## ASPECTS OF TYRE PERFORMANCE AND DESIGN.

# TYRE ROLLING RESISTANCE

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SYNOPSIS.

In the time allowed, only certain aspects can be covered. The writer has chosen to discuss Tyre Rolling Resistance and its effect on truck Fuel Consumption.

Information is given on :

- Energy consumed by the tyres.
- Rolling Resistance of a tyre and its different parameters.
- The cumulative effects on those parameters.
- Measurements and tests done by Michelin.
- Results - on test machines, on inclined ramps, and on actual road conditions.

Conclusion : Differences in rolling resistance do exist between different tyre manufacturers products.

We have to keep in mind the notion of compromise. The total performance package of a tyre is the sum of all of the different intrinsic qualities necessary for SECURITY (grip, handling, carcasse integrity), for ECONOMIC OPERATION, (tread life, rolling resistance), and COMFORT (suppleness, road noise).

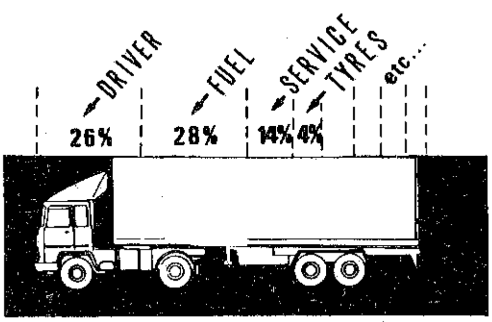
The action of optimising one or another of these parameters, will affect the total compromise and therefore, modify the total performance package.

Only by using the full range of our technical experience can we achieve the best rolling resistance whilst conserving those qualities for which Michelin are well known.

ROLLING RESISTANCE AND TRUCK FUEL CONSUMPTION.

1.0 In todays economic climate, in the same way as for all other industrial undertakings, competition forces road transport operators to reduce their financial on-costs.

For a 38 tonne GVM semi trailer, the major cost item is that of fuel, above that of labour costs.




Alone, the cost of fuel represents almost 1/3 of the total operating costs.

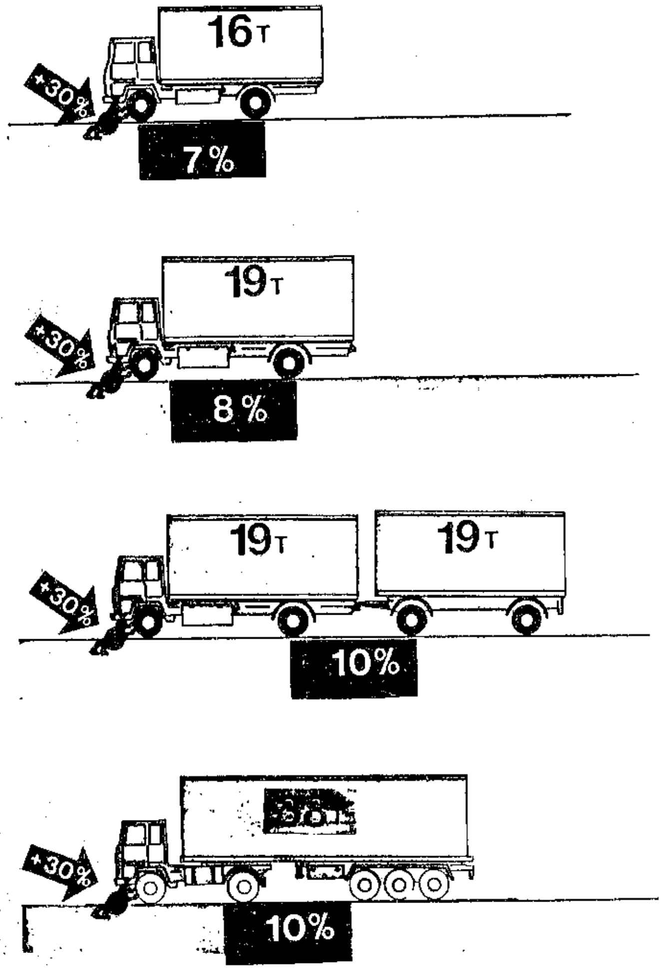
So the transport companies keep a careful eye on the different factors which affect fuel consumption.

Moreover, certain professional training organisations run courses on the art of economic driving.

