while duals would typically be operating at 55% of their rated capacity. The WBS tire is more highly stressed which logically results in earlier failure, particularly under the high temperature and load conditions experienced on long trips.

In Ontario and Quebec, a typical WBS axle load of 7000 kg would be about 65% of the manufacturer's rated load for a 20-ply-rated, 455-mm WBS tire and 60% of a typical dual tired axle. As a result, experience with WBS tires in Canada is closer to that of duals.

3.9/ Ride and Handling

Drivers report a smoother ride with WBS tires due to the reduced vertical stiffness of two sidewalls compared to four on a dual.

Drivers indicate there is an increased tendency for WBS tires to hydroplane under wet or slushy conditions when compared to narrower dual tires. This is the result of the larger single wide contact patch, which is more likely to trap water under the tire than the narrower conventional tire. Tests conducted by MTO in 1980 also suggest that WBS tires have a lower threshold for lateral stability on wet pavements than radial dual tires [8], particularly on the pup trailer of a double trailer truck. The same tests also showed that WBS tires had better braking performance than dual radials on dry pavement and equal performance on wet pavement.

Drivers have also reported steering difficulty with WBS on the steering axles of combination vehicles while manoeuvring at low speeds. This is presumably due to the difficulty in sufficiently loading the steering axles on a tractor trailer unit. In this case, there is no advantage to having the higher load capacity of a WBS tire on this axle unless the truck must frequently be taken off-road.

3.10/ Inventory Requirements

Companies introducing WBS tires into their operations require a greater mix of spares. In any fleet, there is likely to be a mix of tires requiring an inventory of both conventional and WBS tires and rims. This factor is offset by a reduction in the total number of tires, rims, and cap nuts required to be in inventory if dual tires are replaced by WBS tires. In the long run, the net effect may actually be a mixed but reduced amount and value of inventory.

4/ THEORETICAL BASIS FOR FUEL SAVINGS

4.1/ Background

The pneumatic tire is the primary control element in ground vehicle systems. Forces and moments developed at the tire-road interface provide support, directional control, braking and accelerating capability. The manner in which these forces and moments are developed can be influenced through changes in tire design. Tire input-output properties must be completely identified if vehicle motion properties, and the resulting fuel consumption characteristics, are to be predicted.

In normal use of a tire, the individual plies (radial or bias-ply tires) of the tire flex and rub, which produces a wiping motion between the tread and the road. This is one of the main causes of tire wear and high rolling resistance. Another primary cause of rolling resistance of tires on hard surfaces is the hysteresis in tire materials caused by the deformation of the carcass through the footprint made while rolling. Friction between the tire and the road caused by sliding, the resistance due to air circulating inside the tire, the fan effect of the rotating tire on the outside air, road texture and road roughness, tire non-uniformity, adhesion between tire and road, and road deformation, also contribute to the rolling resistance of the tire, but are of secondary importance.

Tire construction has a significant influence on rolling resistance. Thicker treads and an increased number of carcass plies, for example, tend to increase the rolling resistance due to greater hysteresis losses. Other design parameters will also affect rolling resistance. The complex relationship between the design and operational parameters of a tire and its rolling resistance make it extremely difficult to develop an analytic method for predicting the rolling resistance of tires. Therefore, rolling resistance is almost always determined experimentally.

Several people have tried to develop an empirical or theoretical tire model to define and describe the effect of the aspect ratio (ratio of the cross-section height to cross section width) on the rolling resistance of a tire. Although the test results are not conclusive, most of the models indicate that for a tire of similar construction and similar outside diameters, rolling loss is minimized with an aspect ratio of 60% to 65%. Treichel [14] selected a group of commercial radial truck tires with the same outer diameter but different section widths and rim diameters to obtain aspect ratios between 95 and 75%. Construction and compounds of the tires were essentially the same. The rolling loss data indicated that as the aspect ratio was lowered, so was the rolling loss. The loss decrease was more sensitive to cross-section increases than it was to rim-diameter increases. Yoshimura et al. [15] found that for passenger tires with the same outer rim diameters, the rolling loss declined almost linearly from aspect ratios of 82% to 62%.

Other data also indicate minimum rolling resistance at 60% to 65% aspect ratios. Knight [16] reported that, compared to a conventional truck tire, a low-aspect radial truck tire of 75% aspect-ratio had a 9% lower rolling resistance loss, and a wide-base truck tire of 65% aspect ratio had a 20% lower rolling resistance loss. Unfortunately, no details regarding tire construction and test conditions were provided.

Of real interest is the fuel consumption reduction possible due to lower rolling resistance values of a tire. It has been well documented that the rolling resistance of wide base truck tires is about 20% to 25% lower than that of regular truck tires.

The following discussion presents some views of the tire industry and research organizations on the relationship between tire rolling resistance and the effects on fuel consumption.

Several studies have been performed with the objective of correlating the relationship between tire rolling resistance and fuel consumption. Schuring [17] analyzed experimental and analytical results and developed the following equation, which is essentially linear regardless of vehicle type and duty cycle:

$$F_c = F_{co} + k \cdot \sum F_R$$

where,

F_c = vehicle fuel consumption (cm^3/km)

F_{co} = fuel consumption at zero rolling resistance loss.

k = constant data factor, 0.093 $cm^3/(km\text{-}N)$ for all vehicles.

$\sum F_R$ = total rolling resistance loss of all tires (N)

From fuel consumption and rolling resistance data for passenger vehicles and trucks (obtained from constant speed tests), complex road cycles at varying rolling resistance values due to tire pressure variations, tire loads, and tire types were calculated. The average F_{co} values were:

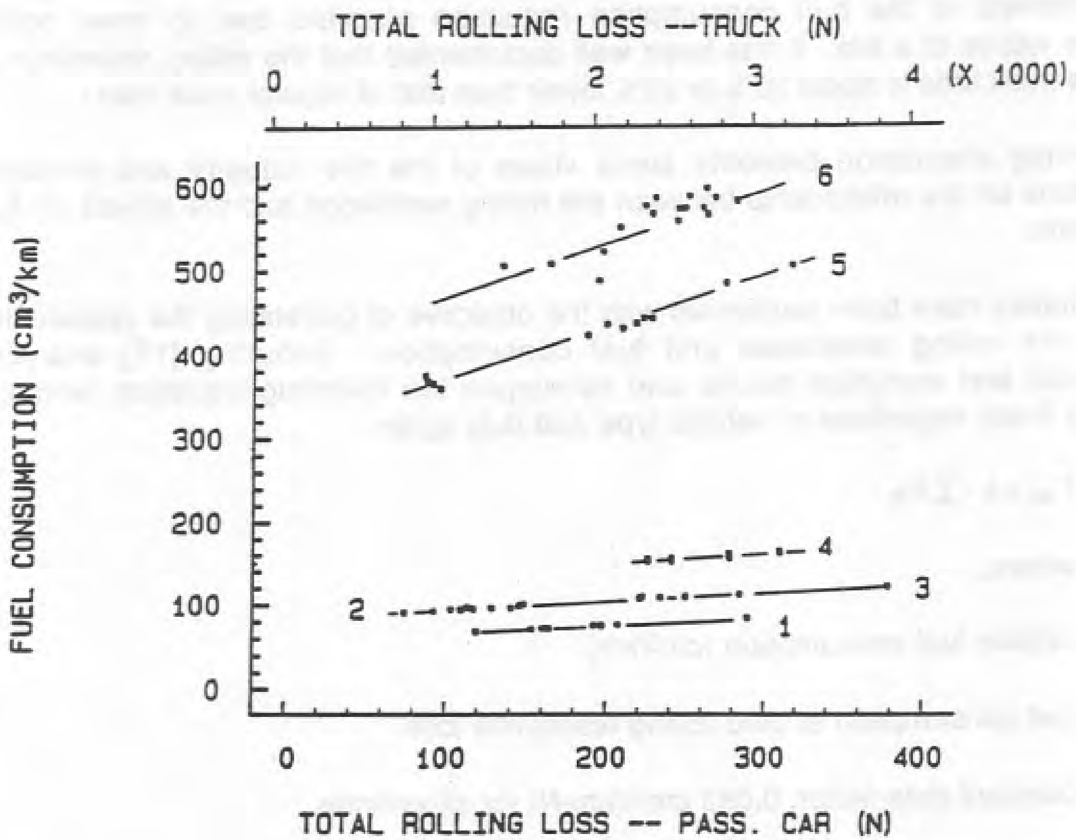
- for passenger cars and light trucks F_{co} = 103 cm^3/km
- for heavy trucks F_{co} = 340 cm^3/km

This F_{co} factor increases with vehicle weight, engine size, vehicle speed, and complexity of road test cycle.

The k value for all vehicles was determined to be $k = 0.093\ cm^3/(km \cdot N)$

Table 4 shows fuel consumption as a function of rolling loss (all tires as based on road test data compiled for passenger cars and trucks).

Figure 1/ Fuel Consumption vs Total Rolling Loss for Passenger Cars and Trucks



Fuel consumption as a function of total rolling loss (all tires):
Road tests:
1. passenger car (highway)
2. passenger car (urban)
3. passenger car (80 km/h)
4. passenger car (urban)
5. truck (96 km/h)
6. truck (96 km/h)

Source: reference [17]

4.2/ Theoretical Fuel Savings Possible for a B-Train Double with Wide Base Single Tires on All Trailer Axles

The only real and accurate means to determine the fuel consumption savings caused by switching all trailer dual tires to wide base tires is to test both configurations under similar test conditions. Further fuel consumption savings can also be obtained when a new tractor trailer rig is specified with wide base tires. This is because the engine and transmission can be better matched with respect to lowered vehicle weights and lowered power requirements due to the use of wide base tires. With accurate engine/transmission matching to the hauling application, the engine can operate at the best fuel consumption points of the engine map.

The following calculation is provided based on the theoretical relationship developed. The predicted fuel consumption savings are theoretical values for one possible set of vehicle, tire and environmental operating conditions. Unfortunately, no wide base rolling resistance tire data could be obtained for this study to substantiate the results.

Based on the equation as presented in Section 4.1, the following can be predicted for a 7-axle B-Train double combination with dual tires:

Assume:	Total vehicle weight	392 kN
	Rolling Loss Coefficient	7N/kN
	F_{co}	360 cm^3/km
	ΣF_R	392kN x 7N/kN

Then the fuel consumption is,

$$F_{c1} = F_{co} + k \cdot \Sigma F_R$$

$$F_{c1} = 360\ cm^3/km + 0.093\ cm^3/km.N \times 392\ kN \times 7\ N/kN$$

Therefore,

$$F_{c1} = 615.19\ cm^3/km$$

If we assume a total rolling resistance loss reduction of 10% from switching to wide base tires on all trailer axles, the predicted fuel consumption with wide base tires is:

(Note: Total rolling resistance of 10% is an estimated value. The above equation indicates the effect of a change in rolling resistance on fuel consumption.)

$$\text{Rolling Loss Coefficient} = 0.9 \times 7\ N/kN = 6.3\ N/kN$$

$$F_{c2} = F_{co} + k \cdot \Sigma F_R$$

$$F_{c2} = 360\ cm^3/km + 0.093\ cm^3/km.N \times 392\ kN \times 6.3\ N/kN$$

Therefore,

F_{c2} = 589.68 cm^3/km

and the calculated change in fuel consumption would be 4.2%.

The above calculation is based on a total rolling resistance reduction of 10%. When only the trailer wheels are switched over to wide base tires, as was the case in the above example, the rolling resistance reduction of the trailer would have to be higher than 10% to provide an overall rolling resistance reduction of 10%. The trailer tires account for up to approximately 60% of the total fuel used by all of the tractor trailer tires.

As indicated earlier, actual rolling resistance and fuel consumption data for WBS tires and conventional tires equipped B-train tractor trailer combinations is not available. As a result, estimated values of rolling resistance are used to show the relationship between rolling resistance changes and the resulting fuel consumption changes.

Also noted earlier, laboratory and controlled tests conducted by MTO [8] indicate fuel savings of 5% in summer and 13% in winter when wide base tires are used instead of regular dual truck tires. However, in many truck fleet applications included in the same test program there were no significant fuel saving with the WBS tires. This may be because power gains due to reduced rolling resistance were used up by additional speed and acceleration performance.

On the positive side, Manitoulin Transport, which has been using WBS tires over a long period, reports fuel savings of about 4%. In addition, W.J. Deans Transportation in Quebec, has been running wide base tires on its fleet of B-Trains with measured fuel savings of 1/4 mile/U.S. gallon to 1/2 mile/U.S. gallon. This corresponds approximately to a 4% to 8% fuel consumption saving.

