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Technical Report

Comparison of Hot to Cold Tire Fuel Economy

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by

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NOTICE

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I. Introduction

As part of a comprehensive tire rolling resistance measurement program, a tire study was conducted to determine the effect of tire warm-up on fuel economy. The study was conducted on 33 different sets of tires at ambient temperature (approximately 75°F). Each set of tires was installed on the rear two wheels of a fully warmed-up vehicle. The vehicle was then driven over an FTP driving schedule on a single large-roll dynamometer and the emissions and fuel economy values were determined for each phase of the schedule (see Appendix B for explanation of the FTP).

In this report, the fuel economy changes due to tire warm-up are summarized and analyzed. In addition, the effect of tire type, size and manufacturer on the fuel economy values are investigated. Finally, the effect of tire warm-up on tire rolling resistance is discussed.

II. Program Design

Two vehicles were utilized during this study, a 1971 Ford stationwagon and a 1971 Vega stationwagon. Tires with nominal size of 14 and 15 inches were mounted on the Ford for test and those with a nominal size of 13 inches were mounted on the Vega. A description of the tires can be found in Table A-1 of Appendix A. For the purposes of this report when the tires were at ambient temperature, they will be referred to as cold tires.

Each test was conducted on a single large-roll (48 inch diameter) dynamometer with the power absorption torque set to duplicate Clayton dynamometer power absorption torques at 50 mph. Only the dynamometer's intrinsic inertia (approximately 1800 pounds) was used. Since the inertia weight was low and held constant for both vehicles, and since fuel economy is highly dependent on inertia weight during vehicle operation over the FTP, we then expect the fuel economy changes found in this study to be larger than they would be under typical test conditions.

The FTP driving schedule used as the test procedure was convenient for measuring tire warm-up effect on fuel economy. There are three phases in the procedure: a cold transient (505 seconds), a stabilized phase (872 seconds), and a hot transient phase (505 seconds). The cold and hot transient phases follow the same speed-time driving schedule, therefore, the tire warm-up effect on fuel economy was determined by comparing the fuel economy values obtained during these two phases.

Prior to testing, the vehicle was run for 30 minutes at 50 mph to achieve a fully warmed-up state. This procedure eliminated the effect of vehicle warm-up on the fuel economy determinations, so that any change in the fuel economy values between the cold and hot phases of the FTP driving schedule should be due to tire warm-up only.

Upon completion of the warm-up, the set of driving tires was then removed and another set of tires at ambient temperature was installed. An FTP driving schedule was then conducted and the vehicle emissions were collected using the Constant Volume Sampler (CVS). The fuel economy values during each phase were then determined from the vehicle's emissions according to the carbon balance method. Repeated tests were conducted on most of the tires only after allowing the set of tires to cool down to room temperature. Therefore, a total of 66 tests were run. Driver variability was minimized by having the same driver conduct the majority of the tests.

III. Analysis

A. Percent Fuel Economy Improvement of Hot Tires

The percent fuel economy improvement of hot tires over cold tires was calculated as follows:

$$\left(\frac{\text{Hot Transient F.E.} - \text{Cold Transient F.E.}}{\text{Cold Transient F.E.}}\right) \text{X } 100$$

The average percent improvement for all 66 tests was 5.4%. Analyses of variance were conducted on the percent fuel economy improvement to determine the effect of tire type, size and manufacturer. No significant differences were found due to any of these factors.

This improvement in fuel economy due to warm-up indicates a consistent decrease in rolling resistance also due to the warm-up effect. A tire rolling resistance study conducted at the EPA laboratories concluded that a 10 percent change in rolling resistance will yield a 2 percent change in the vehicle fuel economy on the road. 2/ Since the change in fuel economy observed on the dynamometer is only due to the rear tire warm-up characteristics, the expected fuel economy improvement on the road would be twice the dynamometer effect (i.e, 10.8%). Based on the conclusions of the above EPA report, a rough estimate of the change in tire rolling resistance during an FTP driven on the road is 50%. It should be noted however that the lack of inertia simulation during the dynamometer testing may over estimate the fuel economy improvement due to tire warm-up characteristics. By increasing the inertia simulation on the dynamometer and therefore the amount of power being transmitted through the tire, the temperature changes within the tire would occur more rapidly, reducing the difference in fuel economy from the cold to hot transient phases of the FTP. A study investigating the effects of tire warm-up on fuel economy incorporating representative inertia simulation is currently underway.

