TRUCK BUS TIRES

TIRE ROLLING EFFICIENCY

ITS INFLUENCE ON FUEL ECONOMY

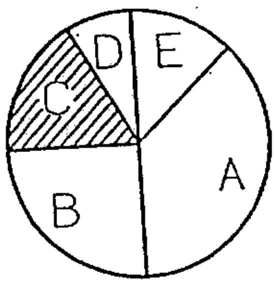
CONTENTS

TRUCK BUS TIRES

TIRE ROLLING EFFICIENCY

Introduction

- Tire rolling efficiency and its influence on fuel economy plays an important role in the overall tire performance profile.
  The incidence of fuel in the total operating cost of a typical truck fleet may be as high as 17% as shown by the diagram below:



A-	salaries (drivers)	38%
B-	interests & amortization	25%
C-	fuel expense	17%
D-	tire replacement	8%
E-	other	12%

Typical Fleet Operating Cost

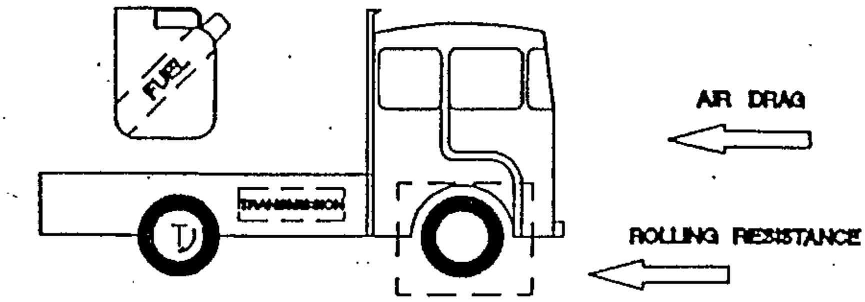
Rolling efficiency of Truck-Bus tires has become one of the primary requirements of the truck industry and will certainly acquire even more importance should the oil price regain the upward trend of the past years.

In the specialized literature of recent years there have been contrasting claims by the major tire manufacturers on the rolling efficiency of Truck & Bus tires.

The purpose of this bulletin is to inform you of our activities and of the results obtained thus far in the study of this important area of tire performance.

Introduction (cont'd)

Fuel Energy Equation & Rolling Resistance



The above sketch gives a simplified representation of the fuel-energy equation.

The available fuel energy in a truck is mainly spent for the following:

a) Chassis power loss including:

   i) Power transmission to the wheel thru a torque "T".
   ii) Internal transmission losses and other power expenditure for internal accessories (pumps, air conditioning, power steering etc..).

b) Aerodynamics losses.

c) Tire rolling resistance losses.

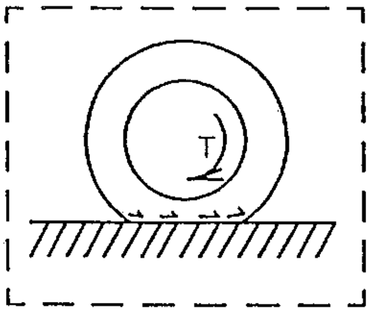
The relative importance of each of the above on fuel consumption depends on many variables such as speed, truck weight & dimensions, tire operating conditions etc. Nevertheless, under normal operating conditions, tire rolling resistance losses may account for 5% to 15% of total fuel consumption.

A considerable amount of fuel-energy is, therefore, lost in the interaction between the tire and the road surface.

Knowledge of the dynamics of the forces present in this interaction with the road surface is the objective of the study of the rolling resistance of tires.

Definition of Rolling Resistance

A simplified definition of rolling resistance is the following:



ROLLING RESISTANCE=
SUM OF THE TANGENTIAL FORCES BETWEEN TIRE AND GROUND SURFACES IN OPPOSITION TO THE TORQUE "T"

Activities on Tire Rolling Efficiency

Recognizing that Rolling Efficiency plays a very important role in the overall tire performance profile, Firestone has been intensively working on this subject during the past few years with these objectives :

- Study of the parameters affecting tire rolling efficiency.

