Review of Vehicle Dimensions and Performance Characteristics

K. A. STONEX, *Assistant Director*
General Motors Proving Ground, Milford, Michigan

This paper is concerned with the review of dimensions and performance characteristics of current passenger cars relevant to highway and traffic engineering, including trends for the last 25 years.

Included are trend studies of such factors as passing performance, acceleration characteristics, fuel economy, horsepower, size, weight, ground clearance, approach and departure angles, tread width, center of gravity height, and driver eye height.

• THE PURPOSE of this paper is to review the trends of dimensions and performance characteristics of American-made passenger cars because of the close relationship of vehicle and highway design.

Dimensional characteristics of passenger cars have been reviewed (*1*) and the trends studied for a 30-year period up to and including 1957 models.

Engineering test data showing characteristic performance trends, including a 25-year trend up to and including 1953 cars, also have been reviewed (*2*).

Because of the increasing interests among highway and traffic engineers in the dimensions and performance characteristics of automobiles, it is timely that these data be brought up to date to include the more important characteristics of current automobiles.

One of the dimensions most interesting to highway designers is that of the driver's eye height. For more than 20 years, the AASHO design policies with regard to stopping distance have been based on a driver's eye height of 4.5 ft above the ground and an obstacle 4 in. high, which is presumably the practical case of the smallest obstacle which a driver would need to avoid (Fig. 1).

In spite of previous data (*1*), there is still growing concern among highway designers that, with the increased emphasis on reduction of over-all height, the driver's eye position may go down to the point where the 4.5-ft standard will no longer be applicable and the design criteria for the crest vertical curves will be invalid. The trend of over-all height of

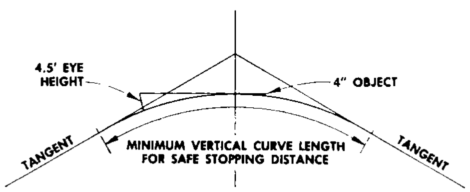

Figure 1. AASHO design policy on heights of eye and object for vertical curves.

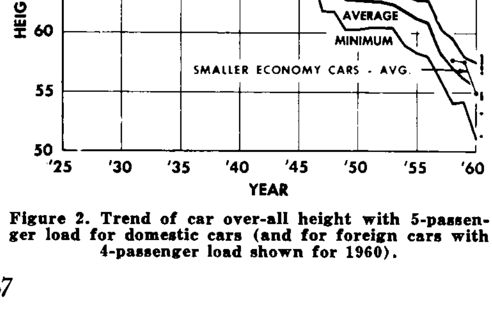

Figure 2. Trend of car over-all height with 5-passenger load for domestic cars (and for foreign cars with 4-passenger load shown for 1960).

representative domestic cars from 1927 through 1960 is shown in Figure 2. A separate curve showing the average of the domestic smaller economy cars is given. Heights of individual 1960 compact and foreign cars are indicated by separate points.

A laboratory test in use at the General Motors Proving Ground to measure comparative driver visibility has been previously discussed (*1*). This procedure was developed 25 years ago and it included a value of driver's eye height which had been determined from the average of a number of male drivers.

An independent observation on male employees by another division in General Motors, at approximately the same time, checked this value approximately. Based on this observation, a driver's eye height of 28.5 in. above a firm seat was established. Observations showed that the average seat cushion depressed about 2 in. under the driver's weight, so that the test procedure provided the location of the driver's eye to be 26.5 in. above the undepressed seat cushion. Adjustments were made in the driver's eye height of the most recent years where actual depressions of seat cushions in modern automobiles had been measured (*1*).

A recent critical review of this test procedure indicated that this value of average driver stature should be modified because of the increasing number of female drivers and because more data of other and larger population samples have become available.

