RADIAL TIRE PERFORMANCE COST/
BENEFIT, AND FUEL EFFICIENCY
CONSIDERATIONS.

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MICHIGAN DEPARTMENT
OF
STATE HIGHWAYS AND TRANSPORTATION

Radial Tire Performance, Cost/Benefit, and Fuel Efficiency Considerations

By

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An Investigation Conducted for
the Michigan Energy Administration

Testing and Research
Division

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PREFACE

This study was conducted for the Michigan Energy Administration by the Michigan Department of State Highways and Transportation, Testing and Research Division. A September 2, 1976 letter from Mr. Mike Dively, State Energy Administration Director to H. Keith Scott, Department Energy Committee Chairperson inquiring about Department interest, initiated the study.

For the most part the study task consisted of reviewing literature on radial tire performance and compiling information. To this end a search of the Department Library was made and a computer search by the Highway Research Information Service was conducted. Documents were purchased from the National Technical Information Service, the Society of Automotive Engineers, the Highway Safety Research Institute, and the Federal Highway Administration.

INTRODUCTION

The Arab oil embargo of October, 1973, and the resulting energy shortages focused the Nation's attention on the growing imbalance between domestic consumption and domestic production of petroleum. Fuel conservation measures were initiated and highway transportation representing a large portion of total petroleum consumption was targeted for many of these measures.

It has been reported that between a fourth and a third of all energy used in the United States is devoted to transportation and of that close to 60 percent is supplied in the form of gasoline to automobiles and light utility trucks.

Nationally the United States Department of Transportation estimates that motor fuel consumption in 1976 will be 118.8 billion gallons, a 5.5 percent increase over 1975 and 3.8 percent higher than 1973.

In Michigan it is expected to reach a record 5.062 billion gallons for 1976.

This total would be a 4.8 percent increase over 1975 but only 1.1 percent higher than the previous record set in 1973 the year the Arab oil embargo began.

Since experts do not foresee a dramatic change in transportation methods or habits in the short run, before 1990, the biggest target for energy conservation is the poor fuel economy of American automobiles. It has been estimated that automobile efficiency can be increased at least 40 percent by 1980 using existing or readily foreseeable technologies.

Of the total energy requirement for a full size automobile approximately 25 percent is needed to overcome rolling resistance. Tire design, materials, and construction influence rolling resistance. It is generally believed that belted radial constructed tires reduce rolling resistance and hence improve fuel efficiency.

FACTORS AFFECTING FUEL CONSUMPTION OF AUTOMOBILES

In any attempt to increase the fuel efficiency of automobiles and thereby reduce gasoline consumption the overall energy requirement must be analyzed in order to concentrate efforts on factors which would provide optimum payoff. From an article in a recent issue of Scientific American:

> Next to building (and persuading Americans to buy) smaller and lighter cars, important gains in fuel economy can be made in cars of every size category by improving the performance of present engines, by reducing transmission losses, by reducing weight (without sacrificing safety or passenger comfort) and, not least important, by reducing aerodynamic drag. (1)

Figure 1 taken from the same article illustrates the division of automobile energy requirements.