- Isolation of the most important ones.

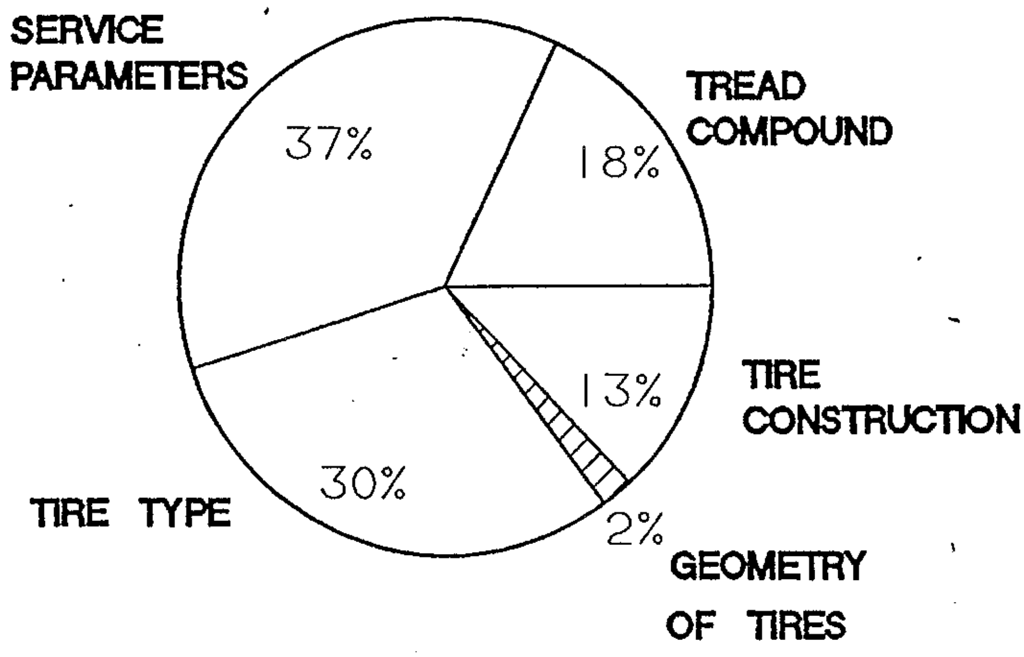
- Introduction of the rolling efficiency in the optimization process of the overall performance of our product.

Summary of Test Program and Results

For the purposes of this investigation we separated the variables involved into five main categories:

1. Service parameters (speed, pressure, load)
2. Tire type (Bias, radial)
3. Tire geometry (flatness, aspect ratio)
4. Tread compound
5. Tire construction (TP construction, body ply material)

Find below a diagram and a detailed table summarizing the relative weight that each area has on rolling resistance.



MAIN EFFECTS OF THE HEAVY DUTY TIRE/SERVICE PARAMETERS ON FUEL SAVING

PARAMETER		EFFECT ON FUEL SAVING (*) POSITIVE	NEGATIVE
SERVICE	LOAD (*)		VERY HIGH
SERVICE	INFLATION PRESS (*)	HIGH	
SERVICE	SPEED (*)		LOW - UP TO 80 KPH HIGH - ABOVE 80 KPH
TIRE TYPE	BIAS → RADIAL	VERY HIGH	
TREAD	TREAD STOCK	VERY HIGH	VERY HIGH
TREAD	TREAD DESIGN (DIFFERENT FAMILY)	HIGH	HIGH
TREAD	TREAD DESIGN (SAME FAMILY)	LOW	LOW
TIRE CONSTRUCT.	BELT/ARC RATIO# (*)		HIGH
TIRE CONSTRUCT.	PLIES ANGLES AND LAY #	LOW WITHIN RANGE OF CURRENT "STATE OF ART"	LOW
TIRE CONSTRUCT.	BODY PLY CORD	LOW	LOW
TIRE GEOM.	ASPECT RATIO ##	LOW	LOW
TIRE GEOM.	TREAD RADIUS	LOW	LOW

(*) For a POSITIVE CHANGE of the Parameter.
see page 11 for the definition
see page 9 for the definition

FUELSAVING TABLE

Interpretation of Results

- Clearly the major parameters influencing rolling loss are service conditions, type of tread stock and whether the tire is of bias or radial construction.