Bridgestone has indicated that, depending on the power train/vehicle, matching the potential fuel savings for a tractor trailer combination using wide base tires as opposed to conventional dual tires is in the range of 5% to 9%.

Based on fuel consumption, power and rolling resistance measurements on dual truck tires conducted by W.R. Davis Engineering Limited [18] for a tractor trailer combination, the following relationship has been developed to provide some insight into the effect on fuel consumption due to a change in rolling resistance. The coefficients in the equations are test and vehicle dependant.

$FR = a + bP_{total}$

where,

FR = fuel rate (ml/sec)
a = data coefficient
b = data coefficient
P_{total} = total power (kW)

Based on test data points collected during the test program over a paved and gravel roads, using the Davis rolling resistance test rig:

$$FR = 1.4 + 6.866 \times 10^{-2} P_{total}$$

and based on rolling resistance and power measurements;

$$RR = 17.1 + 56.31 P_{RR}$$

where,

RR = rolling resistance of test axle, (four Goodyear 11R22.5/Radial Tires at test speed 67 km/hr).

P_{RR} = power associated with test axle rolling resistance (for this example at 67 km/h).

Based on the above test data and calculated parameters for the two test conditions documented in the Davis report, the following calculations present the changes in fuel consumption due to changes in rolling resistance. With total vehicle power minus test axle power measured at approximately 65 kW, at the above test example speed of 67 km/h, an equation for fuel rate and rolling resistance of the test axle can be developed as follows:

$$P_{total} = (RR - 17.1)/56.31 + 65, \text{ and}$$

$$FR = 1.4 + 6.866 \times 10^{-2} P_{total}$$

Therefore;

$$FR = 1.4 + 6.866 \times 10^{-2} \times (((RR - 17.1) / 56.31) + 65)$$

For a change in rolling resistance of the test axle from 902N to 605N the resultant fuel consumption change is as follows:

$$FR_1 = 1.4 + 6.866 \times 10^{-2} \times (((902 - 17.1) / 56.31) + 65)$$

Therefore,

$FR_1 = 6.94$ mL/sec

and;

$FR_2 = 1.4 + 6.866 \times 10^{-2} \times (((605 - 17.1) / 56.31) + 65)$

Therefore,

$FR_2 = 6.57$ mL/sec

Therefore,

$\Delta FR = 0.371$ mL/sec (5.3%)

Therefore under the test conditions as evaluated, a rolling resistance decrease on the test axle of 33% resulted in a fuel consumption reduction of 5.3%.

To obtain a better estimate of real life fuel consumption savings for any tractor trailer combination, it is strongly recommended that on-road vehicle fuel consumption tests be carried out with dual and wide base tires. The DAVIS Rolling Resistance test rig is well suited to provide both rolling resistance data and fuel consumption data.

5/ FLEET EXPERIENCE

5.1/ Manitoulin Transport

Manitoulin is the only firm identified in Ontario that continues to use WBS tires in their fleet. Manitoulin originally conducted controlled fuel-consumption tests using WBS tires in October 1981 under completely controlled conditions in accordance with SAE guidelines. Testing was conducted on a 32 km stretch of new four-lane highway running west from the town of Walden in the Regional Municipality of Sudbury. The testing was conducted to investigate the fuel savings attributable to cab and sleeper mounted airshields pulling various types of trailers, and to test WBS tires vs. conventional dual tires on the trailer only.

For the latter test Manitoulin used a 3-axle trailer with approximately 21 500 kg of bagged cement level over the platform of the trailer. This weight was used since it most accurately reflects the average of empty and fully loaded cement tankers as well as the average weight carried by their north/south freight trailers carrying less-than-truckload northbound and lumber and steel southbound.

The results of the tests showed a consistent 2.61% fuel savings using the WBS tires. As this test was on a 3-axle trailer, they equated this to a 3.5% saving on a 4-axle trailer. Of the 162 4-axle trailers operating in the Manitoulin Fleet, about 90% are equipped with WBS tires. Using an average annual distance of 64 000 km, the 146 trailers equipped with WBS tires run 9.3 million km/yr. Fleet fuel consumption is 1.91 km/litre and at a fleet fuel cost of 38.5 cents/litre, the fuel consumed by their power units while pulling trailers equipped with WBS tires costs $1.9 million. A 3.5% saving on this fuel cost is $66,500/year.

Manitoulin also attributes a number of other benefits to WBS tires including:

- weight savings of about 45 kg/axle
- fewer on the road tire failures
- longer drum and brake life
- added stability by increasing trailer main frame width by about 10%.

Following their tests in 1981, Manitoulin switched most of its fleet to WBS tires. They continue to use them today and are planning to use them on all new equipment in the foreseeable future.

Manitoulin are also using these tires on the front axles of what they call "Super Trucks." These are highway tractors that have a very long wheelbase with a load carrying box behind the cab, followed by the fifth wheel and a semitrailer. With this arrangement, they are able to achieve almost 8100 kg on the front axle. When these tires are taken off the front axle and retreaded, they can then be used on trailer axles.

5.2/ Labatts Breweries

Labatts has used WBS tires widely in the past and continues to do so on some of their fleet. The fuel savings of 8% to 10% claimed by Labatts were based on tests carried out in the late 1970s and early 1980s.

In these tests, Labatts installed fuel metering devices on several of their tractors towing trailers with either WBS or dual tires to monitor fuel consumption over a period of more than one year. The WBS-tired and dual-tires trailers were then exchanged between tractors. In this way the only difference between the vehicle configurations was the tires and the tests consistently showed 8% to 10% fuel savings for the trailers equipped with WBS tires.

Following these tests, Labatts standardized all their trailers with these tires with no exceptions. In addition to the fuel savings, they felt they had cut down on the number of flat tires due to the stronger carcasses on the WBS tires and that overall tire costs were reduced. It was not possible to substantiate this with figures since they do not keep track of individual tire costs and the size of the fleet keeps changing. On new purchases of trailers equipped with WBS they also removed the new tires on the lift axles and replaced them with retreaded tires.

Recent changes in allowable vehicle dimensions allow the use of two 9.5 m semitrailers in a B-train combination, giving them a trailer length of 19.0 m. For Labatts, this made the single semitrailer obsolete, and all their new equipment orders are for this type of vehicle. The pup trailer has doors on both ends and the 5th wheel is capable of sliding the two trailers together to allow loading and unloading of both trailers without uncoupling.

