Motor-Vehicle Performance and Highway Safety

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THIS paper discusses the relationship between motor-vehicle performance and its ability to meet traffic and highway conditions today. The high-performance automobile satisfies the customer demand for rapid individual transportation and at the same time contributes to highway capacity and safety.

Charts giving trend data from the year 1930 to 1952 on curb weight, rated horsepower, maximum car speed, acceleration and fuel economy are presented. The relationships between these factors and the effect on the performance of the motor vehicle is brought out.

A discussion of the relationships between time, distance, speed, and acceleration follows illustrated with charts. The final chart of the series illustrates the advantages gained by a high performance car over a poorer car in a passing maneuver. A saving of 26 percent in distance between the best and poorest car is shown.

The advantage of high performance in a motor vehicle can be attained by certain engine speed and horsepower combinations. Good economy with high performance, however, can be attained only with low engine speed and high horsepower. Charts illustrating the various factors involved are discussed. The design of American cars over the past years has been towards improvement in economy and performance.

● IN presenting data and information on the relationships covered in this paper, it seems worthwhile to start by reviewing briefly some of the factors which made the automobile industry possible.

A high-light history of the development of self-propelled road vehicles shows that the demand for such a device was evident for over 100 yr. before the emergence of the present type of automobile became possible in the 1890's. During this early period, the need for some of the basic essentials was recognized, and they were invented. A differential, springs, steering mechanism, step-gear transmission, and brakes had been conceived and developed. The only power plant available, however, was the heavy steam engine, using solid fuels. Many inventors in the early 1800's differentiated very little between road vehicles and rail vehicles because of the large size and weight restrictions imposed by the use of steam engines. As a result, those early pioneers who turned to rail vehicles were successful and the railroad systems of the world were developed. Those who persisted in attempting to produce a road vehicle failed for lack of a suitable power plant.

Three new factors entered the picture between 1860 and 1890 which completely changed the possible solutions to t he problem Gasoline became available in the 1860's through the development of the petroleum industry to supply the world's demand for lamp oil. Another important event occurred in 1860 when the French engineer, Lenoir, invented an atmospheric-pressure internal-combustion engine which ran on illuminating gas and supplied the first new lead in the search for a more-suitable power plant.

When Otto invented the four-cycle compression-type engine in 1866, the first really satisfactory type of engine was provided. Dunlop's pneumatic tire, patented in 1888, was the third of the essentials that made the modern automobile possible.

In looking back on those early days of automobile history, one cannot help but wonder that the whole idea of the automobile was not abandoned. By the late 1800's the railroads had progressed to a point that travel was, relatively speaking, safe, rapid, and comfortable. In contrast to this, the automobile of that day was slow, unreliable, uncomfortable, and dangerous. Coupled with this, there were no highways in existence that were in any sense adequate to drive an automobile on, which was in contrast to many miles of railroads.

In spite of all the factors against the automobile of those days, there existed in the human mind a desire which was so all-powerful that it overcame the almost insurmountable obstacles of that day and evolved the modern highway and automobile. That desire was satisfied by the automobile's ability to supply the individual and his family transportation from here to there in the shortest possible time. In the early days, as is true today, there were means of mass transportation which had higher speed but failed to satisfy the desire for rapid, individual transportation.

Under pressure of this human urge, both automobiles and highways began to improve, and rapid progress was made in spite of the many obstacles which were placed in the way. That this human urge for more and better individual transportation is still paramount is easily seen when we consider the number of automobiles produced and sold each year.

The advent of World War II and its many adverse affects on our economy along with the existing world situation has slowed down the construction and maintenance of our highway systems. At the same time more and more motor vehicles are operating on our highways for more and more miles each year. As traffic gets heavier on our highways and more and more situations develop which interfere with the individual's basic desire to get from here to there quickly with his automobile, the greater will be the pressure brought to bear on the highway departments and on the automobile manufacturers to do something about it. Since the automobile manufacturer is not in a position to be of much direct help in the building of highways, the one field in which he can contribute to improvement in the present traffic situation is by improvement in the automobile, particularly in regard to overall performance. In doing this he also is under pressure from the driving public and under a moral obligation to the national economy to design for the best possible fuel economy.