- An important aspect of our study, in addition to giving specific information on the relative weight of each area on the rolling losses, lies in the fact that our results, in contradiction with claims made by some competitors in the specialized literature, show that tire geometry has no significant influence on rolling efficiency. More specifically, low-aspect ratio tires yield no significant improvement when compared to conventional series tires.

- On the other hand, other parameters, to our knowledge never considered and/or tested by other competitors, such as TP construction, are of significant contribution to tire rolling resistance.

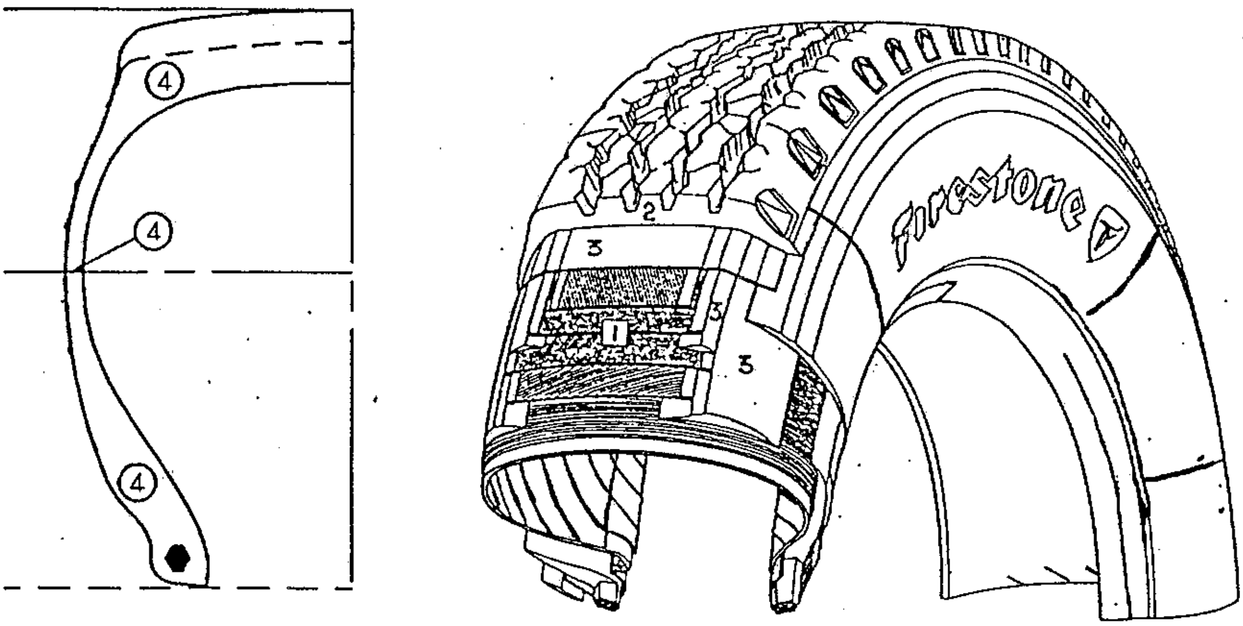
- The implication of the above is to stress the importance of a well designed experiment which takes into account the individual effect of all the variables involved as well as their interactions.

- Appendix "A" provides more details on the results obtained in our testing of the five parameters mentioned above.

CONCLUSION

The results obtained thus far have outlined the framework within which to concentrate our activities to further improve this area of tire performance.