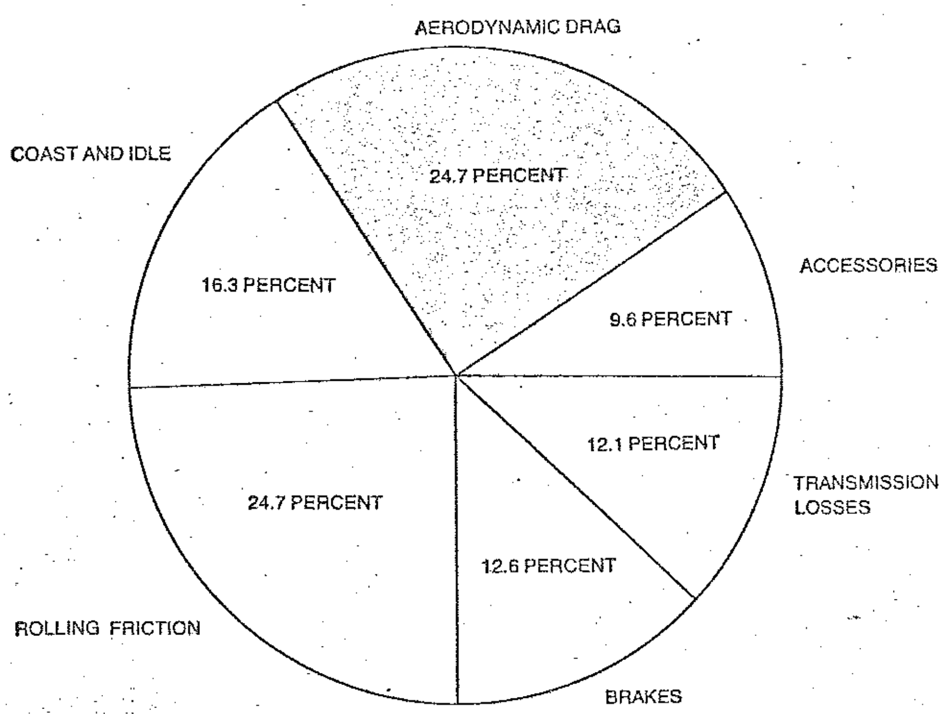

Figure 1. DIVISION OF ENERGY REQUIREMENTS is shown for a 3,500-pound automobile when operated on the EPA composite city-highway test cycle. The energy lost in braking corresponds roughly to the amount of energy previously used to accelerate the car's inertial mass. In steady high-speed crusing most of the engine power is required to overcome aerodynamic drag. In low-speed crusing most of the power is needed to overcome the rolling resistance. In general, reducing the power-to-weight ratio will increase the fuel economy.

In another research study it was reported that as much as one-half of automobile energy consumption can be saved through technical improvements. Advances which are considered of greatest potential include the use of a continuously variable transmission, improvements to the internal combustion engine, and the use of lighter weight structural materials. Reduced spaciousness was also reported as important in energy savings:

> Building a subcompact instead of full size car can result in energy savings comparable to those obtained by combining radial tires, minor aerodynamic changes and a continuously variable transmission in a conventional full size car. (2)

It was found that use of nonpetroleum fuels(methanol and hydrogen) would not result in net energy conservation unless the required production energy is obtained from nonpetroleum sources.

Another factor which should be considered is fuel conservation driving habits and techniques. Fuel conservation driving can be promoted best by encouraging drivers to learn and then practice good fuel driving habits. How one operates a car - avoiding wasteful driving practices, carpooling, and maintaining one's car according to manufacturer's instructions - can add to dollar and gasoline savings. For example, a FHWA investigation reported that about one-third of all drivers accelerate too fast.(3)

There is a surprising inefficiency of cars for short trips without warmups. Starting from an ambient temperature of 70 degrees F, a car gets an average of only 50 percent of its warmed up mileage in a one-mile trip and only about 60 percent in a two-mile trip . In cold weather the efficiency is much worse.

These other factors are mentioned so that the contribution of radial tires to total fuel conservation can be considered in perspective and emphasis placed accordingly.

<u>TIRE TYPES</u>

Tires are classified according to the arrangement of the plies or (layers of closely spaced parallel reinforcing cords) that provide strength. There are three basic construction types. The following excerpt from a recent <u>Consumers Research Magazine</u> article describes these construction types and discusses some of the advantages and disadvantages of each:

Bias-ply tires. The conventional bias-ply is the oldest, simplest, and least expensive type. Auto tires of this type have an even number (usually 2 or 4) of plies crisscrossed diagonally ("on the bias") across the tire from rim to rim of the wheel. This construction results in comparatively uniform stiffness of the tire across both the tread and sidewall areas, in contrast to the two other types which are stiffer in the tread area than in the sidewall. The relatively stiff sidewalls of the bias-ply tire heat up as they flex under load, yet the tread is not stiff enough to prevent it from distoring or "squirming" against the road surface. This squirming causes wear of the tread rubber and tends to reduce traction in some conditions. Main advantages of this type are dependability at a low price, damage-resistant sidewalls, and normally a smooth low-speed ride. Disadvantages include the shortest tread life of the three types and comparatively uncertain or vague steering characteristics. Due to the energy wasted in the squirming tread and heavy sidewalls, rolling resistance is high, which means that extra fuel is needed to keep moving. The low price makes this kind of tire the most practical, economical type for the driver who has little occasion to use the higher overall performance of other types and for the old car or second car that is usually lightly loaded and doesn't travel far.