A test program similar to the cold to hot tire test program was conducted using two sets of elliptical tires at an inflation pressure of 35 PSI and two sets of "equivalent" standard radial tires inflated at 24 PSI. The elliptical tire manufacturer claims that these tires at 35 PSI are the "equivalent" to radial tires at 24 PSI with respect to ride and handling. 3/ The test procedure followed and the equipment used were identical to those described in the previous section. In this study each set of tires was tested three times and the percent fuel economy improvement of hot vs. cold tires was calculated for each test. The means of the three measurements for each set of tires are presented in Table 1.

Table 1

Average Fuel Economy Values for Standard Radial and Elliptical Tires

Tire ID	Tire Manufacturer	Tire Type	Hot Transient F.E. (mpg)	Cold Transient F.E. (mpg)	% F.E. Improvement
26	Uniroyal	Radial	16.5	15.7	5.1%
27	Firestone	Radial	16.4	15.7	4.5
51	Goodyear	Elliptical	16.9	16.4	3.0
52	Goodyear	Elliptical	16.8	16.4	2.4

It is clear from the table that elliptical tires provide higher fuel economy values than standard radial tires. Note that their improvement in fuel economy from cold to hot is not as large as the improvement for radial tires. The weighted city fuel economy value for the vehicle when mounted with elliptical tires was 14.3 mpg and 14.0 mpg when mounted with standard radial tires, a 2.1% improvement. It is not known if the control radial tires would have these same characteristics of lower fuel economy improvement and stabilization with respect to temperature if they were tested at the inflation pressure of 35 PSI, although a trend in that direction would be expected.

B. Analysis of Fuel Economy Values

The fuel economy values obtained during the hot and cold transient phases were analyzed with respect to tire type, size and manufacturer to investigate if any of these factors had a significant effect on the fuel economy values. Vehicle effect was eliminated in the study through the use of only one vehicle for testing 14 and 15 inch tires and one vehicle for testing 13 inch tires. The analysis that follows does not include the results of the elliptical tire study.

The tire type analysis revealed that radial tires had the highest average cold transient fuel economy values within every tire size grouping. They also had the highest average hot transient fuel economy values within every tire size grouping except for 13 inch tires. These values are shown in Table 2. The differences between the tire type means were found to be statistically significant within the groupings of 14 inch and combination of 14 and 15 inch tires only. This difference was due primarily to the high fuel economy values for the vehicle when equipped with radial tires. The fuel economy values for each tire type were compared even more specifically by breaking down the groupings by both tire size and manufacturer. In 71% of these groupings, radial tires had a fuel economy value larger than the values for bias belted and bias ply tires. Therefore, the data does reveal an effect on fuel economy due to tire type.

Table 2

Average Fuel Economy Values by
Tire Type and Tire Size Grouping

	Cold Transient			Hot Transient		
Tire Size	Radial	Bias Belted	Bias Ply	Radial	Bias Belted	Bias Ply
13 inches*	37.03	36.83	35.74	38.59	38.90	37.88
14 inches	15.31	15.05	---	16.17	15.95	---
15 inches	15.88	15.60	15.67	16.75	16.70	16.43
14-15 inches	15.73	15.13	15.67	16.60	16.06	16.43

*13 inch tires were used on the Vega only.

Note in Table 2 that when 15 inch tires were mounted on the test vehicle, it obtained higher fuel economy values than when 14 inch tires were mounted. Analyses of variance showed that this difference is statistically significant for radial tires during both the cold and hot transient phases. Therefore, there appears to be an effect of increasing fuel economy with increase in tire size from 14 inches to 15 inches.

Analyses of variance were conducted to compare the manufacturers' fuel economy means, however, no significant differences nor trends were found.

The tire type and tire size results are consistent with the EPA tire rolling resistance study mentioned earlier in the report. In that study, radial tires were found to have significantly lower rolling resistance coefficients than bias tires. Another conclusion of that study was that for each tire type, the means of the rolling resistance coefficients decrease with an increase in the tire size. Since a reduction in rolling resistance coefficients corresponds to an increase in fuel economy, the results of both studies appear to be in agreement. It should be noted that the fuel economy effect observed in this study may be due to the change in N/V ratio when changing from 14" to 15" tires.

IV. Conclusions/Recommendations

The conclusions of this study are:

1. The average percent fuel economy improvement of hot tires over tires at ambient temperature is approximately 5%. It was found that this improvement does not change with respect to tire type, size, or manufacturer. This 5% improvement in fuel economy on the dynamometer corresponds roughly to a 50% decrease in tire rolling resistance on the road.

2. The average percent fuel economy improvement of hot over cold elliptical tires at the inflation pressure of 35 PSI is significantly less than that of standard radial tires at 24 PSI. These percentages were approximately 2.5% and 4.5% respectively. It is not yet known if the lower percent fuel economy improvement for elliptical tires is due to lower rolling resistance materials or just the higher inflation pressure.

