SDSB 79-13

Technical Report

Fuel Economy Effects of Tires

by

Glenn Thompson

February 1979

NOTICE

Technical Reports do not necessarily represent final EPA decisions or positions. They are intended to present technical analysis of issues using data which are currently available. The purpose in the release of such reports is to facilitate the exchange of technical information and to inform the public of technical developments which may form the basis for a final EPA decision, position or regulatory action.

Standards Development and Support Branch
Emission Control Technology Division
Office of Mobile Source Air Pollution Control
Office of Air, Noise and Radiation
U.S. Environmental Protection Agency

I. Introduction

Tires have a very significant effect on the fuel economy of a vehicle. The best known example of this is the fuel efficiency of radial tires, however, other tire technologies and related factors can also be important. This report discusses the effects of various types of tires and tire related parameters on the fuel economy of a vehicle.

II. General Discussion of the Effects of Tires on Vehicle Fuel Economy

This section presents a general discussion of the fuel economy effects of tires, the subsequent sections provide more specific discussion of the fuel economy effects of various tire technologies.

Tires affect the fuel economy of a vehicle by their effect on the force, and hence the work, required from the engine to propel the vehicle. When the vehicle is operated on a level road the majority of the energy leaving the engine is dissipated in the vehicle tires or in overcoming the aerodynamic drag of the vehicle. Figure 1 shows typical force versus speed requirements for a vehicle.(1)

The tire dissipative forces are approximately constant with speed within the nominal operating speed range, however, they rapidly increase near the maximum design speed of the tire. The aerodynamic drag forces increase as the square of the velocity of the vehicle and consequently predominate at high speeds. The drive train losses are approximately linear with speed and are generally small compared with either the tire losses or the aerodynamic drag.

Figure 1 indicates that the tire energy dissipation is the major engine power requirement below approximately 40 mph. Because a significant portion of all U.S. driving occurs at speeds below 40 mph, and most of the urban driving is in this speed range, the tire has a very significant effect on the fuel economy of a vehicle.

The previous analysis only considered steady-speed operation of the vehicle, under more typical, cyclical, vehicle-use conditions the inertia effects of the vehicle somewhat diminish the tire effects. The EPA emissions and fuel economy driving cycles are representative of typical urban and highway vehicle use. Consequently, the fuel economy effects of vehicle tires over these cycles can be used to predict the fuel economy effects of tires in typical use. The following sections discuss the specific fuel economy effects of various tire technologies over the EPA driving cycles.

III. Radial Versus Bias Tire Constructions

EPA has empirically investigated the fuel economy effects of radial versus bias and bias-belted tires over the EPA driving cycles.(2) The results of this investigation demonstrated that, on the average, radial tires improved vehicle fuel economy by 5 percent. This result is consistent with other reported data obtained under similar test conditions.(3)

Currently about 70 percent of the new vehicles sold are equipped with radial tires; however, only about 40 percent of the tires sold for replacement are radials.(4) These data indicate that there is some consumer transition from OEM radial tires to non-radial replacement tires. Reasonable life expectancies for tires are about 33,000 miles for radials, 25,000 miles for bias-belted and 18,000 miles for bias-ply tires. Therefore, the vehicle which is always equipped with radial tires will require approximately three sets of tires, the OEM set and two replacement sets to reach a reasonable vehicle life expectancy of 100,000 miles. The vehicle which is always equipped with non-radial tires will require the OEM set and approximately four replacement sets to reach its 100,000-mile distance. If, after the OEM radials are worn, the consumer chooses to replace these tires with non-radials, approximately 3 sets of replacement tires will be required to complete the life expectancy of the vehicle. Using the above replacement assumptions, the anticipated percentage of aftermarket sales which are radial tires will match the observed percentage of sales if approximately 15 percent of the OEM radials are replaced with non-radial aftermarket tires.

Using the previous tire sales data, the tire life expectancies and the estimated 15 percent aftermarket transitions from radial to non-radial, it can be calculated that approximately 60 percent of the U.S. mileage is being driven on radial tires. If the remaining 40 percent were also driven on radial tires the current U.S. fuel consumption would be decreased by 2 percent.