The installation of some aerodynamic aids appears to be another means of conserving the expensive fuel.

Speed limits, or even more so, those economy gauges which enable the driver to hold his acceleration and or throttle opening in the most ecnomic levels, contribute also to the reduction of fuel consumption.

1.2 The rolling resistance of the tyres has a most important bearing on the consumption of fuel.




On a straight, flat road surface, at a constant 100 km/h. if the rolling resistance of the tyres, varies by 30%, the fuel consumption can vary by 7 to 10% depending upon the type of vehicle.

Note. These values are obtained in the case where the rolling resistance is at its maximum, and is so, for all tyres on the road.

It is evident of course, that in real operating conditions these figures are modified as a function of
- the vehicle (CX, Frontal area, etc.),
- the load carried (GVM),
- the driving style,
- the conditions of use,
- the type of route,
- and so on.

In these conditions, it is apparent that the choice of qualities of tyres must be made as a function of their performance in economy of energy.

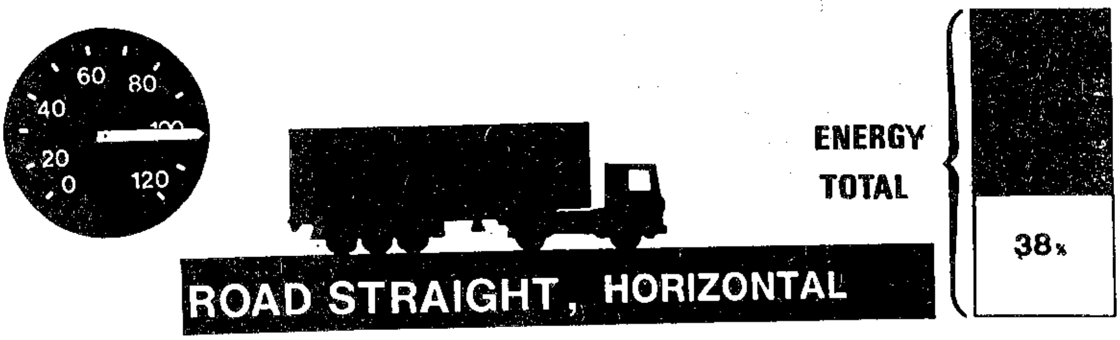
2. Energy consumed by the tyres.

2.1 In a rolling assembly, the engine must not only overcome the forces of inertia, of friction, and of aerodynamic resistance, but also of the rolling resistance of the tyres.

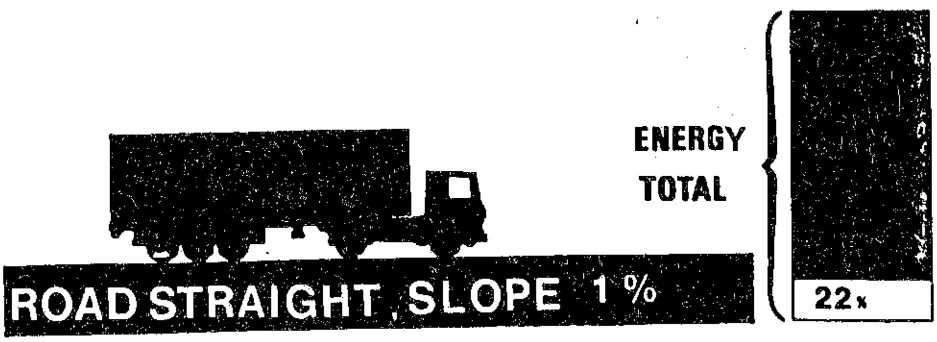
The power necessary to overcome this last is a measure of the wastefullness of the tyre.

For the articulated vehicle shown below the proportion of the energy absorbed by the tyres, represents almost half of the energy required to maintain the vehicle at a constant 80 km/h. on a flat and straight road.


In the same conditions, but at 100 km/h., the proportion due to tyre rolling resistance drops to 38%.