One of the first factors which may be considered in relation to performance and economy is weight. Figure 1 is a chart of curb weight trend beginning with the year 1930. As can be seen, the vertical ordinate is in pounds and the horizontal in years. Each small circle on the chart represents a single car of the year represented by the vertical line on which it appears. There are about 29 cars of different makes and models each year which represent practically all the American manufacturers. This group of cars appears in all of the trend charts which follow, and the data are from General Motors Proving Ground records.

It will be noted that the average weight of cars has increased from 3,500 to 3,800 lb., a difference of 300 lb. However, the data also show that the very large cars have been reduced in weight by almost 1,000 lb, and the small cars have increased in weight by almost 500 lb.

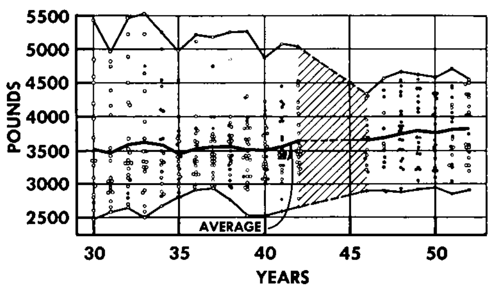

Figure 1. Trend of curb weight from 1930 to 1952.

Other things being equal, a light vehicle accelerates and decelerates at higher rates for a given expenditure of energy than a heavy one does. On the same basis, the lighter vehicle uses less gasoline in accelerating. In view of this it might seem logical to go to lighter and lighter vehicles, and this would be valid if we could think only of performance and economy. The American public, however, demands certain standards of space, comfort, and safety which cannot be met in the light of present knowledge of automobile design if the weight is reduced too greatly. There is much less spread in weight between the heaviest and the lightest cars in 1952 than in 1930. This is brought about by technological improvements in material and design, allowing a closer compromise between comfort, performance, and economy.

The rated horsepower, as shown in Figure 2, has gone up rapidly until about the year 1941, at which time the war halted production. Immediately after the war the average was down somewhat and has a decided upward trend to the present time.

This has been necessary to obtain the better performance demanded by customers, and at the same time retain acceptable fuel economy, as will be pointed out later in this paper. One notes particularly the great increase in horsepower shown in the maximum curve since 1950. Figure 3 shows that the maximum speed of the average automobile increased from 66 to 92 mph. from 1930 to the present time. The increase is a side product as a result

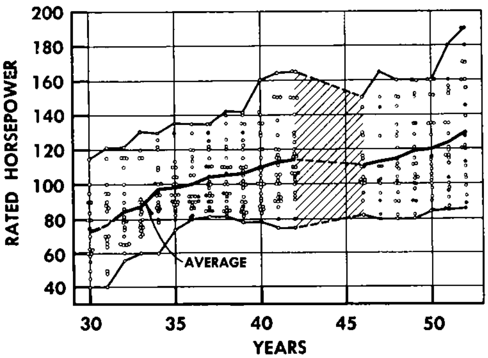

Figure 2. Trend of rated horsepower from 1930 to 1952

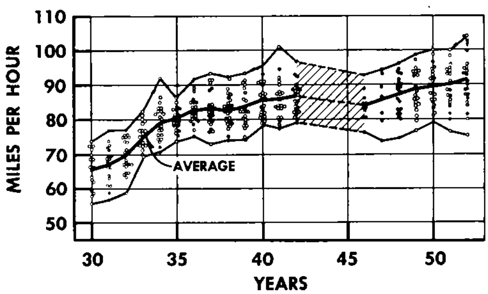

Figure 3. Trend of maximum car speed from 1930 to 1952

of work to give better acceleration and hill climb at all speeds and is nowhere as great as many uninformed people would lead one to believe. In 1941 there were production automobiles on the highways that would do better than 100 mph. From that time to the present increase for the highest-speed production car has been in the neighborhood of only 5 mph. This curve has been discussed before the performance curve because increased top speed is not the aim of the present automotive development, but is a value which results from the increase in performance demanded by drivers confronted with present traffic conditions.