While consistent selection of radial tires would significantly improve the national average fuel consumption, an individual consumer selecting a single set of tires may not incur this benefit. The EPA study which reported an average fuel economy improvement of 5 percent with radial tires also reported an average energy dissipation difference of 25 percent between radial and non-radial tires. However, energy dissipation variations were observed among tires of each generic class. In fact, the observed variation between the "worst case" and the "best" radials was as large as the difference between the mean of the radials and the mean of the non-radials. Unfortunately at the present time, there is no method to accurately predict a low rolling resistance tire. In addition, tires are not consistently tested or graded so that

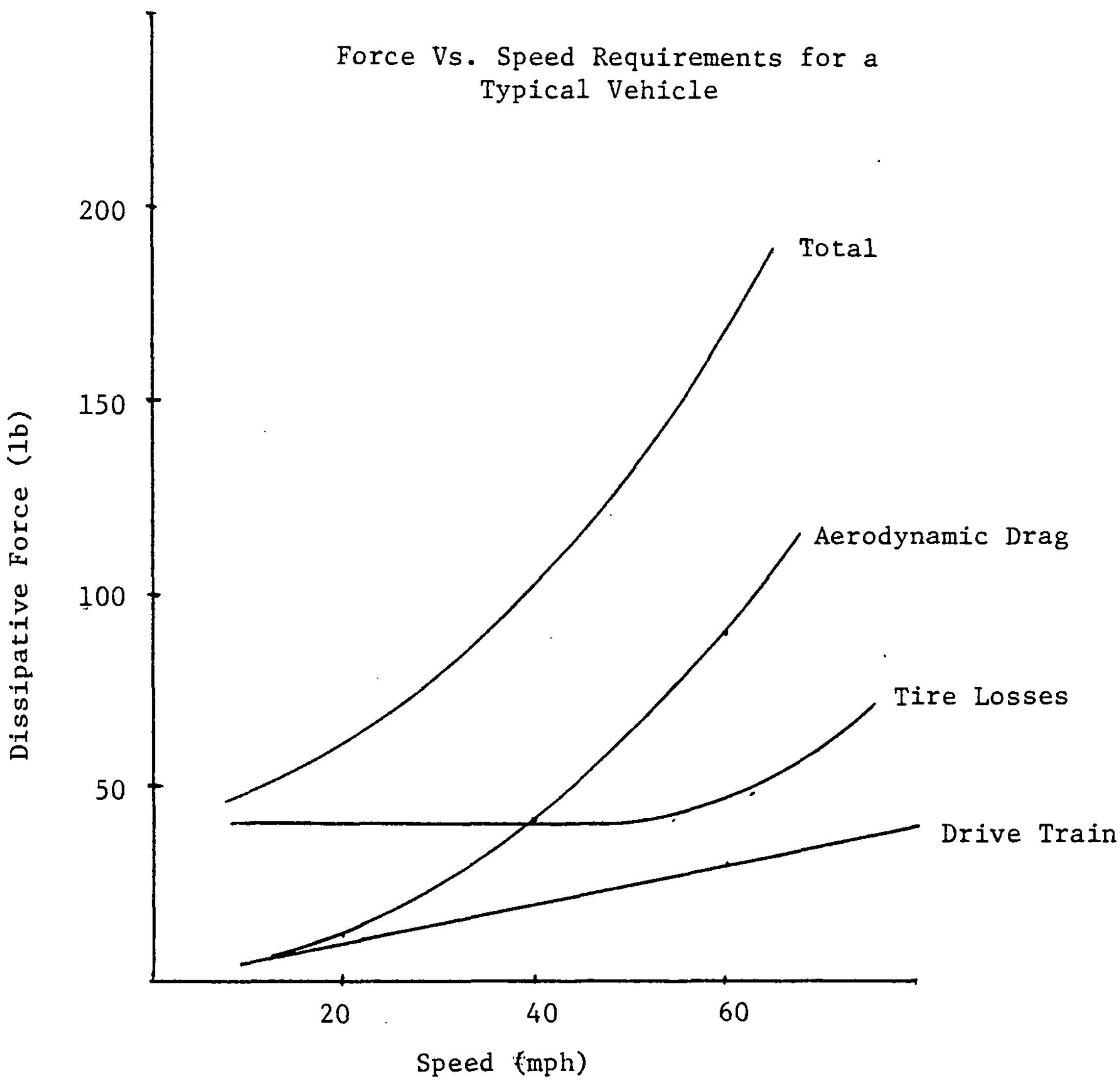
Force Vs. Speed Requirements for a
Typical Vehicle
Dissipative Force (lb)
200
150
100
50
Total
Aerodynamic Drag
Tire Losses
Drive Train
20
40
60
Speed (mph)