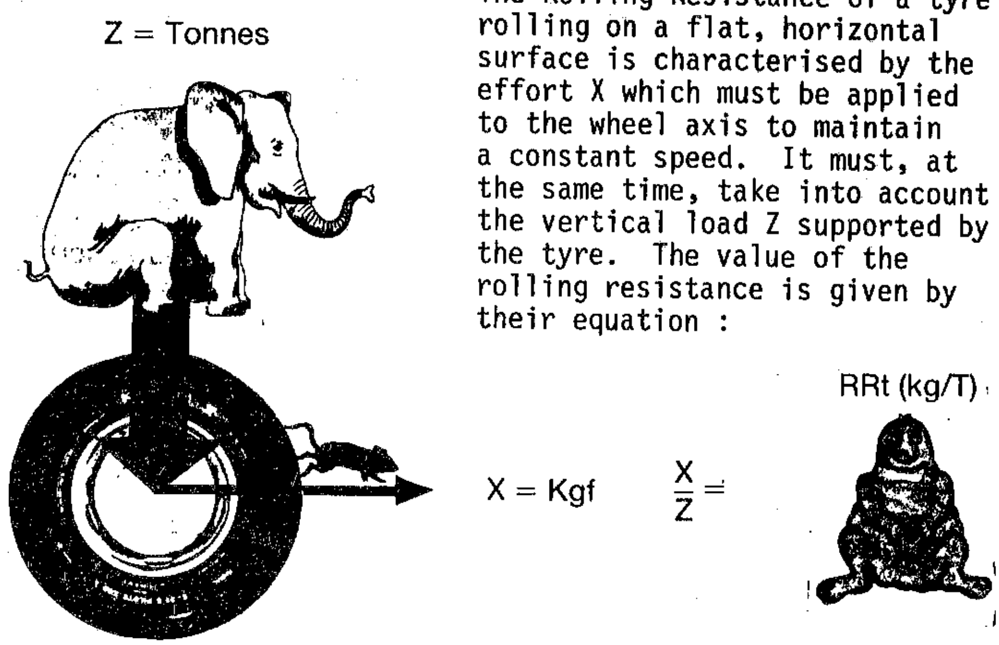

And if the vehicle is on a 1% incline, the proportion drops to 22%.



3. Rolling Resistance of a Tyre and its Factors

3.1 We are going to look now, at the definition generally agreed for rolling resistance, as well as the methods of measurement.

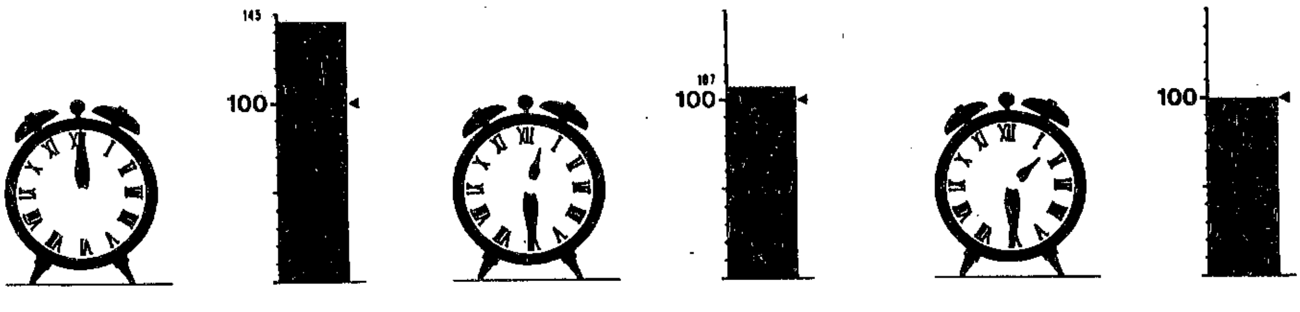
The Rolling Resistance of a tyre rolling on a flat, horizontal surface is characterised by the effort X which must be applied to the wheel axis to maintain a constant speed. It must, at the same time, take into account the vertical load Z supported by the tyre. The value of the rolling resistance is given by their equation :




The value is of the order of 5 to 7 kg. per tonne carried, for a new tyre. But this value varies as a function of the conditions under which the tyre is used.

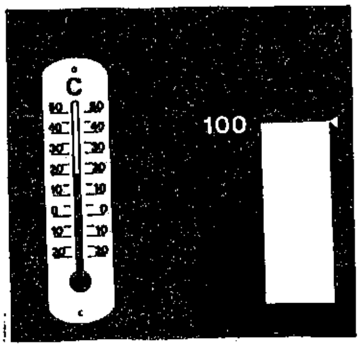
3.2 Thermal Equilibrium of the tyre.