Because of the greater danger associated with having a flat tire on the centre tridem or tandem, and because of the weight limitations on WBS tires, Labatts has decided to go back to the conventional dual tires for all their new trailer purchases. It will continue to use WBS tires on older trailers until such time as the equipment is written off.

6/ FUTURE TRENDS

In spite of their fuel efficiency benefits, WBS tires have not become popular with operators in Canada due to the limits imposed on allowable axle loads. If higher fuel prices or other conditions favouring the use of WBS tires were to prevail, it appears there might be wider usage, but the industry would take a wait and see attitude, following the lead of those who are successful with them. Operators would become more aware of the tire's benefits if their use became more widespread in other jurisdictions and if tire and rim manufacturers begin to promote them more actively in Canada.

WBS tires are gradually gaining acceptance across the U.S. Experience with their use in western U.S., Europe, and Australia has proven that their fuel saving and tare weight benefit operators, and operational problems are being overcome.

The future of WBS tires in Central Canada depends on four factors:

- Allowable axle loads
- Fuel prices
- Tire availability
- Tread life

In regulatory environments that allow the same axle loads on axle groups fitted with WBS tires as dual tires, 30% to 50% of truck configurations with these axle groups switched to WBS tires. If weight restrictions on WBS were removed, there would be an increased move to use these tires on weight limited trucks, which typically make up 25% to 30% of the traffic stream in Ontario and Eastern Quebec. The reason is that within a fixed GVW, the reduced tare weight of WBS tires allows carriers to increase their payload.

If fuel prices rise dramatically, the fuel savings attributable to these tires will begin to outweigh operational and load limitations and the tire will gain popularity more rapidly.

Availability of the tire helps reduce the downtime associated with flat tires and the need to carry a spare. The ability to service a disabled truck rapidly on the road is extremely important to truckers and shippers. If WBS tires were readily available at truck stops and service centres this would help considerably. This is only likely to happen with a wider use of the tire.

Long haul trucking represents one of the largest markets for heavy truck tires. The experience of long haul applications in the U.S. is not as good as carriers might like due to the durability of the tire and this market still appears to be undecided. In Canada, the situation may eventually prove different if TAC's limit of 10 kg/mm is adopted because this would lead to a lower stress in the tires. Alternatively, if WBS tire use increases then tire manufacturers are likely to put greater research effort into these tires to improve durability. This would influence the number of long haul carriers using the tires. In the 1987 MTO truck survey, 80% of trips were greater than 100 km and 45% were greater than 250 km.

In the Western U.S., the benefits of WBS tires are being actively promoted by tire and rim manufacturers. In Canada, where use is limited, surveys of tire manufacturers indicate that little is being done to promote their use. Tire manufactures may have little to gain by promoting a product that generates little revenue unless there is more demand for it. In the Western U.S., where WBS tires have gained acceptance with operators, any manufacturers who do not promote their use only stand to lose market share.

In the U.S., sales of WBS tires have risen about 5% annually since 1980 and market share is about 1% of the replacement market [2]. The main users are short haul heavy load carriers. The future for long haul carriers is still uncertain but most likely lies among the bulk liquid carriers. Tire manufacturers in the U.S. predict that WBS tires may go as high as 10% of the replacement market.

Under current regulations the market for WBS in Central Canada lies within the following groups:

- Bulk liquid carriers for whom roll stability is important.

- Trucks with weight limited payloads, in configurations such as 7- and 8-axle tractor semitrailers and 8-axle B-trains using tridem axles. In these cases WBS tires could be used without reducing the allowable GVW.

- Trucks that consistently carry the same payload and can closely control axle loads.

- Unless WBS tires and service become widely available, their use will only be favoured by shorter haul users.

Table 4 presents some estimates of market penetration under the current regulations restricting WBS tires to 9000 kg/axle and 11 kg/mm of tire width. The truck body types and percentages are taken from the 1983 and 1987 MTO truck surveys [19 and 20]

Table 4/ Potential Usage of WBS Tires Under Current Axle Limits on Highway Trailers

Body Type	% of Population *	Potential WBS Usage	Potential % of Population Using WBS
Van	52.3%	0.6%	0.3%
Reefer Van	9.3%	1.0%	0.1%
Stake	6.1%	1.0%	0.1%
Tanker	9.8%	15.0%	1.5%
Car Carrier	3.1%	0.0%	0.0%
Flat Bed	12.8%	1.0%	0.1%
Float	0.8%	0.0%	0.0%
Other	5.8%	0.0%	0.0%
Total	100.0%		2.1%

*1983 Commercial Vehicle Survey [19]

Van trailers form nearly half of the traffic stream and any switch to WBS in this group will have a large effect on total usage. Van semitrailers with one or two axles make up about 87% of all van trailers and this group is not likely to switch to WBS tires. Three axle trailers make up 9% of van trailers and typically a heavy load is sent on a 3-axle van trailer instead of a 2-axle unit. For this reason there are often more overloads on 3-axle units than 2-axle units. The higher loads and variety of payloads carried also make it more difficult to control axle loads. The additional margin provided by dual tires on 3-axle van trailers makes them unlikely to switch in any great numbers under current regulations. Four and 5-axle van trailers form about 4 % of van trailers and are able to effectively use WBS tires without sacrificing GVW. These trailers may switch in larger numbers up to 10%.

Refrigerated vans are generally heavily loaded with a high centre of gravity. While they could benefit from the greater stability offered by using WBS on the trailers, the weight limits on WBS axles would likely restrict their usage on all but 4- and 5-axle trailers.

Concrete mixers typically are already using WBS tires on front axles. Usage may increase slightly with lift or trailing axles but no significant change is anticipated from current use patterns.

Stake trucks and flat bed trucks tend to carry a variety of heavy manufactured or semi-manufactured loads. As with van trailers, the axle load margin of dual tires is more important on 2- and 3-axle trailers and there is not likely to be any switch on these trailers. Four- and 5-axle stake trailers and B-trains may switch in small numbers since they would not have to sacrifice GVW.

Dump trucks now use WBS tires almost exclusively on front axles to provide added load and flotation capability. The current trend is to use them increasingly on lift axles of straight trucks where they do not restrict GVW. WBS tires are unlikely to be used on rear tandem drives of straight trucks and trailer units, since dump trucks are weight limited and need the payload capability of the dual tires.