FIGURE 1

Table 1

Energy Dissipation - Inflation Pressure Sensitivity

Tire	Cold (%/psi)	Thermal Equilibrium (%/psi)
G78-14	-3.3	-2.4
GR78-14	-2.8	-2.1
H78-15	-3.8	-2.1
Average	-3.35	-2.18
Hot/Cold Average	-2.8%/psi	

no large public data base exists from which the consumer could select optimum tires.

IV. Second Generation Radial Tires

The previous measurements of the fuel economy improvement of radial tires versus bias or bias-belted tires were obtained from primarily 1975 model year tires. Recently, higher pressure tires with reduced energy dissipation characteristics have been introduced. These tires are available on some 1979 model year vehicles, and are anticipated to be widespread by the 1980 or 1981 model year.

These second generation tires were originally described by several names. The current accepted name seems to be "P-metric." This name refers to the prefixed P on the tire size and the metric tread width designation of the tire. At the present time, no large data base on the energy dissipation or fuel economy effect of these tires is available from a single consistent experimental program. The empirical data which do exist indicate that these tires dissipate about 20 percent less energy than that characteristically dissipated by radial tires.(5) Since radial tires typically dissipate 25 percent less energy than bias or bias-belted tires, and this results in 5 percent less fuel consumption, it is reasonable to believe that "P-metric" tires can produce a 4 percent improvement in fuel economy compared with current radial tires.

The role of the "P-metric" tire on fuel consumption is, however, significantly confused since "P-metric" is really a tire size labeling system and is not a generic tire type. These tires are generally capable of operation at higher inflation pressures and with reduced fuel consumption compared with current standard radial tires, however, the "P-metric" designation does not in any manner assure reduced fuel consumption.

V. Pressure Effects

The current vehicle use literature indicates that vehicle tires are typically underinflated by 3 to 4 psi.(6) This, of course, increases the fuel consumption of the vehicle and may account for some of the discrepancies typically observed between the EPA measured fuel economies and those obtained by the vehicles in consumer service.

A small, but consistent, data base does exist on the sensitivity of the tire energy dissipation to inflation pressure.(7) Table 1 presents the data from four tires, two bias-belted and two radial, under both cold and thermal equilibrium operating conditions. The average tire energy dissipation sensitivity to inflation is approximately -3.4 %/psi for cold tires and -2.2%/psi for tires at thermal equilibrium. That is, an increase of 1 psi in the tire inflation pressure will decrease the energy dissipation of a cold tire by 3.4 percent, or will decrease the energy dissipation of a tire at thermal equilibrium by 2.2 percent.

The sensitivity coefficient relating fuel economy to tire energy dissipation is the required link to relate the effects of tire inflation to fuel economy. Several data sets exist which provide estimates of this parameter. The EPA study which reported a 5 percent fuel economy improvement between radial and non-radial tires and a 25 percent difference in the rolling resistance of these tires indicates that the fuel economy inflation pressure sensitivity coefficient is approximately -0.2. That is, a 10 percent decrease in tire energy dissipation would yield a 2 percent improvement in the fuel economy of the vehicle.

A second data set indicated a slightly lower, but similar sensitivity coefficient of 0.15.(8) These differences could easily result from vehicle or tire differences. For example, in the case of a heavy vehicle, or a vehicle with good aerodynamic characteristics the tire effects will be greater. Also as tire energy dissipation decreases, the sensitivity coefficient will decrease since the tire losses will represent a decreasing percentage of the total energy requirements of the vehicle.