Radial Tires. Radial-ply tires were first introduced nearly 30 years ago. In the past couple of years they have come to dominate both the original equipment market and the higher-priced end of the replacement market. The radial body ply or plies that give the type its name go across the tire at right angles to the tread rather than diagonally. A separate set of plies under the tread area forms a belt or hoop around the tire to stiffen and reinforce the tread. The sidewalls are left rather thin and flexible so that they can flex freely under load. That is one main reason why normally inflated radial tires have a "bulgy", underinflated appearance to anyone accustomed to other tires. With radials, correct inflation cannot be judged from appearance. Radial tires call for use of an accurate tire pressure gauge.

The stiff belt greatly reduced distortion and squirming of the tread, gives (usually) crisper, more accurate steering response, and in combination with the flexible sidewalls keeps rolling resistance comparatively low and permits the tread to stay flat against the road even in turning sharp corners.

Handling characteristics are less affected by load and pressure variations than with other tires. Besides reducing the rate of tread wear and keeping the tread grooves open, the reduction in tread squirm yields an important indirect benefit that is less prominently advertised. The manufacturers can use a softer, "stickier" rubber compound and an open tread design better suited to safe traction on wet roads without unreasonably sacrificing durability.

One very practical disadvantage of radial tires is the high price asked for them. Whether or not their longer tread life and their fuel-economy advantage (roughly 5 percent, as an overall average) are sufficient to compensate for the high initial price are difficult questions to answer. Certainly it would be a poor investment in a purely economic sense to equip a car with a high-priced set of radials unless one plans to drive the car long enough to take advantage of the radials' longer tread life.

A further complication is that it is difficult to predict how much longer a set of radials might last. As with the other types, different brands and models differ considerably in potential mileage; though radials in general last longest, it would be entirely possible to buy one with a shorter life than some other tires. On the other hand, a set of radials may last several times as long as the original equipment tires on some cars.

Sidewalls of radial tires are comparatively delicate and can be extensively ruined through carless parking. Radials normally must be purchased in sets of 4 or 5 at once for safe handling and braking. It is considered "acceptable," but definitely not desirable, to combine two radial tires in the rear with two tires of another kind in front. Radials should never be used on the front only or on only one side of either end of a car. Radials, like studded snow tires, should always roll in the same direction after they are broken in. They should, therefore, not be cross-switched from one side to the other when tires are rotated.

One possible source of disappointment with radial tires is not really the fault of the tires at all, but rather is the fault of misleading advertising. Though they are careful not to say so specifically, some companies would have the potential customer believe their radials of the steel-belted variety are so tough as to be virtually immune to road hazards. Such tires while more resistant than most to certain types of damage are still vulnerable to everyday hazards, such as nails.

Radials sometimes tend to have somewhat harsh riding qualities and may cause vibration problems on some older cars with suspensions not designed for radials.

<u>Bias-Belted Tires</u>. The third, and newest, basic tire type was introduced in the late sixties. The bias-belted tire is a sort of hybrid of the two older types. Tires of this type have crossed plies similar to those of the bias-ply tire, but also have a "belt" similar to that of the belted radial. They are intermediate between the other two types in price, in most aspects of performance, and theoretically, in tread durability. They have seemed to be prone to problems and it is not yet clear whether the type will survive competition from less expensive bias tires and some new "economy" radial designs. (Each of the three types now sells in about equal numbers.) (4)

VEHICLE/TIRE PERFORMANCE

For new radial tires, vehicle/tire performance is mainly influenced by mechanical properties such as: dimensions, handling, ride, traction, noise, and power loss. The previous section mentioned some radial tire performance characteristics. Another article evaluates vehicle/tire performance from a more technical standpoint. The following quotes are taken from this article:

> ...their loaded radii are smaller and they have reduced spring rates. It thus becomes difficult to provide reasonable ground clearance.
>
> Application of radial tires reduces vehicle understeer...
>
> Reduction in understeer, coupled with higher cornering stiffness, causes an increase in steering sensitivity or the amount of lateral acceleration produced by a given level of steering input.
>
> This increased sensitivity may be an advantage for manual steering cars, where steering ratios are often higher, due to effort considerations. For power steering cars, some drivers may find the steering more sensitive than they are accustomed to.
>
> The reduction in understeer would normally produce longer vehicle response times and increased vehicle sensitivity to wind disturbances.
>
> ...generally known that radial tires produce less vehicle disturbance when longitudinal road edges or seams are encountered.
>
> Road feel is generally reduced with radials because the front tires operate at lower slip angles...
>
> ...low road feel and high control sensitivity tends to magnify subjective impressions of steering system lash, friction, and hydraulic response characteristics.
>
> Vehicles equipped with radials are generally less sensitive to service factors like load and inflation pressure.
>
> These tires are also less sensitive to load transfer and, therefore, cars with radials respond less to change in roll stabilizer bar characteristics.

Lateral force variation and aligning torque variation in some radials can be large enough to produce very perceptible vehicle "snaking" or "waddle" motion at low speeds.

These forces and moments can produce steering "pull" and "dog tracking" when they are of sufficient magnitude.

In addition to low spring rates, radial tire spring rates increase less with inflation pressure. This may be a partial explanation for improved radial tire ride at high speeds.

...a range of traction performance is available with radial tires, and there is overlap between radial and bias-belted distributions. Radial and bias-belted traction data converge as tread is removed and the performance of all tires is similar in a bald state. Tread design and compounding are controlling factors in traction.

Many factors influence the free-rolling drag force associated with tire motion. This force and the related energy require to propel the vehicle can be reduced in any tire construction by optimization of the design for minimum power loss. These design compromises, such as thin tread and high inflation pressure, can be impractical for bias tires, but lower power loss can usually be achieved with a more practical set of compromises in a radial. (5)

TIRE ROLLING RESISTANCE

Tire rolling resistance is the sum of three factors; aerodynamic drag of the tire itself, friction between the road and the tire contact patch, and hysteresis of the tire materials during deformation. The hysteresis component is caused by damping losses within the rubber when the latter is "flowing" over and around obstacles. Damping is characterized by the rubber's resistance to displacement and recovery. Hysteresis is the major contributor to tire rolling resistance amounting to 90-95 percent of the total tire relative power consumption. Since tire rolling resistance amounts to 25 percent of the total automobile energy requirement, tire materials and construction are a major area of interest to the designer.

Generally speaking, radial tires exhibit lower rolling resistance than either bias or bias-belted tires. Partially this is due to the materials normally used in them, but it is also partly due to their detailed tire design characteristics such as belt stiffness and cord angles. (6)

The lower rolling resistance of radial tires is what (generally speaking) translates into reduced vehicle fuel consumption.

RADIAL TIRES AND FUEL CONSUMPTION

In this section references to published articles documenting specific values of increased fuel economy through the use of radial tires will be cited. Some references are merely unsubstantiated statements and others report well controlled studies.

The values vary in degree and unit of measure. Fuel savings may be reported in percent decrease in rolling resistance, percent increase in mpg, or absolute increase in mpg. All are related, of course, but translating to a common measure is difficult.

There is a generally held opinion that radial tires provide increased fuel efficiency. Quantitative data is scarce, however. Relative to the overall fuel consumption of automobiles, the effect of radial tires in decreasing this consumption appears marginal as compared to other more significant factors, e.g., weight.

The first three citations are quotes which illustrate the aforementioned generally held opinion that radial tires provide increased fuel economy.