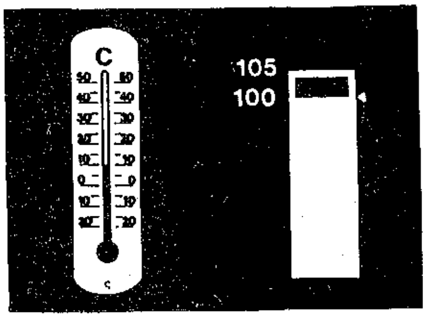
If we take as a base 100, the value of the tyre rolling resistance, in a normal operating temperature condition, the value, for the same tyre, when cold at the start of the cycle, is of the order of 145. After about 30 minutes it would be about 107 and after about 1½ hours, which is the time necessary to stabilise the temperature of a tyre, it will be 100.



3.3 Atmospheric conditions.

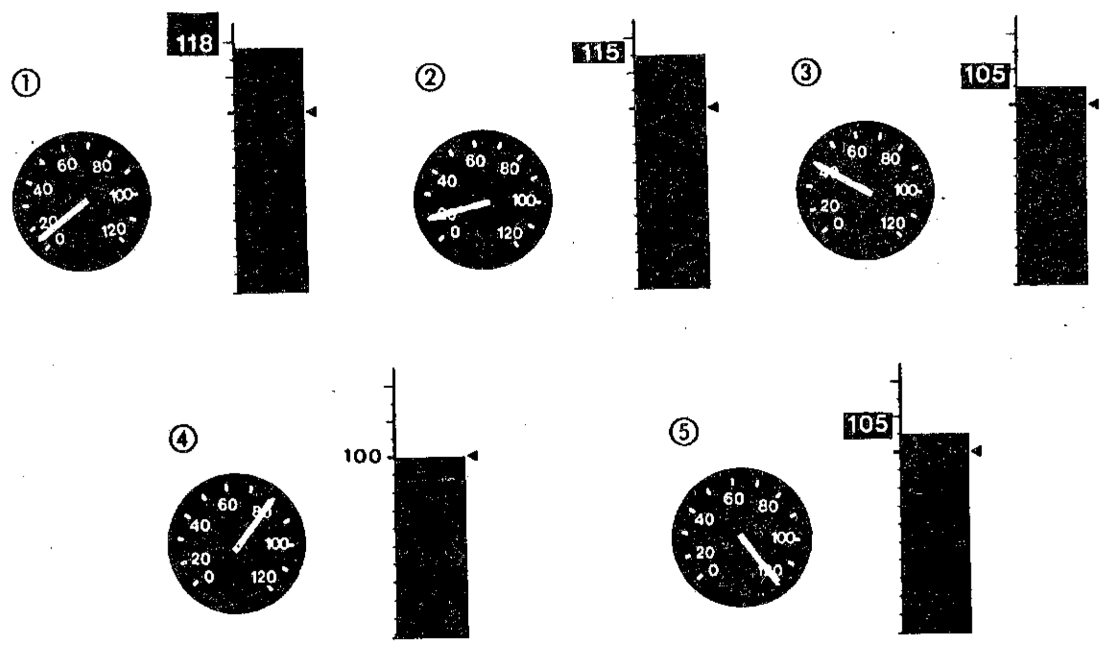
In the same way, if we consider the index 100 at an ambient temperature of 20° C, we will be at 105 if the ambient temperature drops to 10° C.