Figure 3 shows data which have been found in the literature (*3*). Included are certain other observations made by the Proving Ground and other General Motors groups. At the left of the chart are some observations on various classi-

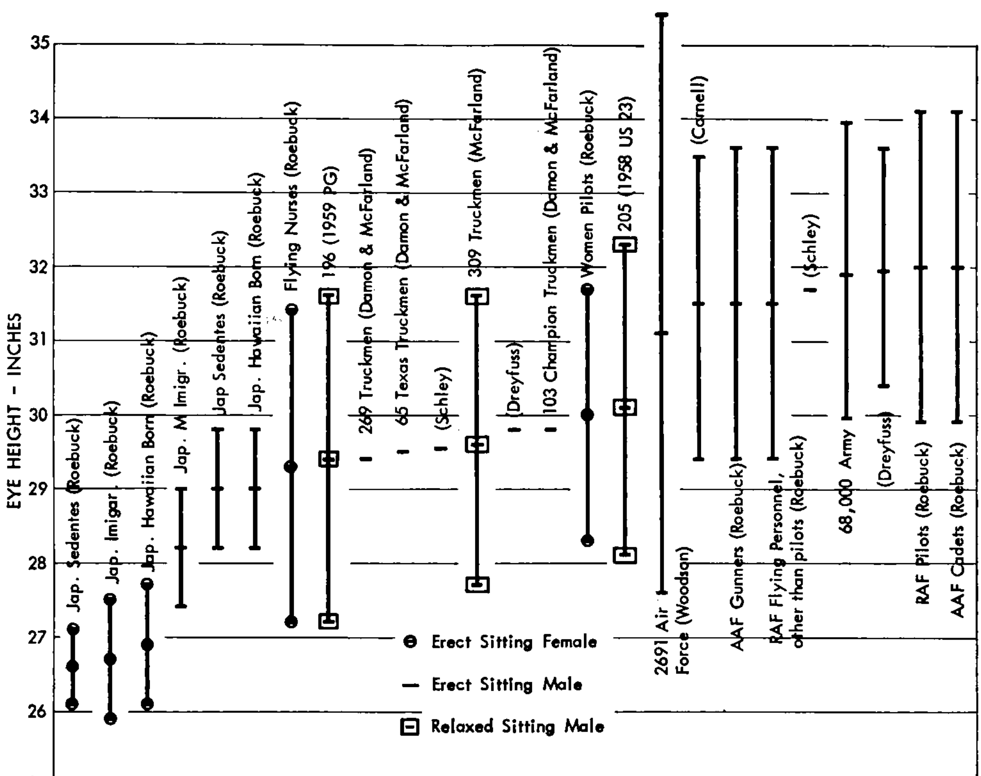

Figure 3. Data found in the literature on driver eye height above a firm seat.

fications of Japanese; on the right of the chart are observations covering Army and Royal and American Air Force personnel. In the central portion of the chart are data from several sources indicating that the average male seated eye height should lie in the range between 29 in. and 30 in. above a firm seat; this group of data shows ranges from minimum to maximum, and these ranges are roughly comparable for all studies.

It should be noted that in many cases the conditions covering the observation of the data reported in Figure 3 are not sufficiently specific to make direct comparisons possible. In some cases, observations are described as "erect sitting," "relaxed sitting," and in other cases, the conditions are not stated.

A driver may slump 2 or 3 in. after some extended period of driving on the road. Because the data shown in Figure 3 are not defined specifically in many cases, it was necessary to make supplementary observations to gain additional information on the amount of driver slump.

In the Proving Ground laboratory test it was necessary to establish the stature heights of normally relaxed drivers from the depressed seat cushion to the eye point. When this value is established

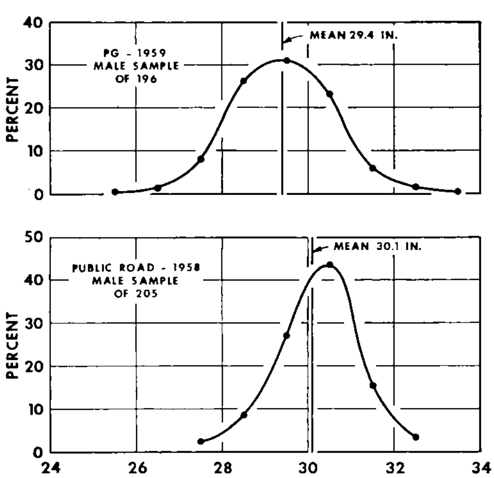

Figure 4. Percent frequency distribution of driver eye height above a firm seat.