Tanker trucks have the highest potential for WBS use. The wider axles allow for greater roll stability due to a lower centre of gravity. These trucks also employ a higher proportion of B-trains and 7-and 8-axle tractor semitrailers with tridem axle groups which can still achieve maximum GVW's within the 9000 kg/axle limit on WBS tire axles.

Float trucks and car carriers are more concerned with tire height and use low profile dual tires since it is more important to these carriers to have a low trailer deck over the tires for purposes of loading or unloading their payloads. There is not likely to be any switch to WBS tires in this group.

Under conditions of sustained higher fuel prices, which would favour technologies such as WBS tires, it is possible to estimate what the ultimate market penetration could be. In axle combinations other than tridems, WBS tires typically result in a 5% reduction in GVW (which translates to about a 7.5% decrease in payload). Therefore, trucks loaded to 95% (or more) of maximum GVW would have little or no benefit from switching to WBS tires. The improved fuel economy would reduce total vehicle operating costs by about 1% while the total reduction in revenue payload would be up to 7.5%. Within current axle load limits there are no foreseeable fuel prices for which weight limited trucks would switch to WBS tires.

In Ontario and Quebec about 20% of trucks are operating at or near their maximum GVW and would not benefit from a switch to WBS tires in the face of steeply rising fuel costs. Of the remaining 80% of cube limited trucks, typically 30% are equipped with trailers with three or more axles and would be candidates for WBS tires. Experience in Europe has shown that in a mature market, about 40% of the axle groups are able to use WBS tires without incurring weight penalties. Under these assumptions the ultimate market penetration of WBS tires in Canada would be:

= (80% cube limited trucks)
x (30% with 3 or more trailer axles)
x (40% switch to WBS tires)

= 10%

It is possible to calculate a fuel price at which operators could justify retrofitting WBS tires. Assuming the dual tires that are being replaced with WBS tires have no remaining slvage value, then the incremental cost of retrofitting three axles with WBS tires would include 6 new rims at $400 each or $2400. With a truck fuel consumption of 1.9 km/L and a fuel saving of 4% due to WBS tires, an operator could ammortize the cost of a retrofit over 100 000 km based on a fuel price of $1.14/L in 1991 dollars.

7/ CONCLUSIONS

The use of WBS tires for intercity transport represents an extremely small market in Canada with little or no interest shown by operators or manufacturers. Most operators are not aware of their potential fuel saving benefits and are unwilling to compromise allowable axle loads by using the tire. The emerging trend in the use of WBS tires in Canada in the 1970s ended with the reductions in allowable weight on WBS axles. Manufacturers are not interested in the tire in Canada since there is no market for them. The industry has generally adopted a wait and see attitude.

The current rate of usage of WBS tires on highway combination vehicles in Central Canada is less than 0.5%. On straight trucks used in construction which frequently go offroad, WBS tires are now widely used on the front axles and increasingly on their lift axles as original equipment.

Under current regulations, which limit axle loads on WBS tires to 9000 kg, and 11 kg/mm of tire width, the potential rate of use of WBS tires on highway trailers is estimated to be 2%. This is based on estimates of the proportion of different vehicle types and axle combinations which could use these tires beneficially. Usage would increase slowly to this level under current regulatory and economic conditions. If fuel prices were to rise substantially and remain high, then usage could increase to 10%.

In jurisdictions that allow the same axle load on WBS tires as dual tires on a particular axle group, WBS usage has gradually increased to a level of about 30% for that axle group over a period of about 10 years. This has occurred in Europe and Australia where the same axle loads are allowed on tridems equipped with either WBS or dual tires. Tandem axles generally are not permitted the same weight. In Ontario and Quebec, less than 5% of trucks are equipped with tridem axles.

The advantages of WBS tires are 5% fuel savings, tare weight savings of 96 kg/axle with steel rims and 160 kg/axle with aluminum, 11% increase in roll stability, longer brake life, smoother ride, good retread life, and a possible reduction in spares inventory.

The disadvantages of WBS tires are increased pavement damage, longer downtime with flat tires, slightly reduced stability after a blowout and slightly lower tire life for new tires. The life-cycle cost of the WBS tire, retreads and rims is about 10% less than conventional dual tires.

If the RTAC recommendations of 3000 kg per tire are implemented, it will limit axle loads to 6000 kg/axle on WBS tires and effectively eliminate any future use of the tire in Canada other than for flotation applications.

In countries or states where WBS axles are permitted the same weight as duals, the main users of WBS tires are weight limited trucks since they are able to increase payload by reducing tare weight. The lower WBS axle loads permitted in Ontario and Quebec remove the advantages of lower tare weight and are the main reason why these tires have not become popular.

Under the current and proposed regulations the market for WBS tires in Central Canada lies with high-centre-of-gravity vehicles such as tankers, carriers who are able to consistently control axle loads, short haul carriers, and 7- and 8-axle tractor semitrailers and B-trains.

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APPENDIX A

LATERAL PERFORMANCE MEASUREMENTS OF WIDE BASE SINGLE TRUCK TIRES

Good Year G165 Super Single

Lateral Force and Aligning Moment Tables

Size = 445/65R22.5 L; Full Tread; Inflation Pressure = 120.0 psi
Cornering Force Table
Lateral Force (lbs) VS. Slip Angle (deg) and Verticle Load (lbs)

	Slip Angle					
Verticle Load	0	1	2	4	8	12
3995.00	0.00	541.89	1007.22	1751.34	2871.54	3574.28
7985.00	0.00	1059.29	2017.15	3575.84	5805.58	6985.06
11970.00	0.00	1558.02	3016.03	5364.98	8400.10	9881.67
14943.00	0.00	1874.78	3669.59	6537.78	10196.30	11788.80

Aligning Torque Table
Aligning Torque (in-lbs) VS. Slip Angle (deg) and Verticle Load (lbs)

	Slip Angle					
Verticle Load	0	1	2	4	8	12
3995.00	0.00	47.30	77.01	105.07	108.02	82.57
7985.00	0.00	134.47	235.68	352.10	403.65	329.75
11970.00	0.00	225.84	466.42	677.72	766.36	588.57
14943.00	0.00	283.02	655.27	954.23	1072.74	720.73