3. Vehicles with elliptical tires at the inflation pressure of 35 PSI were found to obtain better fuel economy than vehicles with standard radial tires at 24 PSI. In this limited experiment the improvement was found to be approximately 2% when comparing the weighted city fuel economy figures. It is not yet known whether the standard radials would achieve the higher fuel economy values of the elliptical tires if they were also inflated to 35 PSI, however, a trend in that direction would be expected.

4. Vehicles equipped with radial tires obtain better fuel economy than vehicles with bias belted and bias ply tires. Those with 15 inch tires appear to achieve better fuel economy than those vehicles with 14 inch tires, however this effect may be caused by a change in the N/V ratio for the particular vehicle used in this experiment.

The above results indicate a consistent percent change in fuel economy, and therefore in tire rolling resistance during an FTP regardless of tire type and size (a lesser effect was observed for elliptical tires). Since a single large-roll dynamometer was used for this program, it can be assumed that if an FTP were driven on the road with the vehicle and tires under the same conditions similar results would be obtained. However, it is a well known fact that behavior of tires on the Clayton dynamometer is not the same as on the road or on the single large-roll dynamometer. Since the twin small-roll dynamometer requires the tire to absorb nearly twice the power they would on the road, the fuel economy effect due to tire warm-up characteristics is small. This fact could partially explain the current "EPA versus consumer" fuel economy discrepancy. The consumer typically uses a vehicle for short trips so that the tire never reaches an equilibrium temperature. Therefore, the consumer rarely benefits from the lower rolling resistance caused by increased temperatures.

References

1. "Control of Air Pollution from New Motor Vehicles and New Motor Vehicle Engines," Federal Register, Vol. 42, No. 124, Tuesday, June 28, 1977.

2. Thompson, Glenn D. and Torres, Myriam, "Variations in Tire Rolling Resistance," EPA Technical Support Report for Regulatory Action, October 1977.

3. Eagleburger, John, Manager of Technical Coordination, Product Quality and Safety, Goodyear Tire and Rubber Company, Telephone conversation, January 1978.

Appendix A

Tire Description and Fuel Economy Data

Table A-1

Tire Descriptions

Identification Number	Manufacturer	Size	Model/Type
010	Goodyear	BR70X13	Polyglass Radial WT
020	Goodyear	BR78X13	Polyglass Radial
050	Goodyear	HR70X14	Polyglass Radial WT
060	Goodyear	H78X15	Custom Power Cushion Polyglass
070	Goodyear	HR78X15	Polyglass Radial
080	Goodyear	HR70X15	Polyglass Radial WT
090	Goodyear	HR78X15	Custom Polysteel Radial
100	Goodyear	B78X13	Cushion Belt Polyglass
110	Goodyear	H78X14	Polyglass Cushion Bias Belted
12A	B. F. Goodrich	HR78X15	Silvertown Steel Radial
12B	B. F. Goodrich	HR78X15	Silvertown Steel Radial
13B	B. F. Goodrich	H78X15	Custom Long Miler
180	Firestone	GR78X15	Steel Belted Radial
200	Goodyear	HR78X15	Custom Tread Steel Belted Radial
210	Uniroyal	GR78X15	Steel Belted Radial PR6
220	Goodyear	GR78X15	Custom Tread Steel Belted Radial
230	General	GR78X15	Dual Steel II Radial
240	Uniroyal	LR78X15	Steel Belted Radial PR6
250	Goodyear	ER78X14	Custom Tread Steel Belted Radial
260	Uniroyal	FR78X14	Steel Belted Radial
270	Firestone	FR78X14	Steel Belted Radial
290	Firestone	HR78X15	Steel Belted Radial
300	Uniroyal	ER78X14	Steel Belted Radial
320	Goodyear	E78X14	Custom Power Cushion Polyglass
340	Firestone	E78X14	Sup-R-Belted Deluxe Champion
350	Uniroyal	B78X13	Fastrak Belted
360	Goodyear	BR78X13	Steel Belted Radial
370	Firestone	BR78X13	Steel Belted Radial
380	Uniroyal	BR78X13	Steel Belted Radial
390	Firestone	B78X13	Deluxe Champion
400	Uniroyal	HR78X15	Steel Belted Radial
410	B. F. Goodrich	B78X13	Silvertown Bias Ply
420	B. F. Goodrich	GR78X15	Lifesaver 78 Steel Belted Radial