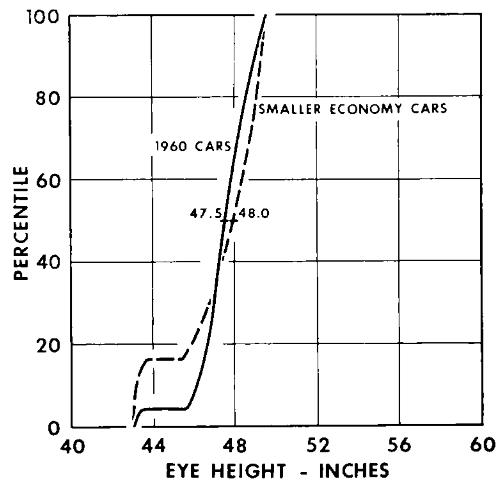

Figure 5. Percentile distribution of driver eye height above the ground for 1960 cars.

with some degree of confidence, it is comparatively simple to convert the results of laboratory tests to terms of driver eye height above the road. Primary interest, however, was in developing a technique by which visibility from representative cars can be compared.

Figure 4 shows frequency distributions in percent of measurements of the vertical distance from the depressed seat cushion to the eye point of two samples of males. The upper curve is a sample of 196 male employees at the Proving Ground which shows a mean value of 29.4 in. The lower curve is from a group of 205 males observed as they were driving on a public highway and shows a mean of 30.1 in. These distributions cover a relatively wide range, from approximately 26 in. to more than 33 in.

After extensive study, it was concluded that the best single value representative of the average American driver is 29.1 in. above the depressed seat cushion; this is an average of male and female drivers, weighted 60:40 in favor of males because of the preponderance of male drivers.

Figure 5 is a percentile distribution of "average" driver eye heights above the road on 1960 cars; a separate curve is shown for 1960 smaller economy cars alone.

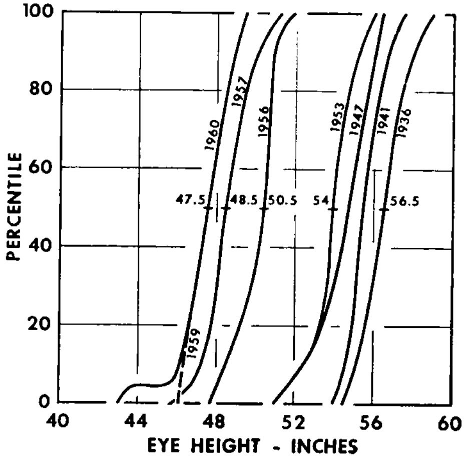

Figure 6. Percentile distribution of driver eye height above the ground since 1936.

Figure 6 shows percentile distributions of the best estimate of average driver eye height above the ground since 1936. This shows that the median driver eye height above the ground has decreased from 56.5 in. in 1936 to 47.5 in. in 1959.

It is conceded that the trend toward the lower driver eye height will have some bearing on the crest vertical curve sight distance and some of the existing highways built according to the minimum standards may be rendered obsolete with the change in the driver eye height (*4*). Any forecasts of future automobile trends must take into account two basic problems in vehicle design, entrance and visibility. Because automobiles must conform to the existing highways, it is not anticipated that the minimum height of volume production passenger cars will be much lower than 52 or 53 in., or that average driver eye heights will fall below 42 to 43 in. (*1*).