Figure 4 presents performance trends in terms of time to accelerate from 10 to 60 mph. Note that the vertical scale of this chart is in seconds and is inverted. By this system of plotting, the higher a point appears on the chart the better the performance and the smaller the time in seconds required to accelerate from 10 to 60 mph.

The curves of acceleration indicate increased performance over the period studied, but since resumption of production in 1946, some unusual factors have affected the trend.

We have several very-low-performance models and a number of very-high-performance cars. The low cars have sacrified performance to gain economy. It will be of interest to point out that the highest-performance

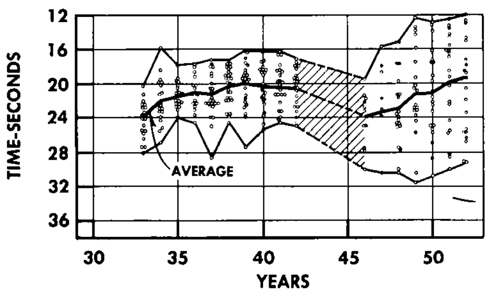

Figure 4. Trend of time to accelerate from 10 to 60 mph., 1933 to 1952.

cars represent those with the most-modern high-compression engines, which are, at the same time, among the most economical.

Many people think that the automobile industry has sacrificed economy when it has increased performance and size of the car over the years. The average curves, Figure 5, of level road constant speed economy at 20, 40, and 60 mph. show that there has been a constant upward trend in miles per gallon, which comes as a surprise to many. For instance, at a cruising speed of 40 mph., the average has increased from approximately 15 mi. per gal. to almost 20 mi. per gal. from 1930 to 1952. This is more than a 30 percent increase in economy, even though our automobiles have become larger and better performing. A large increase is noted at all speeds from the lowest to the highest.

A more fundamental analysis from the standpoint of engine and transmission development is based on a figure of ton-miles per gallon, as in Figure 6. The term ton-miles per gallon has been devised in automobile engineering to permit a comparison of efficiency between vehicles of different sizes and weights. For instance, it is perfectly evident that a motor scooter should run on less gasoline per mile than a 5-ton truck, but from that basis we know nothing about the relative efficiency of the two engines. If, however, we determine the number of gallons of fuel to drive each vehicle a mile and then calculate from their relative weights the number of tons of weight each gallon of fuel will move a mile, we have a basis for comparing directly the efficiencies of the engines and power trains.

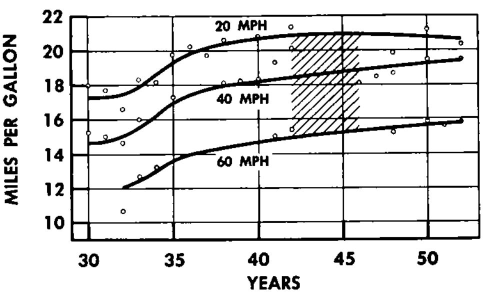

Figure 5. Trend of fuel economy at 20, 40, and 60 mph., 1933 to 1952.

In the figure we have plotted the spread in ton-miles per gallon at a speed of 40 mph. Here it can be seen that the best 1930 model gave 35 ton-mi. per gal. while the poorest 1952 model gave 40.

The spread from the poorest in 1930 to the best in 1952 was from about 22 to almost 50 ton-mi. per gal. At the 40-mph. cruising speed, the average ton-miles per gallon has increased from 28 to 43. This represents a gain of about 53 percent in the ability to move a ton 1 mi. with a given quantity of fuel.

These first figures give a historical picture of trends in automobile design, in so far as performance and economy are concerned, over the past two decades. We have increased the ability to accelerate greatly and at the same time have improved fuel economy in general. It will now be of interest to look at what the improvement in acceleration in the current automobile can do for us. As everyone is well aware, on our highways of today we have a variety of vehicles moving at widely different rates of speed. We have the heavily laden truck pulling up a grade in creeper gear, the vacationer with a house trailer, the businessman who urgently needs to get to a business appointment in as little time as possible, the country dweller trying to get a sick child to the hospital, the soldier on furlough with just a few hours to spend at home, and a host of others, each having a need for a different rate of speed depending on his particular situation. Now without the ability to accelerate and pass slowly moving vehicles, traffic on the highways would become in essence a series of railroad trains without the safety afforded by couplings and headed by the slowest-moving vehicles on the highway.