The first also indicates that the manifestation of such economy is speed related:

> Another factor is rolling resistance. At all but very low speeds this resistance is dwarfed by the resistance extended on the body of the car by its passenger through the air. The principle contributor to rolling resistance is the friction provided by the loaded tires of the vehicle. Newer tire designs, in particular the steel belted radial-ply tires, provide a substantial reduction ranging from 15 percent on ice to 45 percent on sand. This may be translated into a fuel economy of 5 to 10 percent on the average road. (7)

In a special issue of Automotive News an article commented on the continued gain in popularity of radial tires both for original equipment and in the replacement market and:

> In addition, radials provide longer tire life and improved gasoline mileage because they have less rolling resistance. Firestone tests have shown radials can reduce fuel consumption 7 to 10 percent when run at constant highway speeds. In the tests, Firestone compared its top-of-the-line radial with a bias-belted tire. (8)

In another article on fuel economy of automobiles the following statement was made regarding the effect of tires:

> The rolling resistance of tires is highly dependent on their construction. However, tires are normally designed to optimize other qualities, and low rolling resistance has not been emphasized as a design goal (although, presumably, low power consumption would be highly correlated with slow tread wear). At speeds below 60 mph, radial tires can give about 28 percent less resistance than bias-ply tires, with bias-belted tires being intermediate. For minimizing power consumption at low speeds, the best present combination of materials is steel for the belts with rayon or polyester for the plies. Bald tires have about half the resistance of new ones, and wide tires have less resistance than narrow ones. (9)

In terms of specific miles/gallon advantage the following is one of the few references:

> Rolling resistance is primarily dependent upon tire construction. In general, an increase in rolling resistance produces losses in both fuel economy and acceleration, while decreases result in economy and acceleration gains (Table 1). At low speeds, rolling resistance forms the major contribution to total force required; the aerodynamic drag is the prime contributor at high speeds. The acceleration effect of a 10 percent rolling resistance change is about equal to that previously quoted for aerodynamic drag.
>
> The 1970 fiberglass-belted tire was about 1 mpg poorer than the bias, non-belted polyester cord tire previously used. Improvements in this tire reduced the penalty to 0.3 mpg. Steel belted radial tires can provide a 0.3 mpg advantage over the polyester cord. (10)

Table 1. Rolling Resistance-Intermediate car with Automatic Transmission - Effect of 10% Rolling Resistance Change.

70 mph road - load fuel economy, mpg.	0.4
Urban cycle fuel economy, mpg.	0.2
Acceleration effect, %	
Through gears	1
Direct gear	3

A rolling resistance test conducted on a road surface with fully instrumented tire test trailer is described in another report. While the project objective was to demonstrate that a trailer method for measuring tire rolling resistance in a real environment could produce reliable data, the test procedure did compare radial and bias-belted tires.

> "Results are plotted for the intermediate-size while in Figure 2 as a function of hot, stabilized tire pressure. Not surprisingly, radial tires and increased tire pressure give improvement in fuel mileage...(11)

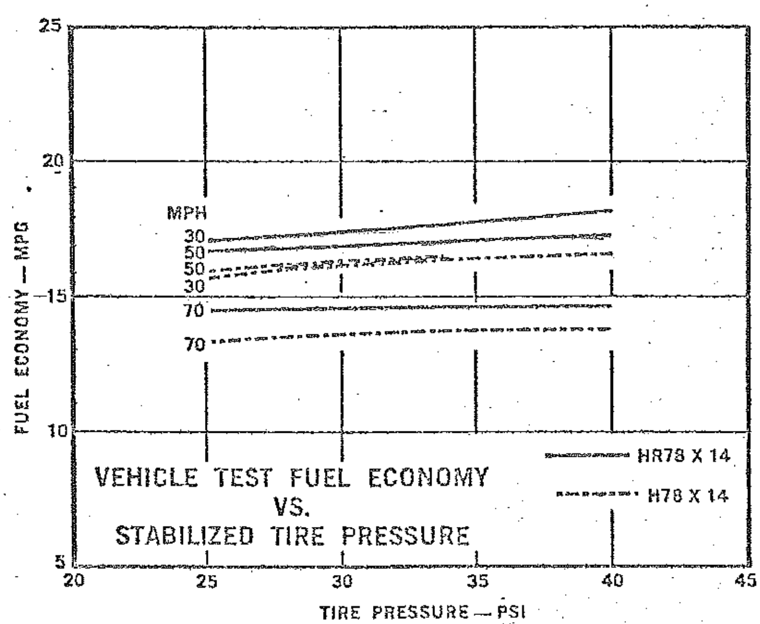

Figure 2 - Vehicle test fuel "economy" versus stabilized tire pressure for radial HR78-14 and bias-belted H78-14 tires.