The reduction in the over-all height of the vehicle has permitted a reduction in the center of gravity height. Figure 7 shows the trend of the center of gravity heights for domestic cars from 1935 through 1959; the center of gravity height has been reduced from an average of approximately 24.7 in. in 1935 to an average of approximately 21.5 in. in 1959. Thus, it is shown that it has been re-

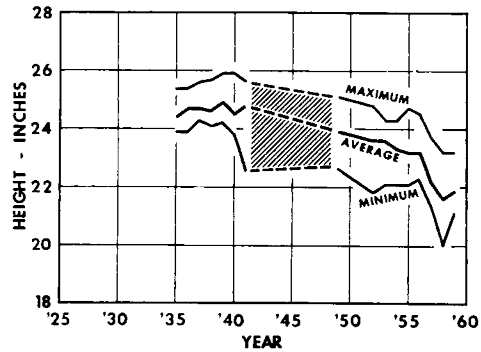

Figure 7. Trend of center of gravity height of domestic cars from 1935 to 1959.

duced more or less proportionately with the over-all height.

The significance of the effect of the center of gravity height on vehicle stability is discussed elsewhere (*5*).

The over-all length of domestic passenger cars has increased somewhat during the last 30 years, as shown in Figure 8.

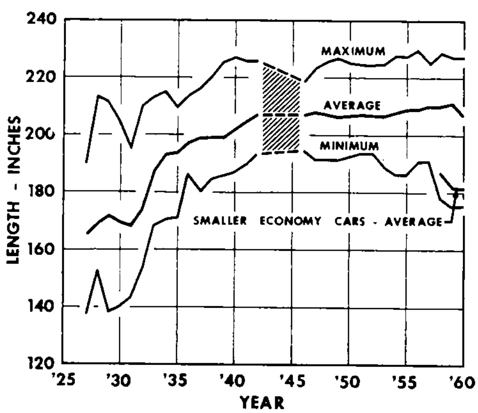

Figure 8. Trend of over-all length of domestic cars from 1927 to 1960.

However, the longest car has not changed appreciably since 1939, and the shortest car has become approximately 15 in. shorter since 1946. A separate curve shows the average of the domestic smaller economy cars.

Figure 9 shows the trend of over-all widths of domestic passenger cars since 1927. There was a steady increase in width of all cars until the 1942 models,

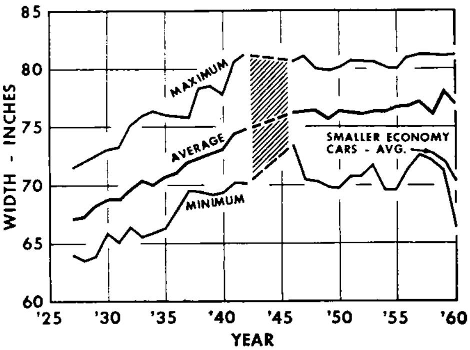

Figure 9. Trend of over-all width of domestic cars from 1927 to 1960.

where the widest cars began to become complicated with some state regulations; there has been little change since. The widest cars have not increased in width for the last 15 model years and the average of the late domestic economy cars is not far different from that of the narrow cars of previous years.

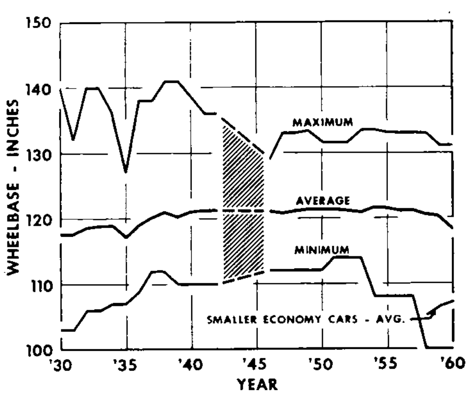

Figure 10. Trend of wheelbase of domestic cars from 1930 to 1960.

Figure 10 shows the trend in the wheelbase of domestic passenger cars from 1930 through 1960. The longest post-war car is shorter than several of the pre-war cars; the average has not changed significantly since 1938; the minimum car has been of the order of 108 in. to 112 in. since approximately 1936; and the average of the domestic cars is about the same as the minimum wheelbase.