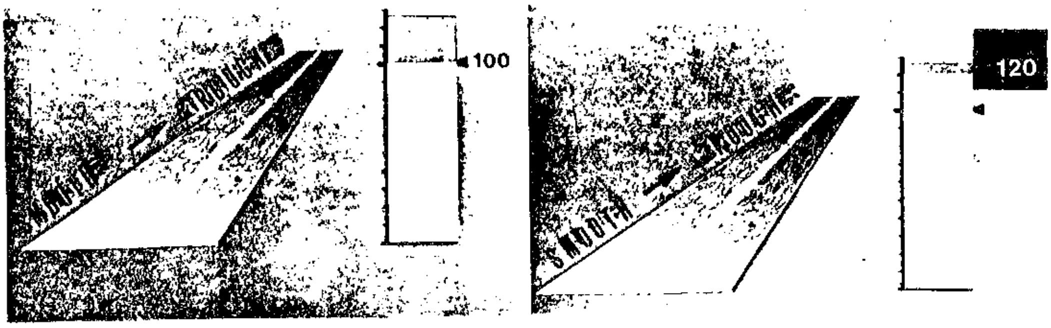

3.4 Speed.

1). At 10 km/h. the rolling resistance index is 118.
2). At 20 km/h. the index will be 115.
3). At 40 km/h. the index has reduced to 105.
4). At 80 km/h. the index has reached the optimum of 100.
5). At 120 km/h. the index has risen to 105.



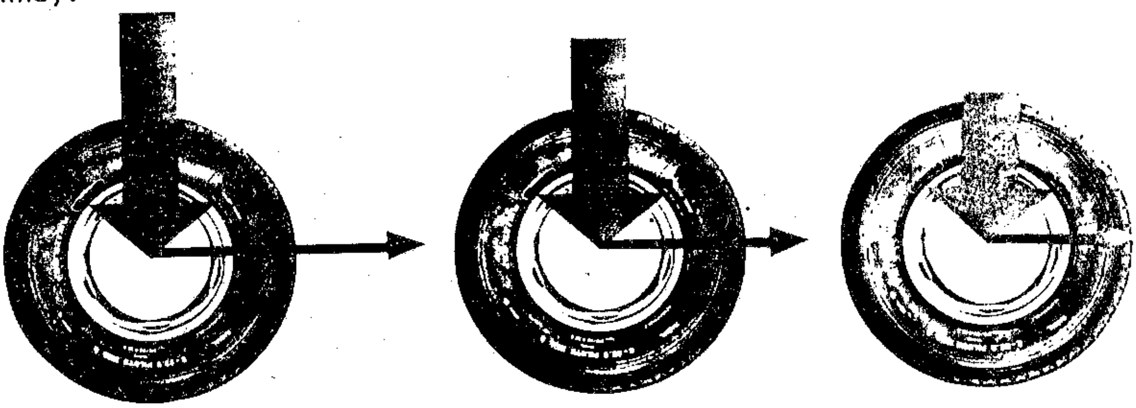
## 3.5 State of the Road Surface.

The rolling resistance index of 100 is valid for a smooth surface. A coarse surface can increase that index by 20%.



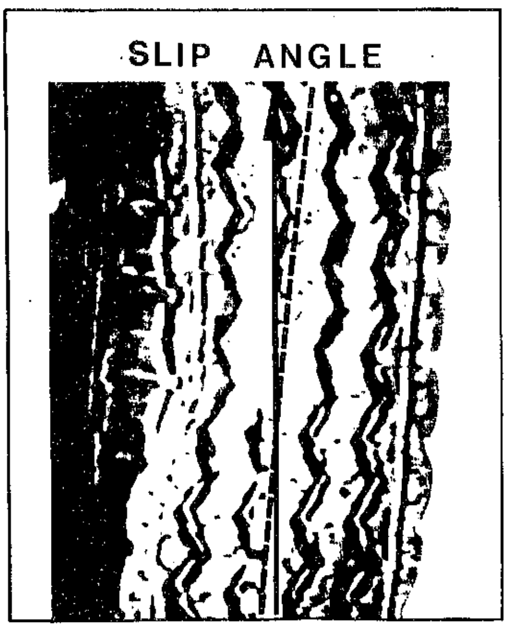

## 3.6 Load.

When the tyre carries a load around its nominal maximum the value of the rolling resistance is generally proportional to the load. This is why we express rolling resistance as a ratio of force (kgf) related to load (tonne).



As an example, the '80' series Pilote tyres have good rolling resistance levels of about 6 kgf/tonne.

## 3.7 Slip Angle.




This parameter intervenes each time a lateral force is applied to the vehicle and its tyres. It is the case, albeit briefly, when the truck overtakes another, when on heavily cambered roads, when subject to side winds, or when in corners.

When this sideforce is not too big, it does not provoke lateral skidding of the tyre relative to the road, but a deformation of the tyre which brings about a difference between the vehicle trajectory and the plane of rotation of the wheel. This is known as the slip angle.

It is apparent that the rolling resistance of a tyre, when subject to a slip angle, becomes much greater than when running straight.