Size = 445/65R22.5 L; Full Tread; Inflation Pressure = 132.0 psi
Cornering Force Table
Lateral Force (lbs) VS. Slip Angle (deg) and Verticle Load (lbs)

	Slip Angle					
Verticle Load	0	1	2	4	8	12
4008.00	0.00	547.59	973.38	1705.61	2765.11	3611.72
7979.00	0.00	1075.95	1900.29	3435.52	5582.30	6881.41
11956.00	0.00	1663.45	2897.06	5260.33	8224.84	9759.51
14941.00	0.00	1966.44	3485.13	6342.00	9912.57	11629.10

Aligning Torque Table
Aligning Torque (in-lbs) VS. Slip Angle (deg) and Verticle Load (lbs)

	Slip Angle					
Verticle Load	0	1	2	4	8	12
4008.00	0.00	45.61	73.88	95.25	91.47	100.17
7979.00	0.00	121.76	220.47	314.22	357.21	350.21
11956.00	0.00	215.05	386.78	598.17	691.49	610.43
14941.00	0.00	263.31	591.74	838.67	962.93	743.75

Good Year G165 Super Single

Lateral Force and Aligning Moment Tables

Size = 445/65R22.5 L; 43% Tread; Inflation Pressure = 120.0 psi
Cornering Force Table
Lateral Force (lbs) VS. Slip Angle (deg) and Verticle Load (lbs)

	Slip Angle					
Verticle Load	0	1	2	4	8	12
4002.00	0.00	672.30	1177.02	1995.78	2963.74	3299.12
8007.00	0.00	1415.65	2543.38	4263.09	5944.13	6411.57
11990.00	0.00	2081.10	3775.37	6283.16	8464.36	9078.06
14987.00	0.00	2364.93	4451.18	7629.48	10127.70	

Aligning Torque Table
Aligning Torque (in-lbs) VS. Slip Angle (deg) and Verticle Load (lbs)

	Slip Angle					
Verticle Load	0	1	2	4	8	12
4002.00	0.00	55.13	75.89	102.67	93.57	60.06
8007.00	0.00	162.27	257.68	351.52	293.35	173.21
11990.00	0.00	263.79	448.32	653.55	515.89	303.93
14987.00	0.00	321.35	575.80	934.41	676.96	

Size = 445/65R22.5 L; 43% Tread; Inflation Pressure = 132.0 psi
Cornering Force Table
Lateral Force (lbs) VS. Slip Angle (deg) and Verticle Load (lbs)

	Slip Angle					
Verticle Load	0	1	2	4	8	12
3984.00	0.00	626.13	1127.95	1869.93	2847.11	3245.61
7993.00	0.00	1319.88	2411.68	4047.79	5746.74	6294.01
11991.00	0.00	1965.42	3636.36	6040.09	8290.39	8967.51
14982.00	0.00	2349.39	4364.14	7449.09	10056.30	

Aligning Torque Table
Aligning Torque (in-lbs) VS. Slip Angle (deg) and Verticle Load (lbs)

	Slip Angle					
Verticle Load	0	1	2	4	8	12
3984.00	0.00	50.62	77.64	95.10	90.65	63.81
7993.00	0.00	148.12	240.49	332.63	276.62	175.95
11991.00	0.00	234.47	407.95	599.97	479.19	287.72
14982.00	0.00	304.91	534.44	895.99	648.67	

Good Year G165 Super Single

Lateral Force and Aligning Moment Tables

Size = 445/65R22.5 L; 36% Tread; Inflation Pressure = 120.0 psi
Cornering Force Table
Lateral Force (lbs) VS. Slip Angle (deg) and Verticle Load (lbs)

	Slip Angle					
Verticle Load	0	1	2	4	8	12
4006.00	0.00	698.12	1217.23	2053.23	2998.02	3326.90
7994.00	0.00.	1486.05	2661.48	4385.47	5953.21	6399.61
11984.00	0.00	2135.60	3953.59	6469.08	8454.14	9025.19
14978.00	0.00	2481.90	4720.26	7859.92	10101.90	

Aligning Torque Table
Aligning Torque (in-lbs) VS. Slip Angle (deg) and Verticle Load (lbs)

	Slip Angle					
Verticle Load	0	1	2	4	8	12
4006.00	0.00	58.54	88.09	115.41	100.44	64.21
7994.00	0.00	168.72	271.28	381.88	289.66	177.99
11984.00	0.00	273.77	523.13	706.08	520.43	303.40
14978.00	0.00	345.05	714.54	982.97	700.50	

Size = 445/65R22.5 L; 36% Tread; Inflation Pressure = 132.0 psi
Cornering Force Table
Lateral Force (lbs) VS. Slip Angle (deg) and Verticle Load (lbs)

	Slip Angle					
Verticle Load	0	1	2	4	8	12
3995.00	0.00	641.05	1162.68	1942.44	2890.81	3252.79
7976.00	0.00	1451.00	2579.63	4188.03	5876.59	6375.52
11986.00	0.00	2125.07	3910.45	6302.97	8414.56	8988.64
14996.00	0.00	2299.33	4757.06	7715.84	10126.00	

Aligning Torque Table
Aligning Torque (in-lbs) VS. Slip Angle (deg) and Verticle Load (lbs)

	Slip Angle					
Verticle Load	0	1	2	4	8	12
3995.00	0.00	53.01	76.60	104.49	100.08	67.88
7976.00	0.00	150.60	234.66	355.99	280.36	182.81
11986.00	0.00	238.20	439.58	652.34	467.56	287.57
14996.00	0.00	291.52	566.07	902.46	635.87	

BRIDGESTONE M747

Lateral Force and Aligning Moment Tables

Size = 445/65R22.5 L; Full Tread; Inflation Pressure = 120.0 psi
Cornering Force Table
Lateral Force (lbs) VS. Slip Angle (deg) and Verticle Load (lbs)

	Slip Angle					
Verticle Load	0	1	2	4	8	12
4023.00	0.00	636.56	1122.10	1949.37	2978.97	3529.92
7992.00	0.00	1297.08	2304.49	3989.16	5938.02	6776.84
11988.00	0.00	1883.60	3241.55	5870.28	8459.21	9468.18
14975.00	0.00	2254.22	3872.86	7095.89	10115.50	

Aligning Torque Table
Aligning Torque (in-lbs) VS. Slip Angle (deg) and Verticle Load (lbs)