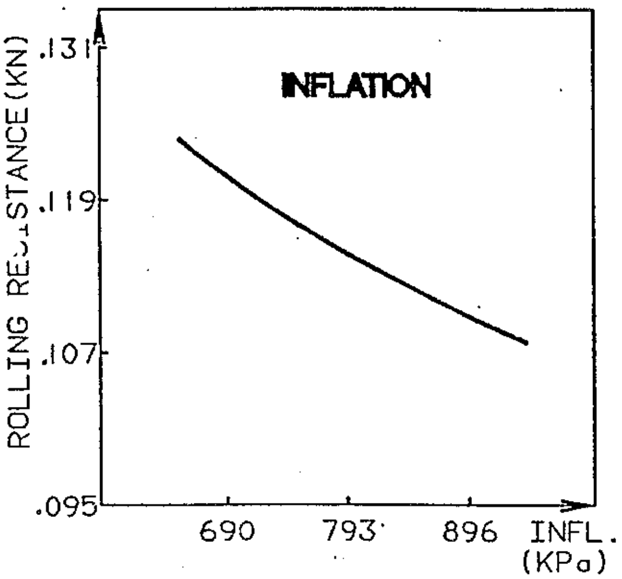
FIRESTONE FIELDS OF INTEREST
TO OPTIMIZE TIRE ROLLING EFFICIENCY

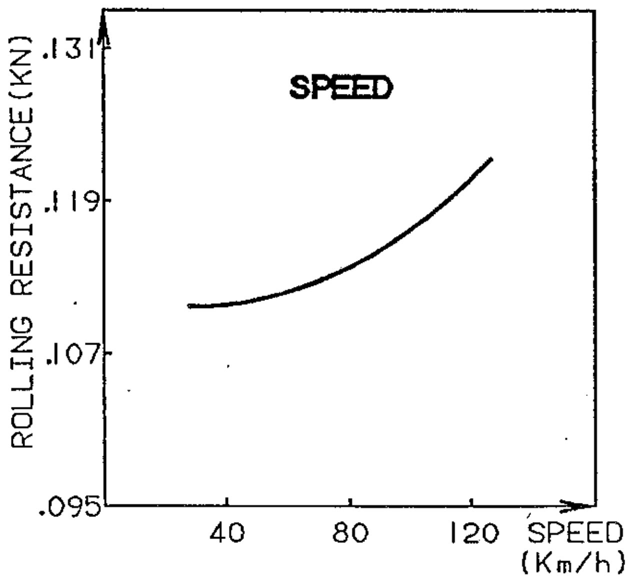


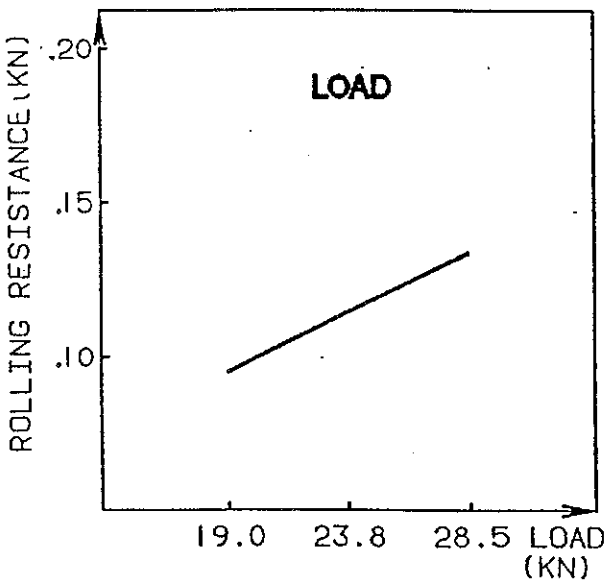
1) TREAD PLIES CONSTRUCTION.
2) TREAD DESIGN AND STOCK.
3) STUDY OF THE INSERT ELEMENTS TO OPTIMIZE THEIR HISTERESIS PERFORMANÇES.
4) CURED TIRE GAUGES OPTIMIZATION TO MINIMIZE RUNNING TEMPERATURE.