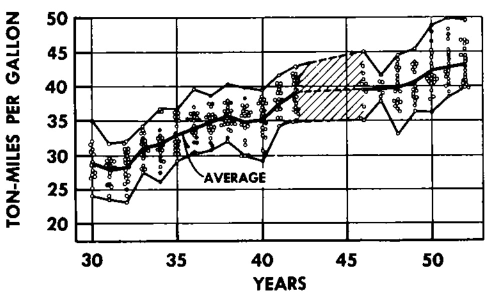

Figure 6. Trend of fuel economy at 40 mph., 1930 to 1952.

In fact, such is almost the situation in many over-crowded highways today. We can all agree that the safest condition to drive in is when we have a great excess of clearance from other vehicles on all sides of us. Due to the need and desire of different drivers for different rates of speed, trains of traffic which develop at stop lights or from other temporary obstructions tend to separate if given the ability and opportunity to do so. This, of course, is accomplished by passing slower-moving vehicles. In doing this, the driver trades the long-continued hazard of driving in close proximity with other vehicles for the much shorter, if somewhat greater, hazard of passing. The shorter is the time required to pass a vehicle ahead and get back in the driving lane the safer is the maneuver; this also gives the driver more opportunity to pass safely. Because of this, the automobile manufacturer has, over the years, steadily increased the ability of the automobile to accelerate.

In order to give you some idea as to what this added acceleration will do for us, the following figures were prepared.

Figure 7 is the time-distance curve of a car traveling at a constant speed of 40 mph. In every second's time, it has traveled on its course about 60 ft., as can be read from the vertical scale on the left.

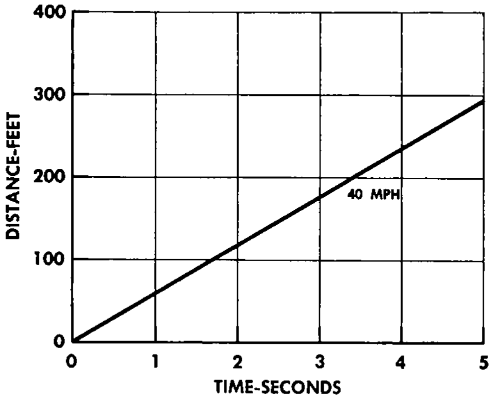

Figure 7. Time and distance at a constant speed of 40 mph.

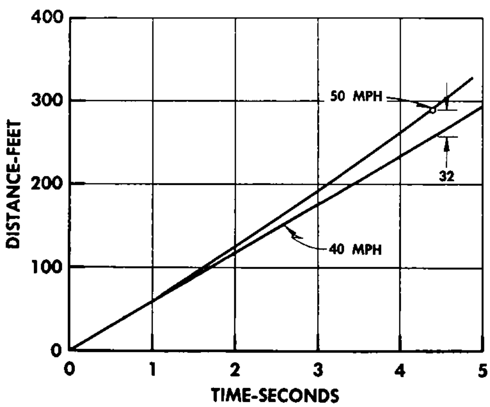

Figure 8. Time-and-distance comparison of two cars; one at a constant speed of 40 mph. and the other accelerating from 40 mph., wide-open throttle.

Figure 8 is the same chart, except that we have added to it the curve in time and distance of a car which is accelerating from 40-mph. velocity at wide-open throttle. The point at which this car reaches an instananeous velocity of 50 mph. is indicated by the dot on the upper curve. Reading along the horizontal scale we find that it required 4.4 sec. for this car to accelerate from 40 to 50 mph., and reading along the vertical scale we find it required 292 ft. of distance. During the 4.4 sec. the car traveling at 40 mph. constant speed covered a distance, again reading from the vertical scale, of 260 ft., which placed the accelerating car 32 ft. ahead of it at the 50-mph. point, as indicated by the two arrows.