From the graph it appears that radial tires provide approximately one mpg advantage at 50 mph and perhaps a two mpg advantage at 30 mph under simulated intermediate-size vehicle trailer testing conditions.

In a highly technical paper the torque input of a pneumatic tire in various operating modes is analyzed and the tests required to determine

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the energy consumption of a tire are discussed. The energy expended by tires is combined with other vehicle losses, and the magnitude of possible fuel savings by use of low-loss tires is estimated. This was a sophisticated laboratory test and mathematical modeling procedure performed at the Calspan Tire Research Facility. (12)

Stipulating a full sized V8, 350 cu. in. engine at a constant speed of 50 mph on a level highway, fuel consumption was estimated to be 18.2 mpg for a vehicle equipped with bias-belted tires and 18.8 mpg for a vehicle equipped with radial tires.

Test methodologies for laboratory testing, rolling resistance trailer, vehicle coast-down, and vehicle fuel consumption tests are discussed in another paper. (13) This paper provides some basic results of these tests and how variations in a specific test method affect the results. A major emphasis is on the direct comparison of the bias-belted tire with the steel belted radial tire to demonstrate the effect of tire construction, test method, and test parameters on tire performance.

Short-term (up to 25 miles) and long-term (up to 40,000) fuel economy tests were run. In each case radial tires provided an initial fuel efficiency advantage of six percent. This advantage decreased with increasing mileage in the long-term test due to tread wear. At 20,000 miles there was only a slight advantage.

An interesting figure from this paper is shown below:

> Figure 3 is generalized plot of the range of fuel efficiency for city and highway driving as determined by 1975 EPA tests. This figure has a secondary plot of projected radial tire fuel efficiency advantage in percent when applied to these vehicles assuming a bias-belted tire is the baseline performance. The plot suggests a 3 percent to 6 percent

fuel efficiency improvement. Radial tire advantage in percent is lowest for the large, heavy, high drag vehicle and for those with extremely efficient drive systems, low weight, and lower drag.

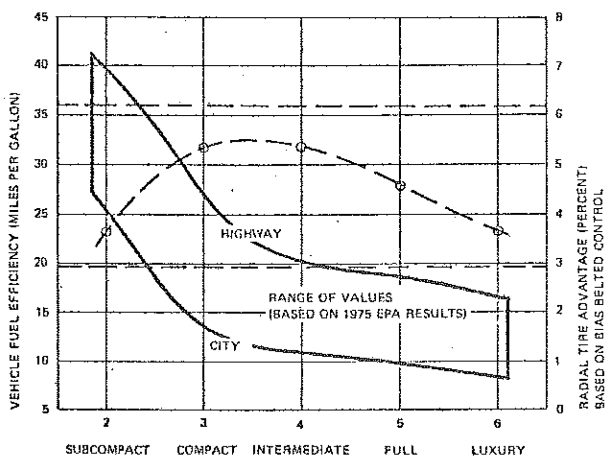

Figure 3. Fuel Efficiency and Radial Tire Advantage by Passenger Car Type.

One of the more definitive papers reviewed described a vehicle test procedure for determining the effect of bias, belted-bias, and radial tires of different designs on constant spread fuel economy. (14) Test results were analyzed on a statistical basis and indicated that the use of steel belted radial tires decreases the fuel consumption approximately 6 percent when compared to bias and belted-bias tires. The Table 2 below from this paper summarizes the results:

Table 2 - Fuel Consumption

	Gasoline Consumption, mpg		
	35 mph	50 mph	75 mph
Steel belt/rayon body	18.758	18.403	13.681
Rayon belt/rayon body	18.143	17.718	(13.298)
Glass belt/polyester bias body	(17.614)*	(17.068)	(13.024)
4-ply nylon body	(17.636)	(17.207)	(13.102)
Limits for significant difference at 95% confidence	0.408	0.462	0.376

* The bracketed figures show less than 95% confidence.