The net inflation pressure fuel economy sensitivity coefficient is the product of the inflation pressure energy dissipation sensitivity coefficient and the energy dissipation fuel economy coefficient. Using the average values of -2.8%/psi for the inflation pressure energy dissipation coefficient and the average value of 0.17 for the energy dissipation fuel economy sensitivity coefficient, the average tire inflation pressure fuel economy sensitivity coefficient is approximately 0.5%/psi.

The typical tire underinflation of 3 to 4 psi therefore results in a fuel economy penalty of about 2 percent, or about 0.5 mpg for an average current production vehicle.

An additional aspect of the pressure sensitivity coefficient is that it indicates that an 8 psi increase in tire inflation pressure would reduce the vehicle fuel consumption by about 4 percent. This is the approximate pressure increase associated with the "P-metric" tire and also the vehicle fuel economy improvement associated with these tires. It is therefore concluded that the fuel economy benefit of this class of tires primarily occurs because of the increased inflation pressure. This conclusion has also been reached by other observors.(9)

The trend toward increased recommended tire inflation pressures introduces a significant question. Will vehicle owners maintain the higher inflation pressures or will they inflate to current typical tire pressures? If the higher inflation pressures of the "P-metric" tires are not maintained the discrepancies between the EPA fuel economy measurements and the fuel economies obtained by vehicles in consumer use will increase. In addition, if the increased inflation pressures are not maintained, significant portions of the current strategies to reduce U.S. passenger vehicle fuel consumption will not result in actual fuel savings or at least will result in a significantly lower reduction in fuel consumption than anticipated.

V. Tire Wear Effects

Studies of the effects of tire wear are difficult because of the problem of obtaining matched tires and the the time required to "wear out" one tire while retaining the control tire. Alternate approaches used are to buff the tread from a tire to simulate tire wear, or to obtain tires which have been worn in service. The former approach does not subject the tire to the side wall flexing which occurs as the tire is typically worn, while the latter approach cannot provide the experimentally desireable control tire.

In general, the tire energy dissipation decreases as tire wear increases. This is logical since the hysteretic energy loss of the tire rubber is primarily responsible for the tire energy dissipation, and the volume of tire rubber decreases as the tire wears. In addition, loss of the tread has a significant effect on the stiffness of the tire. While the number of tires for which wear effects have been reported is small, the literature indicates that the energy dissipation of a completely worn tire may be 40 percent less than the energy dissipation when the tire is new. (10,11)

These wear effects should be noted since they would reduce the fuel economy improvement a consumer might expect when replacing worn tires of one type with new tires of a type more fuel efficient.

VI. Conclusions

Two types of conclusions can be reached; those from a consumer standpoint and those from a national fuel conservation standpoint.

A. Consumer Standpoint

From a consumer standpoint the most cost-effective option is to buy a tire pressure gauge and to use it. For a typical vehicle owner traveling about 10,000 miles or more per year on tires underinflated by 3 to 4 psi, the average annual fuel savings which would result if this underinflation were corrected is 12 gallons per year. In addition, it is probable that improved tire life would also occur with better maintenance of tire inflation pressures. Therefore, it is monetarily advantageous for a vehicle owner to maintain appropriate tire inflation pressures.

From the standpoint of tire selection, the only fuel efficient choice a consumer can make when replacing worn tires is to select some form of a radial tire. At present, there is insufficient data available in the marketplace to allow the selection of an optimum tire from a fuel economy standpoint.

B. National Fuel Conservation Standpoint

Radial tires should be promoted in preference to other types of tire constructions. In general, this has already occurred for new vehicles since about 70 percent of current OEM tires are radials. If all OEM and aftermarket tire sales were radial tires, the total annual U.S. fuel consumption would be reduced by about 2 percent. This would result in a total annual passenger car fuel savings of about 1.4 billion gallons.