To the designer of garage and drive-

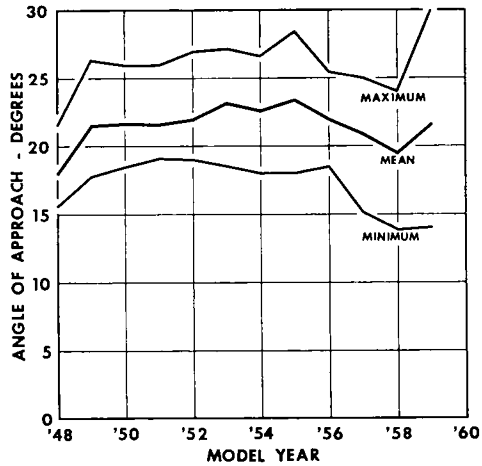

Figure 11. Trend of the angle of approach of domestic cars from 1948 to 1959.

way and parking lot ramps, the approach, departure, and ramp break over angles are of significance. Figure 11 shows the trend of the angle of approach. Since 1948, the maximum angle has increased to 30 deg and the minimum angle has varied from 15 deg up to 19 deg and then down to 14 deg.

The trend of angle of departure is shown in Figure 12; the minimum value here decreased to approximately 10 deg in 1954 and has stabilized at approximately that value.

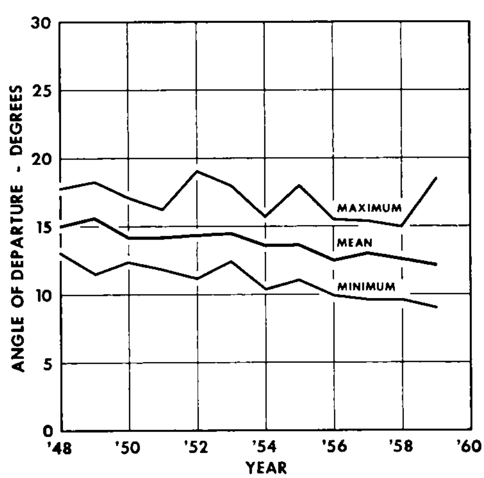

Figure 12. Trend of the angle of departure of domestic cars from 1948 to 1959.

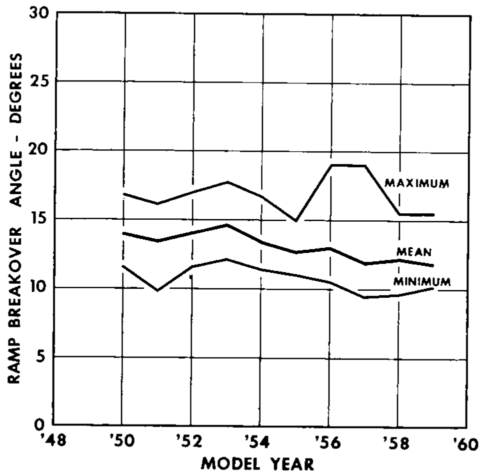

Figure 13. Trend of the ramp breakover angle of domestic cars from 1948 to 1959.

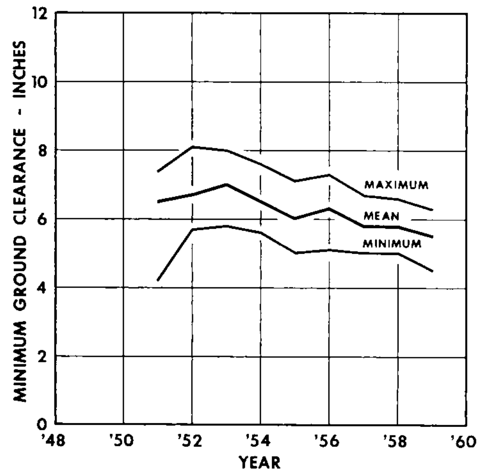

Figure 14. Trend of the minimum ground clearance of domestic cars from 1951 to 1959.

The ramp breakover angle trend is shown in Figure 13. There has been a steadily decreasing trend of the average value, but the minimum has stabilized at approximately 10 deg since 1957.