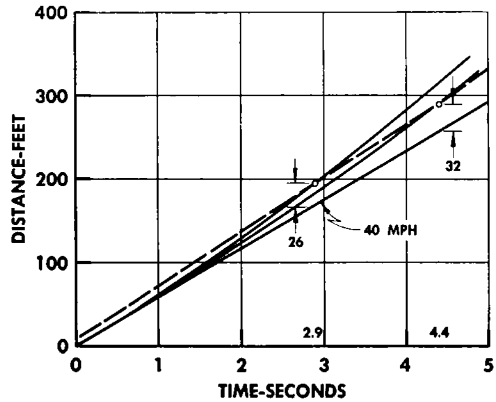

Figure 9. Time-and-distance comparison; one car at a constant speed of 40 mph. and two others accelerating at wide-open throttle from 40 mph. but at different rates.

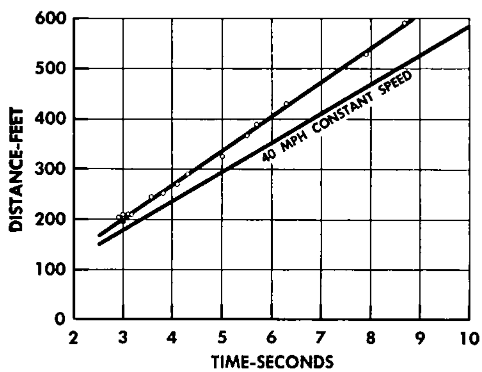

Figure 10. Comparative distance-time to accelerate from 40 to 50 mph. at wide-open throttle, 1952 cars.

Figure 9 is the same chart except that we have added the curve of another car having a higher accelerating rate. Again we have marked with a dot the point in time and distance at which this car reaches the instantaneous velocity of 50 mph., starting from 40 mph. The broken line between the two dots has a slope of 64 ft. per sec.

Figure 10 is a plot of the 50-mph. points of a number of current production cars all accelerating from a constant speed of 40 mph.

From this we can see that all points fall on a straight line within a fair approximation, and that the slope is about 68 ft. per sec. Looking at the points at the extremities of the line we can see that among current production cars the best performers can accelerate from 40 to 50 mph. in about 200 ft. and the poorest require nearly 600 ft. These values were derived by use of transmission gear combinations giving maximum performance in this speed range.

Figure 11 presents schematically the benefits gained by a high-performance car in passing on the highway. At the top of the chart we have a plan view of a two-lane highway on which are traveling three cars, A, B, and C. Car A overtakes and passes Car B, following the path of the arrow. Car C is traveling in the opposite direction, meeting Cars A and B.

The horizontal bars below the sketch are in pairs representing the two lanes of the roadway and the distances traveled by the different vehicles. The level of performance is measured by the time it takes Car A to pass Car B, allowing only minimum clearance; this required Car A to travel three car lengths farther than Car B, which is assumed to be 60 ft. The six pairs of bars represent cars of different levels of performance. The 4.6-sec. car and the 7.1-sec. car have about the best and poorest passing times of this year's production; these values represent the maximum performance in any gear ratio. All cars on the chart are assumed to be traveling at a constant speed of 40 mph. with the exception of Car A, which accelerates at its maximum rate starting from 40 mph. at the zero line on the left side of the chart and passing Car B. The cross-hatched bar at the left represents the distance traveled by Car B while Car A is passing it. The black bar at the right of the chart represents the distance traveled by the opposing Car C while A is passing. The space between the two sloping lines extending from the bottom of the chart upward and marked 200 ft. represents an arbitrary minimum safe clearance distance for the passing Car A. This is held a constant for all cars on the chart. The sloping line through the right terminals of the black bars mark the closest point which the oncoming Car C can be for a safe passing clearance of Car A. Reading from the zero line to this point gives us the minimum distance at which Car A can attempt to pass Car B.