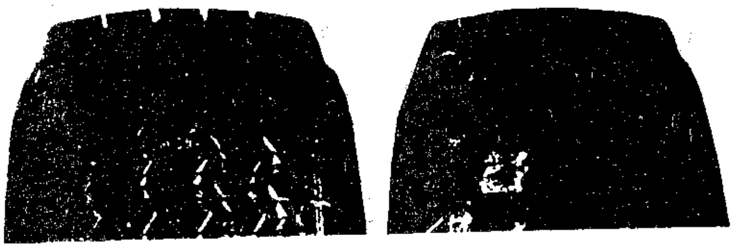
| | RRt | | RRt |
|---|---|---|---|
| 275/80 22.5 | 100 | 2° | 240 |
| 11-22.5 | 100 | 2,3° | 260 |
| 80 km/h | | | |

We can take an example of a 38 tonne GVM semi trailer running at 80 km/h. on a flat, straight road. The rolling resistance index is 100. If the same vehicle is in a curve of 225 m. radius, the mean slip angle varies according to the tyre type used, and the rolling resistance varies accordingly.

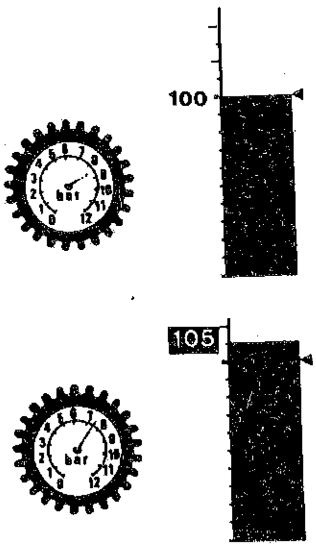
The improved road grip of the '80' series Pilote Tyres brings about a reduction in rolling resistance in a winding road operation.

## 3.8 Tyre Wear.

For a given condition of operation, and on straight roads, whilst the rolling resistance index of a new tyre is 100, it reduces to 75 when the tyre reaches 1.6 mm. remaining tread depth. Between these two extremes the resistance varies proportionately with wear.



## 3.9 Inflation Pressure.




At 80 km/h. on a flat, straight road, and at the nominally correct tyre pressure, our rolling resistance index is 100. If the pressure is reduced by 100 kPa the index increases to 105.

Even if the influence of the pressure seems small, it must be remembered that it acts at all times. However, the negative effects can be corrected by frequent pressure maintenance.

4. Combinations of these Factors.

4.1 As functions of the conditions of operation, these different factors discussed earlier can combine to significant effect.

| | 1 |
|---|---|
| LOAD | NOMINAL |
| PRESS | NOMINAL |
| SPEED | 80 Km/h |
| TEMPERATURE AMBIANT | 20° C |
| TIME | >1h30 |
| ROUTE | STRAIGHT |


As an example, let us consider a 275/80 R 22.5 XZA L146 operating at its nominal load and pressure, at the indicated conditions; the index of rolling resistance is 100.

| | 1 | 2 |
|---|---|---|
| LOAD | NOMINAL | NOMINAL |
| PRESS | NOMINAL | N – 1 b |
| SPEED | 80 Km/h | 120 Km/h |
| TEMPERATURE AMBIANT | 20° C | 10° C |
| TIME | >1h30 | 0h30' |
| ROUTE | STRAIGHT | CURVE 500m RAD. |


Now, if we reduce the pressure by 100 kPa, and increase the speed to 120 km/h. The ambient temperature reduces to 10° C, and the period of use is only 30 mins., and the vehicle is in a 500 m. radius curve, the index of rolling resistance is of the order of 300.

Thus, for a given vehicle with specified tyre equipment, the rolling resistance values can vary enormously when subjected to different operating conditions.

4.2 The effect of the rolling resistance of a tyre is meaningful, only when associated with the conditions of operation at the time of a comparison, the role of the driver, in this respect is of major importance.

The understanding of these conditions is even more important whilst there does not yet exist an international standard governing rolling resistance measurements.

In this regard, it should be noted that there is an ISO project in progress which should remedy this situation.

5. Measurements and Testing at Michelin.

5.1 The measurement of the rolling resistance of a tyre is not a problem new to Michelin, as witness a measuring machine which was in use in 1927, and which was specifically built for truck tyre tests.