	Slip Angle					
Verticle Load	0	1	2	4	8	12
4023.00	0.00	58.85	94.94	125.77	118.44	80.41
7992.00	0.00	155.11	273.84	423.95	393.83	251.56
11988.00	0.00	250.43	499.01	786.82	699.18	455.17
14975.00	0.00	317.65	685.30	1080.56	958.96	

Size = 445/65R22.5 L; Full Tread; Inflation Pressure = 132.0 psi
Cornering Force Table
Lateral Force (lbs) VS. Slip Angle (deg) and Verticle Load (lbs)

	Slip Angle					
Verticle Load	0	1	2	4	8	12
4011.00	0.00	561.27	1062.45	1813.65	2877.68	3416.17
8007.00	0.00	1124.08	2178.71	3741.98	5821.10	6630.34
11974.00	0.00	1631.38	3224:19	5545.60	8321.94	9302.61
14993.00	0.00	2171.01	3963.09	6789.00	10014.80	

Aligning Torque Table
Aligning Torque (in-lbs) VS. Slip Angle (deg) and Verticle Load (lbs)

	Slip Angle					
Verticle Load	0	1	2	4	8	12
4011.00	0.00	49.92	89.36	118.09	116.91	80.43
8007.00	0.00	146.50	265.08	397.06	380.19	251.57
11974.00	0.00	240.52	423.44	721.48	667.33	458.57
14993.00	0.00	302.43	551.74	954.47	909.88	

BRIDGESTONE M747

Lateral Force and Aligning Moment Tables

Size = 445/65R22.5 L; 46% Tread; Inflation Pressure = 120.0 psi
Cornering Force Table
Lateral Force (lbs) VS. Slip Angle (deg) and Verticle Load (lbs)

	Slip Angle					
Verticle Load	0	1	2	4	8	12
3989.00	0.00	674.22	1205.41	2054.30	2963.69	3258.58
7994.00	0.00	1548.72	2799.92	4614.68	5966.91	6294.70
11991.00	0.00	2115.50	4186.02	6787.27	8633.80	9012.62
15007.00	0.00	2425.15	5034.11	8323.53	10407.90	

Aligning Torque Table
Aligning Torque (in-lbs) VS. Slip Angle (deg) and Verticle Load (lbs)

	Slip Angle					
Verticle Load	0	1	2	4	8	12
3989.00	0.00	57.73	88.20	119.45	85.89	29.24
7994.00	0.00	185.00	302.86	425.52	251.85	142.62
11991.00	0.00	294.53	588.16	775.04	457.63	242.93
15007.00	0.00	357.47	772.15	1084.19	624.62	

Size = 445/65R22.5 L; 46% Tread; Inflation Pressure = 132.0 psi
Cornering Force Table
Lateral Force (lbs) VS. Slip Angle (deg) and Verticle Load (lbs)

	Slip Angle					
Verticle Load	0	1	2	4	8	12
3989.00	0.00	587.09	1100.64	1881.72	2823.03	3190.59
7991.00	0.00	1443.79	2655.67	4348.98	5861.67	6198.00
11989.00	0.00	2022.12	4045.81	6480.68	8545.43	8896.01
15004.00	0.00	2442.07	4949.51	8027.07	10307.80	

Aligning Torque Table
Aligning Torque (in-lbs) VS. Slip Angle (deg) and Verticle Load (lbs)

	Slip Angle					
Verticle Load	0	1	2	4	8	12
3989.00	0.00	30.54	68.40	80.20	60.40	20.36
7991.00	0.00	160.06	293.41	362.54	236.45	138.92
11989.00	0.00	265.89	509.01	715.66	436.03	234.30
15004.00	0.00	339.98	709.30	1026.11	604.67	

BRIDGESTONE M747

Lateral Force and Aligning Moment Tables

Size = 445/65R22.5 L; 32% Tread; Inflation Pressure = 120.0 psi
Cornering Force Table
Lateral Force (lbs) VS. Slip Angle (deg) and Verticle Load (lbs)

	Slip Angle					
Verticle Load	0	1	2	4	8	12
4007.00	0.00	754.14	1308.65	2198.96	3099.05	3320.02
7996.00	0.00	1704.44	2957.19	4862.09	6222.05	6495.17
11991.00	0.00	2510.97	4504.34	7175.27	8888.30	9247.06
14987.00	0.00	2749.09	5399.67	8708.20	10655.60	

Aligning Torque Table
Aligning Torque (in-lbs) VS. Slip Angle (deg) and Verticle Load (lbs)

	Slip Angle					
Verticle Load	0	1	2	4	8	12
4007.00	0.00	58.80	88.77	119.80	93.13	70.46
7996.00	0.00	213.62	342.60	448.74	272.39	141.29
11991.00	0.00	300.68	616.18	806.71	477.02	251.30
14987.00	0.00	384.04	824.45	1123.10	640.50	

Size = 445/65R22.5 L; 32% Tread; Inflation Pressure = 132.0 psi
Cornering Force Table
Lateral Force (lbs) VS. Slip Angle (deg) and Verticle Load (lbs)

	Slip Angle					
Verticle Load	0	1	2	4	8	12
4015.00	0.00	676.62	1229.06	2058.40	3012.65	3241.40
7991.00	0.00	1531.39	2808.25	4620.16	6116.56	6385.94
11994.00	0.00	2363.18	4328.25	6943.13	8828.53	9135.52
14986.00	0.00	2737.94	5247.54	8472.83	10612.20	

Aligning Torque Table
Aligning Torque (in-lbs) VS. Slip Angle (deg) and Verticle Load (lbs)

	Slip Angle					
Verticle Load	0	1	2	4	8	12
4015.00	0.00	54.73	82.59	109.34	94.28	29.54
7991.00	0.00	178.92	285.51	421.22	282.21	144.52
11994.00	0.00	294.86	578.20	771.96	471.22	250.17
14986.00	0.00	356.26	755.90	1030.78	628.09	

Lateral Force and Aligning Moment Tables

Size = 445/65R22.5 L; Full Tread; Inflation Pressure = 120.0 psi
Cornering Force Table
Lateral Force (lbs) VS. Slip Angle (deg) and Verticle Load (lbs)