Finally, in their 1976 gas mileage guide for new car buyers, the Environmental Protection Agency states that, "Using radial tires, instead of conventional or bias-ply tires, can result in a 3 percent improvement in gas mileage."

COST/BENEFIT CONSIDERATIONS

There is not one tire that is the most economical and meets the difference requirements of all motorists. It is quite likely that no one tire line at any price is the best performer overall. Tire manufacturers settle on different compromises in attempting to reconcile the unavoidably conflicting requirements of cost, ride, handling, high-speed durability, treadwear, resistance to damage, rolling resistance, and traction under various driving and braking conditions.

Also, there are many factors which affect fuel economy. The condition of the automobile, driver, type of driving, load, tire inflation pressure, temperature, speed, weather, and road condition all can affect the fuel economy of an individual vehicle. Few tests or experiments can consider the whole gamut at once. Those studies directed solely at the effect of tires attempt to fix or isolate all other variables. Vehicle fuel economy tests run under real environmental conditions are necessary, however, to determine actual over-the-road tire, vehicle, and roadway interactions.

It is difficult to select one best estimate of the fuel efficiency improvement gained through the use of radial tires. Perhaps there is none since there are many factors involved. For the references cited in the previous section, values ranged from 3 to 10 percent improvement in miles per gallon and from 0.3 mph to approximately 2.0 mph in absolute terms. No one value can apply to all situations.

In order to arrive at a range of possible gasoline (energy) savings through the use of radial tires, the advantage in percent as given in Figure 3 will be used. Using the approximate mid-range value for vehicle fuel efficiency for each of the weight classes given, the following fuel savings can be expected based on 40,000 miles of driving:

TABLE 3

	Efficiency (MPG)	Radial Tire Advantage (Pct.)	Savings (Gal.)
Subcompact	34	3.6	40
Compact	20	5.3	101
Intermediate	15	5.3	135
Full	14	4.6	117
Luxury	12	3.6	107

The fuel efficiency values are for combined city and highway driving as determined by 1975 EPA tests.

From Table 3, dollar savings based on a gasoline cost of $0.60 per gallon for example, range from $24.00 to $81.00 for 40,000 miles of driving.

Michigan reported 4.7 million registered passenger vehicles in the 12 month period ending June 30, 1976. Assuming an average annual mileage of 10,000 miles per vehicle, the expected gasoline savings per vehicle per year through the use of radial tires would be about one-fourth that given in Table 3. In order to get an accurate estimate of fuel saved would require knowledge about the number of vehicles in each weight class in the total population of 4.7 million.

However, again assuming that the population is all intermediate size for example, if all the vehicles were equipped with radial tires as opposed to non-radial tires, this could result in a savings of approximately 170 million gallons of gasoline.

This savings is misleading, however, not only because the assumptions may not be realistic but also because there is already a certain proportion of the passenger vehicle population equipped with radial tires.

In any energy analysis, total energy flow should be considered. With respect to radial tires such analysis would include the energy of manufacture. An inquiry to the Rubber Manufacturer Association relative to this aspect met with no response. Radial tires cost more than other tire types and it could be that some of this cost is directly or indirectly related to energy requirements.

Another consideration which is not directly related to the question of radial tire and fuel efficiency but is related to the relative effect of this relationship and this is the proposed federal mandatory mileage standards. This regulatory program will be a revolutionary impact on the American auto industry and car owners if adhered to as set forth. The mileage standards require each manufacturer's production of cars to average a relatively easy 18 mpg for 1978 but this average increases each year until 1985 when the average fuel efficiency of vehicles produced is to be 27.5 mph. To the extent radial tires can help meet these requirements it can be expected that they will become standard equipment.