Todays equipment has greatly evolved with technical progress.

5.2 The measurements and tests are conducted on two types of equipment:

- machines with test drums or flat surfaces
- on special vehicles.

We know now, that it is most important to understand in which conditions the tests are conducted.

On these extremely precise installations, meausrements are made

- of speed to $\pm$ 0.1 km/h.
- of load to $\pm$ 1%
- of inflation pressure to $\pm$ 5 kPa.

The ambient temperature is controlled to within 1° C.

This continuous surveillance of all parameters, is, moreoever, supported by a recording of all results.

A flat bed machine, equipped with a dynometer allows us to measure, directly, the rolling resistance at the wheel centre, whilst varying the conditions of a test.

The results are immediately available on a computor video display unit.

5.3 Additionally, these measurements effected on machines are supplemented by tests on actual vehicles, always under the most rigorously controlled conditions.

On road comparisons are made. They are made using two vehicles as nearly identical as possible, but with permutation of tyres and wheels, to neutralise any vehicle influences. Speed is electronically measured every ½ second and the on-board recording apparatus faithfully records all required parameters.

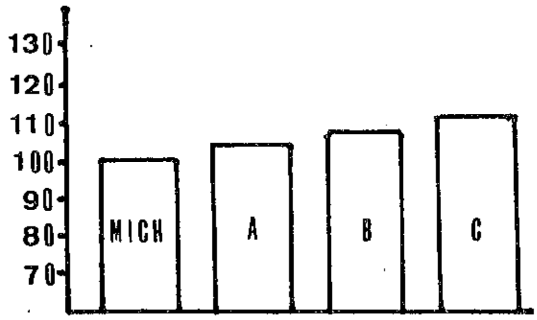
At the test site, the meterological data is recorded, allowing investigation into the effect of wind strength and direction, humidity, temperature and atmospheric pressure. These factors are transmitted telemetrically to the vehicle, on which extremely accurate flow meters are installed. Thus instantaneous "read outs" are available for all conditions encountered during the test, allowing a sensible interpretation of the results.

## 6. Results.

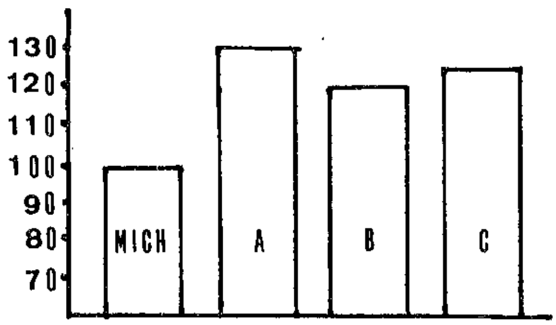
6.1 Machine tests were carried out early in 1985 using the latest tyres available from a range of suppliers around the world. The measurements were made at 70 km/h. and at the nominal loads and pressures.

To save embarassment, we will not name the other manufacturers but merely state that A, B and C are, respectively, a well known American company, a well known Japanese company and a well known European company.

The comparisons were done using specifically designated steer axle tyres on steering axles and trailers, and specifically designated drive axle tyres on drive axles. One further difference is that the Michelin dimension shown is 275/80 R 22.5 L146 whereas the competitor brands were in 11 R 22.5 PR16.




Steer axle tyres Michelin XZA Pilote = 100 (Also used on semi trailer bogie)




Drive Axle tyres Michelin XZT Pilote = 100.

## 6.2 Comparisons on inclined plane.

To visualise the effect of rolling resistance measured on machines, we have compared the distances covered by a vehicle rolling down a ramp and coasting to stop on a flat surface. The comparisons were done by changing <u>only</u> the 4 tyres equipping the drive axle.

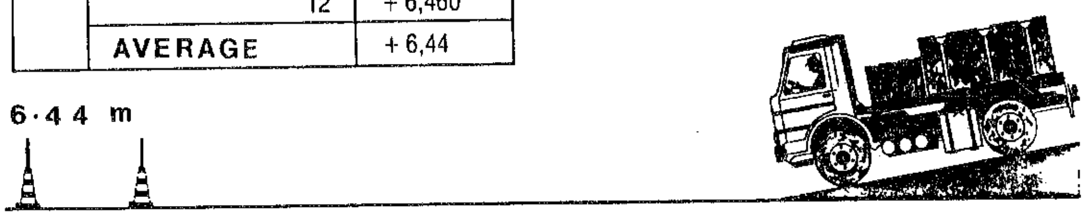
The vehicle was a rigid two axle fully loaded to the nominal tyre load capacity, with tyres inflated to the level consistent with the load. In this case the two fitments were both Michelin XZT tyres, however one set was retreaded with a well known precured retreading system with a pattern virtually identical to the XZT.