An SAE Technical Committee has been reviewing this problem and it is hoped that SAE standards on these three angles will be approved in the near future.

The trend of minimum ground clearance is shown in Figure 14. The minimum value appears to have stabilized at about 5 in.

One of the features which makes the domestic car desirable in the eyes of its owner is its flexibility in the traffic stream; flexibility is a significant factor in the most effective use of modern traffic facilities, especially entrance ramps. This flexibility is reflected as the time and distance required to complete a passing maneuver at road speed: 40 mph has been used as an example (*2, 6, 7*).

Figure 15 shows how this measurement is observed and gives representative passing times and distances for several cars ranging from the highest performing to the poorest performing in 1959 domestic production.

In the schematic at the top of Figure 15, it is assumed that car B is proceeding uniformly at the speed of 40 mph and that the driver of car A wishes to pass. In the meantime, car C is approaching from the opposite direction, also at the speed of 40 mph. It is evident that a car which will complete this passing maneuver within the shortest distance preserves a greater margin of safety and flexibility than a car which requires a longer distance. In this maneuver it is assumed that car A starts in the left lane with its front bumper even with the rear bumper of car B, accelerates full throttle until it passes car B and pulls back into the

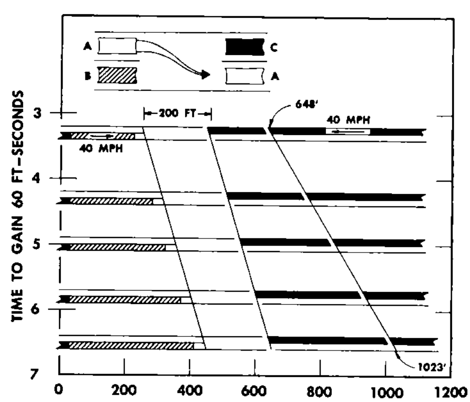

Figure 15. Range of passing distance from a 40-mph start for 1959 domestic cars.

right lane at a distance 200 ft ahead. The distance measured is that required to gain 60 ft on car B, plus the 200-ft clearance, plus the distance which car C would travel in this same length of time. The car with the optimum performance in 1959 would complete this maneuver in 648 ft and in 3.3 sec. In contrast, the car with the lowest performance in 1959 required a distance of 1,023 ft and 6.5 sec. There is a considerable variation in the passing distance capacity of cars.

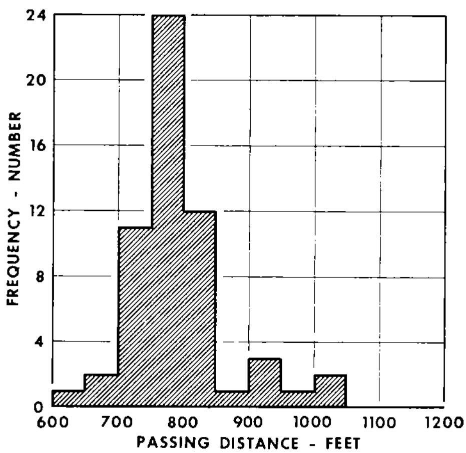

Figure 16. Frequency distribution of passing distance from a 40-mph start for 1959 domestic cars.

Figure 16 is a frequency distribution showing the variation in the passing distance capability of the 1959 cars at 40-mph start full-throttle acceleration; the mean value is 790 ft.

For comparison purposes, the data in Figure 16 are expressed as a percentile distribution in Figure 17. This is computed by accumulating the frequency in each class interval from Figure 16, expressed in percent. This gives a curve with a minimum passing distance of 600 ft, a maximum distance of 1,050 ft, and a median distance of 775 ft.