An additional improvement could also be made if vehicle manufacturers and consumers would select optimum, low energy dissipation, radial tires. The vehicle manufacturer has an incentive to choose optimum tires for his vehicle because of the EPCA fuel economy standards and, at least, the large manufacturers will have the necessary data available to make this selection. However, these data are not available to the average consumer. Until this information is available to the consumer, the choice of optimum replacement tires is not possible. Consequently, the discrepancy between the fuel efficiency of production versus aftermarket tires will probably increase. Since about two-thirds of the normally expected total useful life of the vehicle will be driven on replacement tires, this will impair national fuel conservation efforts.

Maintenance of recommended tire inflation pressures would also result in large fuel savings. Correcting the average tire underinflation of 3 to 4 psi would also reduce fuel consumption by about 2 percent or more than 1 billion gallons.

Vehicle manufacturers are beginning to increase the recommended inflation pressures for their new vehicles. The EPA regulations, specifically the provision for requesting alternate dynamometer power absorptions, provide the manufacturers with credit for these increased inflation pressures in the EPA-DOT fuel economy programs. If these increased recommended inflation pressures are not followed by the consumer, the increased inflation pressure benefits will not be seen in the national fuel consumption. This will result in overestimation of the fuel conservation which is occurring and may increase the discrepancy between the EPA fuel economy measurements and the fuel economy achieved by the typical in-use vehicles. It is therefore imperative to encourage that recommended inflation pressures be maintained.

References

1. D. A. Glemming and P.A. Bowers, "Tire Testing for Rolling Resistance and Fuel Economy," Tire Science and Technology, TSTCA Vol. 2, No. 4 November 1974.

2. G. D. Thompson and M. Torres, "Variations in Tire Rolling Resistance - A Real World Information Need," Proceedings of the 1977 SAE-DOT Conference Tire Rolling Losses and Fuel Economy - An R and D Planning Workshop.

3. W. K. Klamp, "Power Consumption of Tires Related to How They Are Used," Proceedings of the 1977 SAE-DOT Conference, Tire Rolling Losses and Fuel Economy - An R and D Planning Workshop.

4. S. LaFerre (Editor), "Tire Industry Analysis," Modern Tire Dealer, January 1978.

5. T. M. Fisher (GM), letter to Charles Gray (EPA), July 25, 1978.

6. O. J. Viergutz, H. G. Wakely, L. Dowers "Automobile In-Use Tire Inflation Survey," Society of Automotive Engineers, Paper No. 780256.

7. S. K. Clark, R. N. Dodge "A Handbook for the Rolling Resistance of Pneumatic Tires," Final Report No. DOT-TSE-78-7 prepared for the Department of Transporation, Transportation Systems Center.

8. T. M. Fisher op. cit.

9. S. K. Clark, op. cit.

10. W. W. Curtiss, "Low Power Loss Tires," Society of Autmotive Engineers, Paper No. 690108.

11. J. D. Walter and F. S. Conant "Energy Loses in Tires," Tire Science and Technology, TSTCA Vol. 2, No. 4, November 1974.

Public Relations Information Abstract

Fuel Economy Effects of Tires

On the average, radial tires improve the fuel economy of a vehicle by about 5 percent, or 1 mpg for a 20 mpg automobile. At the present time, this fuel efficiency combined with the longer average life of radial tires more than offsets the higher initial cost of the radial tires. The payback of the radial tire will increase as fuel cost continues to rise. Consequently, the radial tire will continue to be the less expensive tire to purchase, on a cents per mile basis, when obtaining a new car or replacing existing worn tires.

With any type of tire, the tire inflation pressure has a very significant effect on the fuel consumption of a vehicle. On a typical 20 mpg vehicle, tire underinflation of 3 to 4 psi will increase fuel consumption by about 2 percent or 0.5 mpg. Therefore, from a consumer standpoint, it is cost effective to buy a tire pressure gauge and to use it. For a vehicle owner traveling about 10,000 miles or more per year, proper tire inflation would typically save 12 gallons of fuel per year. Therefore, it is monetarily advantageous for a vehicle owner to maintain appropriate tire inflation pressures.

More extensive information on the fuel economy effects of tires can be obtained from the 1979 EPA Technical Report, "Fuel Economy Effects of Tires."