Evaluating the advantage of radial tires from a dollar benefit aspect is another difficult task. Brands, materials and construction type differ considerbly in cost and potential mileage. Tires advertised as having steel belts are not necessarily radials and bias-belted tires sometimes have belts of steel or fiberglass. Certainly, however it would be a poor investment in a strictly economic sense to equip a car with high-priced radials unless one plans to drive the car long enough to take advantage of the radials generally longer life.

Bias tires are usually the cheapest at about $30 or $35 each, belted bias intermediate in cost at about $40 to $60 each, and radial tires are the most expensive at about $60 to $80 each. The longer life attributed to radial design has been reported to be from two to three times that of conventional design and materials.

Using the extremes $30 each for conventional tires and $80 each for radial tires and assuming a 20,000 mile and a 40,000 mile useful life respectively, the net cost of a set of radial tires is $80 over 40,000 miles of driving. The break even point would be realized if a conventional or belted-bias tire costing $40 is used in the comparison. A net savings is realized if a belted-bias tire costing more than $40 is compared, however, useful life might be greater for a higher quality non-radial tire.

Variations in dollar advantage/disadvantage can be computed by assuming different cost and mileage data. It appears, however, that the magnitude of dollar savings would be marginal and therefore not the only consideration in whether or not to purchase radial tires.

For the example used above, the net $80 cost of purchasing radial tires would be off-set by the $81 saved through reduced gasoline consumption if installed on the intermediate class vehicle of Table 3.

For comparison purposes, the information in Table 4 on the effect of radial tires was taken from another Society of Automotive Engineers paper included with other SAE papers and published as one volume on automotive fuel economy (15).

Analysis of several individual modifications including radial tires was made for both compact and standard sized vehicles.

TABLE 4

	Standard	Compact
Mileage Improvement (% mpg)	2.5	3.5
Fuel Reduction (% gpm)	2.3	3.3
Fuel Saved	158	174
Δ Initial Cost	70	60
Δ Repair and Maintenance	-	-
Δ Replacement Cost	(60)	(40)
Δ Total Cost	10	20
Estimated Net Savings @ 75¢/gallon	108	110

Fuel savings and the incremental (Δ) costs are for a 10-year period and 100,000 mi.

CONCLUSIONS

1. The preponderance of information indicates that belted radial tires provide a fuel efficiency advantage relative to bias-ply tires. The magnitude of this advantage depends on several variables including vehicle weight class, tire inflation pressure, and other which affect rolling resistance.
2. Although some reports indicate that this advantage as much as 10 percent, the majority of the information and the information which seems better documented indicates that more realistically this advantage ranges between 3 percent and 6 percent. For the data in Table 3 this translates to approximately 0.4 mpg to 1.2 mpg.
3. Most documents on automobile fuel economy treat total energy demand. The effect of belted radial tires seems to be considered marginal in comparison

or taken for granted. When considered on a vehicle population basis, however, individual marginal gasoline savings can amount to significant savings of several million gallons a year.

4. There is a seemingly endless variety of tires on the market each representing a different combination of brand, materials and type of construction. Hence, there is not a distinct radial tire cost advantage/disadvantage. Although a realistic cost comparison would depend on several factors related to type of driving anticipated and desired performance factors, it appears that there is no overwhelming cost advantage or disadvantage. In a strictly economic sense, belted radial tires would only be cost beneficial if driven long enough to take advantage of their longer tread life.
5. There might be significant energy savings involved through developing better gasoline conservation driving habits. If, based on further study, this is the case, such habits could be encouraged by publicity, through driver education programs and as part of driver licensing examinations.
6. Although use of belted radial tires does conserve gasoline, it appears that more significant savings would be realized through a program aimed at improving the fuel efficiency of the automobile as a whole.
7. It may be, considering current market conditions and production capabilities in addition to the forthcoming mandatory mileage requirements, that belted radial tires will become standard equipment in the near future.
8. Driverattitude will be a significant factor in any gasoline conservation effort. Will technological improvements to automobiles resulting in increased fuel efficiency be considered as allowing more travel for the same amount of fuel thus resulting in no net savings? Perhaps motorists will overreact to increased fuel efficiencies and increase travel more

than warranted by the better mileage thus causing a net increase in consumption.

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