	Slip Angle					
Verticle Load	0	1	2	4	8	12
4008.00	0.00	444.29	834.51	1497.66	2580.16	3291.49
7985.00	0.00	863.22	1697.56	3057.90	5052.13	6237.21
11962.00	0.00	1276.53	2523.95	4560.79	7334.95	8776.06
14946.00	0.00	1518.19	3051.42	5608.10	8863.03	10508.70

Aligning Torque Table
Aligning Torque (in-lbs) VS. Slip Angle (deg) and Verticle Load (lbs)

	Slip Angle					
Verticle Load	0	1	2	4	8	12
4008.00	0.00	49.90	70.42	95.42	123.84	99.89
7985.00	0.00	133.05	212.94	298.87	388.34	317.92
11962.00	0.00	208.71	359.30	603.56	690.24	540.47
14946.00	0.00	260.85	544.98	813.85	970.79	761.63

Size = 445/65R22.5 L; Full Tread; Inflation Pressure = 132.0 psi
Cornering Force Table
Lateral Force (lbs) VS. Slip Angle (deg) and Verticle Load (lbs)

	Slip Angle					
Verticle Load	0	1	2	4	8	12
4010.00	0.00	416.11	810.89	1450.51	2443.25	3265.92
7989.00	0.00	828.06	1628.49	2906.82	4820.76	6118.62
11963.00	0.00	1230.87	2429.06	4340.88	7101.02	8633.18
14955.00	0.00	1489.09	2927.39	5357.87	8605.61	10365.40

Aligning Torque Table
Aligning Torque (in-lbs) VS. Slip Angle (deg) and Verticle Load (lbs)

	Slip Angle					
Verticle Load	0	1	2	4	8	12
4010.00	0.00	48.54	67.34	102.19	101.70	125.58
7989.00	0.00	118.58	192.83	284.90	327.94	322.05
11963.00	0.00	196.13	368.20	566.02	611.10	551.53
14955.00	0.00	245.95	521.56	777.68	911.57	760.76

MICHELIN XZY

Lateral Force and Aligning Moment Tables

Size = 445/65R22.5 L;   47.9% Tread;   Inflation Pressure = 120.0 psi
Cornering Force Table
Lateral Force (lbs) VS. Slip Angle (deg) and Verticle Load (lbs)

	Slip Angle					
Verticle Load	0	1	2	4	8	12
3986.00	0.00	591.72	1031.05	1753.01	2654.87	3140.17
7992.00	0.00	1244.68	2283.66	3941.51	5704.90	6290.12
11984.00	0.00	1904.89	3528.47	6035.66	8232.14	8934.03
14981.00	0.00	2304.05	4298.73	7456.78	9918.00	

Aligning Torque Table
Aligning Torque (in-lbs) VS. Slip Angle (deg) and Verticle Load (lbs)

	Slip Angle					
Verticle Load	0	1	2	4	8	12
3986.00	0.00	42.90	66.51	89.84	89.10	53.18
7992.00	0.00	164.10	273.08	374.47	296.20	172.88
11984.00	0.00	273.10	559.41	725.16	529.37	310.23
14981.00	0.00	341.22	743.15	1041.27	731.68	

Size = 445/65R22.5 L;   47.9% Tread;   Inflation Pressure = 132.0 psi
Cornering Force Table
Lateral Force (lbs) VS. Slip Angle (deg) and Verticle Load (lbs)

	Slip Angle					
Verticle Load	0	1	2	4	8	12
3983.00	0.00	535.85	980.52	1661.91	2557.10	3073.40
8001.00	0.00	1165.70	2161.75	3682.46	5473.58	6156.98
11983.00	0.00	1832.43	3365.55	5743.31	8030.54	8767.84
14999.00	0.00	2307.69	4146.23	7134.47	9736.61	

Aligning Torque Table
Aligning Torque (in-lbs) VS. Slip Angle (deg) and Verticle Load (lbs)

	Slip Angle					
Verticle Load	0	1	2	4	8	12
3983.00	0.00	41.76	65.50	89.86	85.37	39.21
8001.00	0.00	135.38	249.17	339.70	282.42	160.53
11983.00	0.00	253.39	492.33	682.53	513.99	295.70
14999.00	0.00	323.16	685.23	966.46	699.98	

MICHELIN XZY

Lateral Force and Aligning Moment Tables

Size = 445/65R22.5 L; 31.7% Tread; Inflation Pressure = 120.0 psi
Cornering Force Table
Lateral Force (lbs) VS. Slip Angle (deg) and Verticle Load (lbs)

	Slip Angle					
Verticle Load	0	1	2	4	8	12
3994.00	0.00	646.44	1120.66	1879.94	2783.20	3162.17
7997.00	0.00	1382.12	2512.19	4255.08	5839.92	6344.24
11985.00	0.00	2113.09	3856.20	6431.55	8425.67	8985.45
14999.00	0.00	2608.33	4708.78	8007.25	10218.30	

Aligning Torque Table
Aligning Torque (in-lbs) VS. Slip Angle (deg) and Verticle Load (lbs)

	Slip Angle					
Verticle Load	0	1	2	4	8	12
3994.00	0.00	48.68	74.17	93.92	85.88	48.44
7997.00	0.00	172.26	300.18	381.98	280.54	154.13
11985.00	0.00	296.29	522.20	750.87	502.96	273.84
14999.00	0.00	359.90	805.29	1051.69	683.22	

Size = 445/65R22.5 L; 31.7% Tread; Inflation Pressure = 132.0 psi
Cornering Force Table
Lateral Force (lbs) VS. Slip Angle (deg) and Verticle Load (lbs)

	Slip Angle					
Verticle Load	0	1	2	4	8	12
3988.00	0.00	596.58	1065.26	1764.49	2660.71	3086.38
8000.00	0.00	1300.83	2379.97	4000.94	5701.31	6246.76
11989.00	0.00	2039.47	3723.25	6182.05	8298.93	8923.12
14987.00	0.00	2609.95	4611.00	7637.06	10056.90	

Aligning Torque Table
Aligning Torque (in-lbs) VS. Slip Angle (deg) and Verticle Load (lbs)

	Slip Angle					
Verticle Load	0	1	2	4	8	12
3988.00	0.00	45.38	70.25	86.17	79.96	49.32
8000.00	0.00	153.53	260.70	349.99	274.05	159.43
11989.00	0.00	268.14	521.53	702.53	480.98	276.07
14987.00	0.00	343.68	732.98	1008.88	654.90	