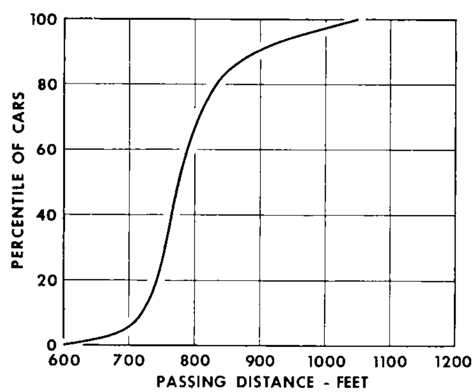

Figure 17. Percentile distribution of passing distance from a 40-mph start for 1959 domestic cars.

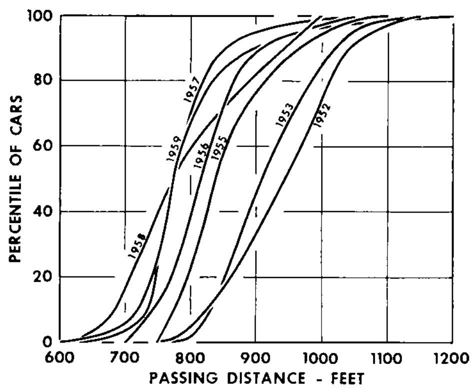

Figure 18. Percentile distribution of passing distance from a 40-mph start for successive model years from 1952 to 1959.

Figure 18 shows the percentile passing distance curves from 40-mph start for the successive model years from 1952 through 1959. There was a steady reduction in median passing distance until 1957. Because the passing distances required by the current economy cars are generally greater than those of the larger, higher-powered cars, it may be antici-

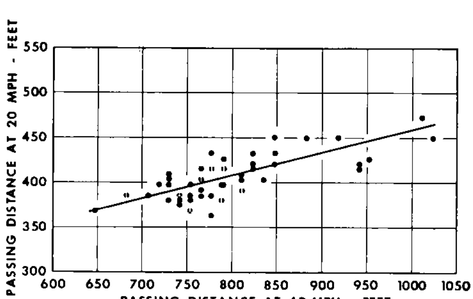

Figure 19. Comparison of passing distances at 20 mph and 40 mph.

pated that the median passing distance will remain near the 1957 value.

Figure 19 shows passing distance at 20 mph plotted against passing distance at 40 mph with the 1959 cars. In general, cars with relatively short passing distance at 40 mph also have relatively short passing distance at 20 mph, indicating that the single value at 40-mph initial speed may be used to represent comparative traffic flexibility.

In some instances, the time required to accelerate through some arbitrary speed range, such as 10 to 60 mph, is more useful than the passing distance as a measure of relative performance.

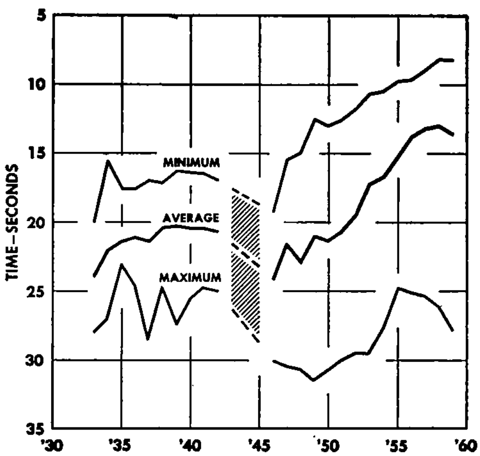

Figure 20. Trend of time to accelerate from 10 to 60 mph for 1933 through 1959.

Figure 20 shows the trend of time to accelerate from 10 to 60 mph for car models from 1933 through 1959. The cars with the minimum passing distance are shown at the top of the scale. The performance of most cars has increased quite rapidly since World War II. Cars with the lowest performance have required from 25 to 32 sec to accelerate through this speed range consistently.

Figure 21 shows the trend of rated horsepower from 1930 through 1960. The curve of maximum horsepower reached a peak in 1958 and that of the minimum horsepower car increased somewhat from 1946 to 1956 and then started a downward trend.