Table A-2 -- Continued

Tire ID	Tire Mfg.	Tire Type	Tire Size	Cold Trans (MPG)	Hot Trans (MPG)	% F.E. Imp.
250	Goodyear	Radial	14	15.3	16.2	5.9
110	Goodyear	Bias Belted	14	15.4	16.3	5.8
320	Goodyear	Bias Belted	14	15.3	16.1	5.2
300	Uniroyal	Radial	14	15.3	16.2	5.9
270	Firestone	Radial	14	15.4	16.3	5.8
340	Firestone	Bias Belted	14	14.8	15.6	5.4
010	Goodyear	Radial	13	41.1	43.9	6.8
100	Goodyear	Bias Belted	13	36.8	39.1	6.3
100	Goodyear	Bias Belted	13	36.5	38.7	6.0
350	Uniroyal	Bias Ply	13	37.2	39.2	5.4
410	Goodrich	Bias Ply	13	34.2	36.8	7.6
380	Uniroyal	Radial	13	36.2	37.9	4.7
360	Goodyear	Radial	13	36.7	38.5	4.9
370	Firestone	Radial	13	36.1	38.0	5.3
020	Goodyear	Radial	13	37.5	38.4	2.4
390	Firestone	Bias Ply	13	35.0	37.4	6.9
360	Goodyear	Radial	13	36.4	37.8	3.8
370	Firestone	Radial	13	37.0	37.1	0.3
010	Goodyear	Radial	13	35.7	37.4	4.8
380	Uniroyal	Radial	13	36.6	38.1	4.1
410	Goodrich	Bias Ply	13	36.2	37.9	4.7
100	Goodyear	Bias Belted	13	37.8	39.3	4.0
350	Uniroyal	Bias Belted	13	36.2	38.5	6.4
390	Firestone	Bias Ply	13	36.1	38.1	5.5
020	Goodyear	Radial	13	37.0	38.8	4.9

Table A-2

Tire Fuel Economy Data

Tire ID	Tire Mfg.	Tire Type	Tire Size	Cold Trans (MPG)	Hot Trans (MPG)	% F.E. Imp.
12B	Goodrich	Radial	15	15.8	16.7	5.7
210	Uniroyal	Radial	15	15.8	16.5	4.4
180	Firestone	Radial	15	16.2	16.6	2.5
220	Goodyear	Radial	15	15.8	16.7	5.7
200	Goodyear	Radial	15	16.1	16.8	4.3
060	Goodyear	Bias Ply	15	16.0	16.6	3.8
13B	Goodrich	Bias Ply	15	15.4	16.5	7.1
290	Firestone	Radial	15	15.7	16.6	5.7
230	General	Radial	15	15.8	16.4	3.8
110	Goodyear	Bias Belted	14	15.3	16.2	5.9
12A	Goodrich	Radial	15	15.8	16.4	3.8
420	Goodrich	Radial	15	15.9	16.4	3.1
400	Uniroyal	Radial	15	16.5	17.0	3.0
080	Goodyear	Radial	15	16.0	16.7	4.4
070	Goodyear	Radial	15	16.0	16.8	5.0
240	Uniroyal	Radial	15	16.2	17.0	4.9
090	Goodyear	Radial	15	16.0	16.9	5.6
210	Uniroyal	Radial	15	15.5	16.4	5.8
13B	Goodrich	Bias Ply	15	15.6	16.2	3.8
200	Goodyear	Radial	15	16.0	16.7	4.4
060	Goodyear	Bias Belted	15	15.6	16.7	7.1
250	Goodyear	Radial	14	15.1	15.7	4.0
300	Uniroyal	Radial	14	15.2	15.9	4.6
260	Uniroyal	Radial	14	15.2	16.3	7.2
270	Firestone	Radial	14	15.5	16.3	5.2
320	Goodyear	Bias Belted	14	14.9	15.9	6.7
050	Goodyear	Radial	14	15.4	16.4	6.5
340	Firestone	Bias Belted	14	14.6	15.6	6.8
230	General	Radial	15	15.7	16.7	6.4
180	Firestone	Radial	15	15.5	16.6	7.1
220	Goodyear	Radial	15	16.1	16.9	5.0
12B	Goodrich	Radial	15	15.7	16.9	7.6
12A	Goodrich	Radial	15	16.2	17.0	4.9
240	Uniroyal	Radial	15	16.1	17.3	7.5
070	Goodyear	Radial	15	15.9	17.1	7.5
420	Goodrich	Radial	15	15.5	16.7	7.7
400	Uniroyal	Radial	15	15.8	17.1	8.2
290	Firestone	Radial	15	15.7	16.9	7.6
080	Goodyear	Radial	15	15.5	16.5	6.5
050	Goodyear	Radial	14	15.3	16.3	6.5
260	Uniroyal	Radial	14	15.4	16.1	4.5