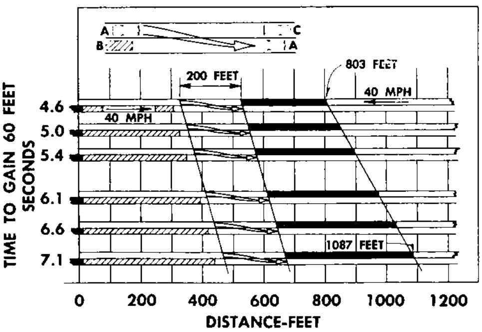

Figure 11. Comparison of passing distance and performance level.

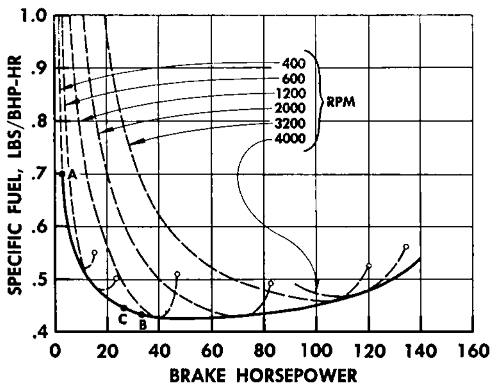

Figure 12. Relationship of specific fuel consumption and brake horsepower at constant engine speeds.

It will be of interest to note that the poorest car requires that the oncoming car must be a distance away of 1,087 ft. at the start of the pass, while the best performance car required 803 ft. This represents a saving of 26 percent in distance and 35 per cent in time. The best 1952 car completes the passing maneuver in 284 ft. shorter distance and 2.5 sec. shorter time than the poorest; this gives additional head clearance at the rate of 114 ft. per sec. improvement in performance level. This illustrates to some degree the advantages to be realized from the modern high-performance car. It is understood, of course, that these data were measured on current cars in the best mechanical condition and adjustment and carrying a reasonable test load. Some older cars, cars in poor condition, and overloaded cars will fall somewhere down along the right diagonal line on the chart.

This high level of performance has been achieved by the use of high-horsepower engines. Many people have asked cannot this high performance be attained by means of lower axle ratios and smaller engines, which will reduce the top speeds. The answer is that it can, but at an appreciable sacrifice in economy. The following figures will illustrate the characteristics of gasoline engines which bring about this loss in economy.

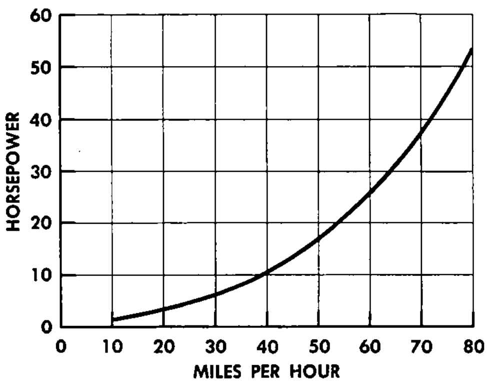

Figure 13. Wind and rolling resistance at constant speed.

The next chart, Figure 12, is a plot of specific fuel in pounds per brake-horsepower-hour against brake horsepower for a number of different speeds in revolutions per minute of a typical automobile engine; the data for this chart were derived from dynamometer tests. As can be seen, the horsepower-fuel relationship for this engine is plotted in a family of curves for 6 different speeds of the engine in rpm. From these curves we can determine the most economical speed at which we can develop any horsepower. As an example, suppose we want to develop 40 brake horsepower. If we follow the vertical coördinate upward from 40 horsepower we first cross the 1,200-rpm. curve at about 0.43 lb. per bhp.-hr., next we cross the 2,000-rpm. curve at 0.5 lb. per bhp.-hr. and finally we cross the 3,200-rpm. curve at 0.62 lb. per bhp.-hr., showing that the best economy can be obtained when the engine is developing 40 horsepower at the lower speed. A similar condition is found at other horsepowers throughout the range.