Appendix "A" (Details on Results)

RESULTS
ROLLING RESISTANCE VS SERVICE PARAMETERS
(REF. SIZE - 11 R 22.5)

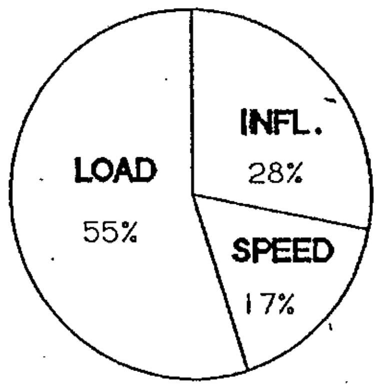






RELATIVE WEIGHT

ON ROLLING RESISTANCE



KEY POINTS:

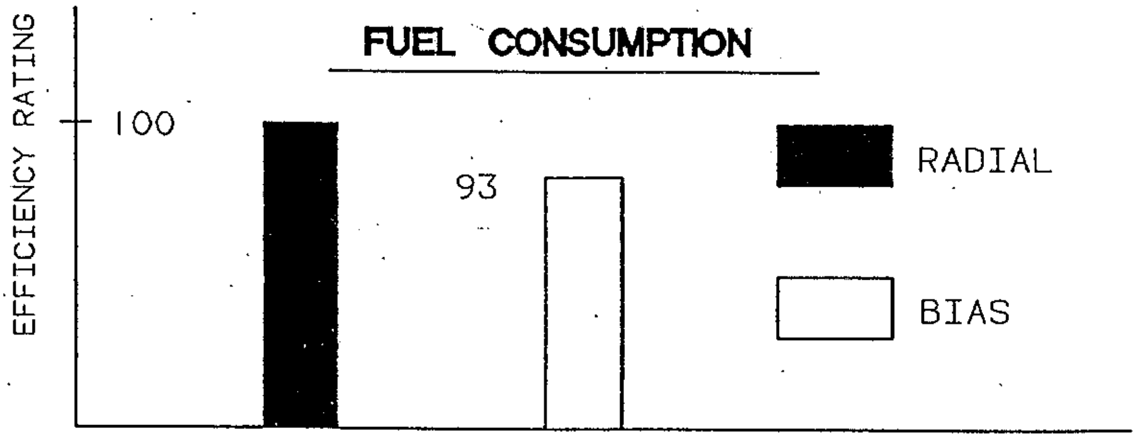
1) LOAD IS MAIN CONTRIBUTOR

2) RR CHANGE MOST SENSITIVE IN THE 80/120 KPH SPEED RANGE

Appendix "A" (cont'd)

TIRE TYPE

Radial vs Bias construction



GEOMETRY OF TIRE

a) Low aspect ratio (##) vs conventional series

(##) Nominal Aspect Ratio : One hundred times the ratio of the section height to the section width of the tire.

Ref sizes: 11R22.5 vs 295/75R22.5 at equivalent tread design and same tire construction.

Findings: no significant difference found in fuel consumption.