The results measured in terms of additional distance covered by the new Michelin XZT are below.

| MICH.XZA – RECAP ZA | | | = DIST. |
|---|---|---|---|
| | 6/02/85 | nº 1 | + 6,710 m |
| | | 2 | + 6,820 |
| | | 3 | + 6,420 |
| | | 4 | + 6,980 |
| | | 5 | + 6,650 |
| | | 6 | + 6,125 |
| | 7/02/85 | nº 7 | + 6,190 |
| | | 8 | + 6,130 |
| | | 9 | + 6,130 |
| | | 10 | + 6,200 |
| | | 11 | + 6,430 |
| | | 12 | + 6,460 |
| | AVERAGE | | + 6,44 |

| RESULT ON MACHINE | |
|---|---|
| MICHELINXZT | RECAP ZT |
| 100 | 118 |

The reduced rolling resistance measured on the machine test (-18%) of the new tyre allows a significant further distance to be covered with the kinetic energy derived from the ramp.




On a straight flat road, after 1H 30 min. of running,the vehicle equipped with retreads would use some 3% more fuel when compared to a vehicle using new tyres.

This point is made not to argue against retreading, but to reinforce the notion,that only results obtained with different tyres when in the same condition, are comparable.

## 6.3 Results in Actual operating conditions.

It is evident that the reduced rolling resistance of which we have spoken, must translate into actual fuel economy. It is this actual saving which we have demonstrated by actual road experience.

In the test detailed below two inter factory transport vehicles were used at identical load conditions. On each successive day the tyre equipment on the drive axle alone was interchanged from one vehicle to the other. The drive axle tyres used were Michelin 80 Series Pilote XZT and a well known American brand specifically aimed at drive axle use.

The results obtained are tabulated below :

| | MICHELIN XZT | | BRAND A | | ADVAN. MICHELIN | |
|---|---|---|---|---|---|---|
| Date | SPEED km/h | FUEL CON Lt/100 km | SPEED km/h | FUEL CON LT/100 km | L1 | %/100 |
| 26/1/85 | 69,84 | 48,42 | 70,80 | 49,62 | + 1,2 l | + 2,47 % |
| 4/2/85 | 67,84 | 47,89 | 65,75 | 48,99 | +1,1 l | + 2,27 % |
| 6/2/85 | 65,79 | 47,52 | 66,63 | 49,35 | + 1,83 l | + 3,85 % |
| | 66,70 | 45,46 | 66,80 | 48,11 | + 2,65 l | + 5,82 % |
| 7/2/85 | 67,53 | 47,10 | 67,75 | 48,39 | + 1,29 l | + 2,73 % |
| 8/2/85 | 65,27 | 48,58 | 65,51 | 47,57 | − 1,01 l | − 2,12 % |
| AVG. MEAS. | 67,16 | 47,49 | 67,20 | 48,67 | + 1,18 l | + 2,48 % |
| | MEAN DIFF. | | | | | + 2,3 % |

The other important point to be raised in these tests, apart from the average fuel consumption advantage derived from the use of 80 series Pilote tyres, is that a wide spread of results was obtained, from day to day. Whilst the calculated average shows a certain affinity with the bulk of the individual results, it is clear that actual on road tests, in working conditions are valid only if done over a period, with frequent interchange of control and test tyres.

To make a judgement only on test day 4 or 6 would be to vastly exagerate the result, or in fact to reverse the trend!

7.
Conclusion : Differences in rolling resistance do exist between different tyre manufacturers products.

We have to keep in mind the notion of compromise. The total performance package of a tyre is the sum of all of the different intrinsic qualities necessary for SECURITY (grip, handling, carcasse integrity), for ECONOMIC OPERATION, (tread life, rolling resistance), and COMFORT (suppleness, road noise).

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