Figure 13 is the road-load-horsepower chart of a typical, 4,000-lb car. Road-load horsepower is the horsepower required to maintain any constant speed on a level road. As an example from this chart, a driver who cruises at a speed of about 55 mph. requires 20 horsepower most of the time, and if he travels at 40 mph. he requires 10 horsepower. Considering just those two cruising speeds for the sake

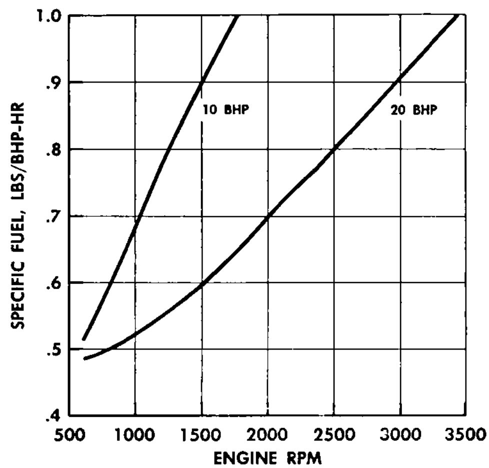

Figure 14. Relationship of specific fuel consumption and engine speed at constant outputs in brake horsepower.

of simplicity we will now look at Figure 14. Here we have plotted the fuel used in pounds per hour to develop 10 horsepower and 20 horsepower at different engine speeds in rpm. From this it becomes evident that if we install a small engine in a car which has to be geared to the drive wheels with such a ratio for the sake of performance that it turns 1,800 rpm. to develop 10 horsepower, we can expect it to burn 1 lb. of fuel for every brake-horsepower–hour. On the other hand, if our engine is large enough to give us this same level of performance when it is geared to the drive wheels with such a ratio that it develops 10 horsepower at 600 rpm., we can expect it to burn only 0.52 lbs. of fuel for every brake horsepower. This same thing holds true of course for any other horsepower which may be required, and so if we are to get fuel economy from an engine, we must gear it to the drive wheels of the car so as to keep its revolutions per minute as low as possible.

The design of American cars over the past years has been toward improvement in economy and performance, which requires powerful engines; in the package with this comes some increase in top speed.

In the future we can expect further improvements in economy by wider use of the new high-compression engines and further improvement in fuels. Some improvement in performance will probably be made, although at the lower speeds, especially with modern high-compression engines and automatic transmissions, the ultimate has been about reached. This ultimate, of course, is the point at which the coefficient of friction between the drive wheels and a dry pavement is insufficient to keep the wheels from spinning under full acceleration.

Braking Distances of Vehicles from High Speeds

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Braking distances were measured for 53 passenger cars making stops from speeds ranging from 20 to 90 mph. on a concrete surface. The average distances traveled after the brakes had been applied were 22 ft. from a speed of 20 mph., 130 ft. from 50 mph., and 585 ft. from 90 mph. Some of the passenger cars required more than 600 ft. to stop from 75 mph.

During the tests, information was obtained on the acceleration rates of passenger cars, the reaction time of drivers, and the effect of brake fade or the temporary reduction of brake effectiveness resulting from heat.

In an effort to relate the braking distances of the vehicles to the coefficient of friction between the tires and the road surface, equipment was developed to measure coefficients of friction of road surfaces. Comparisons were obtained for different types of road surfaces when dry and wet and for different tires. It was found, for example, that some surfaces which had the highest friction coefficients when dry had the lowest coefficients when wet. It was also found that two sets of tires which had identical tread patterns and consisted of the same rubber compound could cause a difference of 30 percent in braking distances.

● IN December 1940, the late Ernest E. Wilson, who was at that time director of the General Motors Proving Ground, reported the results of tests to determine deceleration distances for high-speed vehicles. He used 15 passenger cars in perfect condition and eight highly experienced test drivers to obtain braking distances for speeds ranging from 50 to 70 mph. Since 1940, about 35 million passenger cars have been built in the United States, but few if any results of tests to determine braking distances from high speeds have been reported. There have been numerous reports for tests made from speeds of 20 to 40 mph., but passenger cars are now being operated at an average speed of about 52 mph. on our main rural highways, with about 12 percent exceeding 60 mph., and an occasional vehicle traveling in excess of 80 mph.

One possible reason that more high-speed tests have not been conducted is the common assumption that any passenger car with brakes in good condition can lock all four wheels and that shorter stopping distances can be realized only through improving the texture of road surfaces to obtain higher coefficients of friction, especially for wet surfaces, and by avoiding the use of tires that have worn smooth.