b) Tire flatness

Tire flatness = $\frac{\text{2 tread radius}}{\text{section witdh}}$

Ref size: 295/75R22.5 at equivalent tread design and same construction

Flatness values: 4 vs 6

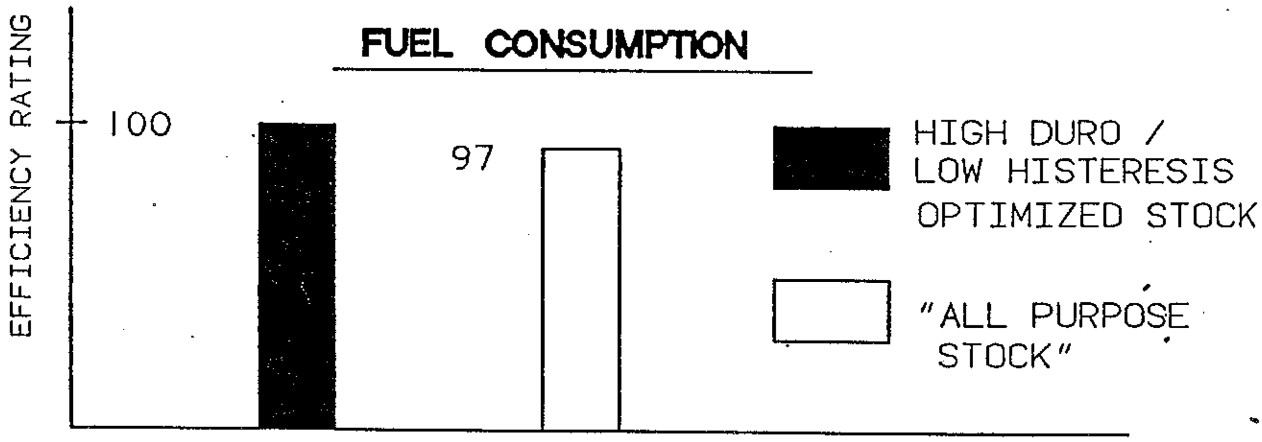
Findings: no significant difference found in fuel consumption.

Appendix "A" (cont'd)

TREAD COMPOUND

Testing involved 3 different tread stock formulae. Results confirmed that physical properties, such as higher hardness and low hysteresis, play a significant role in influencing the rolling efficiency of tires.

In our testing the optimization of the tread stock formula with respect to the above properties led to a 3% saving in fuel consumption when compared to an "all purpose" tread stock.



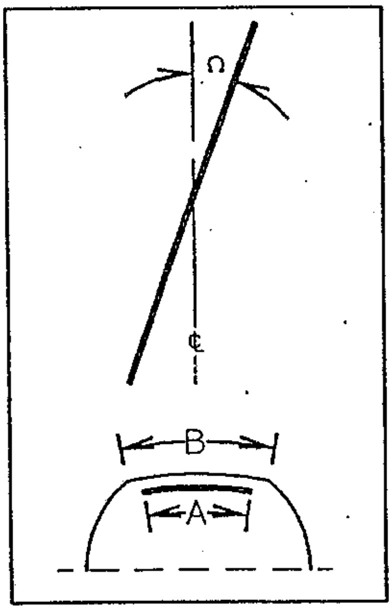
Ref size: 295/75R22.5 at equal tread design and tirè construction:

Appendix "A" (cont'd)

TIRE CONSTRUCTION

Parameters studied : 1) Body ply - (steel vs synthetic fiber)
2) Tread plies angles and lay (various)
3) Belt over arc ratio (89% vs 95%)

Definition of parameters:



Ω = Tread ply angle
Lay = Direction of TP cord (right lay in the example)
¢ = Centerline of tire (circumferential direction)

Belt over arc ratio = $\frac{A}{B} \times 100$

A = width of largest TP
B = width of tread arc

Ref size : 295/75R22.5 at equal
Tread design and tread stock compound

Results:

- The body ply and tread plies angles and lay did not show a significant influence on rolling efficiency.

- A surprising increase of 3% in fuel consumption was found when the belt/arc ratio was increased from 89 to 95% due to the higher energy necessary to deform a stiffer tread ply package.

Appendix "A" (cont'd)

TIRE TREAD DESIGN

Studies on this parameter indicated that changes in fuel consumption may be expected only in the comparison of significantly different tread design.

Tests conducted with different patterns, all belonging to the same 5 rib highway design family, showed no significant variation in fuel consumption, while in the comparison of a 3 rib vs a 5 rib highway design our tests indicated a significant improvement in rolling efficiency in favour of the 5 rib design.