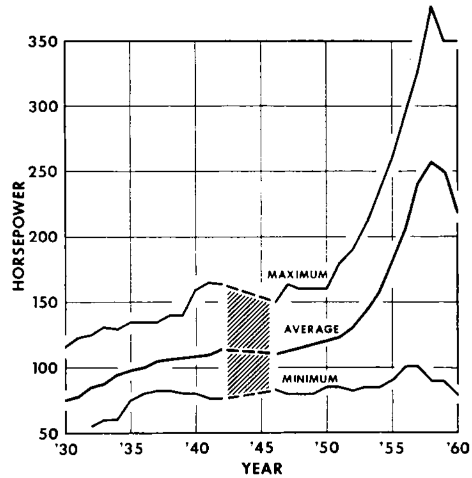

Figure 21. Trend of rated horsepower for domestic cars from 1930 to 1960.

The trend of the average curve continued to rise from World War II to 1958; since 1958, the average has decreased. It is probable that current levels will prevail indefinitely.

It is appropriate to discuss again the distribution of horsepower. Figure 22 shows the various aspects of horsepower

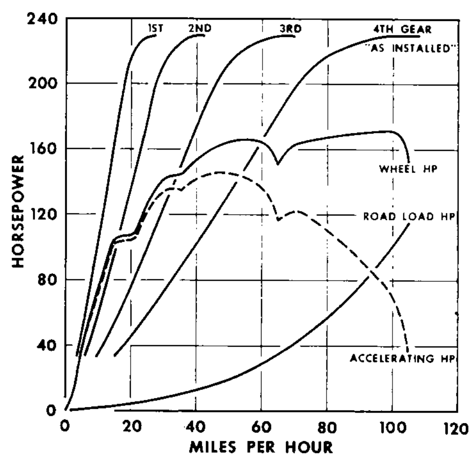

Figure 22. Comparison of "as installed", road wheel, acceleration, and road load horsepower.

on one of the larger 1959 cars. With the engine installed in a car and carrying certain accessories such as a fan, a generator, and other power-absorbing components, it developed an "as-installed" power of 230 hp. In the first range of this transmission, the 230 hp was developed at about 25 mph; in third gear, at about 65 mph; and in the top gear, at about 105 mph.

When the power required to accelerate the rotating parts of the power train is taken into account, the horsepower developed at the rear wheels has a maximum value of 172 hp. The power required to overcome wind and rolling resistance, or road load, rises approximately as the cube of the speed and, in this case, reaches approximately 100 hp at 100 mph, nearly the practical maximum speed of the car. At 100 mph, this leaves a residue of 72 hp which is available to accelerate the car; and the maximum of 146 hp available to accelerate the car occurs at 47 mph.

Since it is rear-wheel torque rather than horsepower which accelerates the car, it is perhaps more realistic to consider the output of this engine in torque as a function of speed and transmission gear ratio. Figure 23 shows four pairs

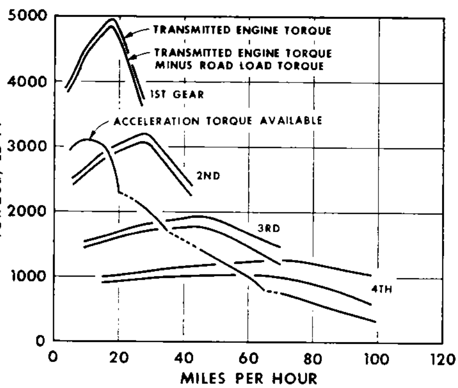

Figure 23. Comparison of engine torque transmitted to rear wheels and torque available for acceleration.

of curves, one pair for each of the gear ranges in the transmission. The upper curve of each pair represents the engine torque transmitted to the rear wheels, and the lower represents the residual torque after that required to overcome road load, wind and rolling resistance is subtracted. In first gear, the effect of road load, wind and rolling resistance is almost negligible, as wind resistance is low at low speed; in fourth gear, there is a considerable difference between the curves, approximately 50 percent of the transmitted engine torque at 100 mph. The residual torque available for acceleration, as measured on the road, is also shown. This reaches a maximum of 3,200 lb-ft at about 11 mph and drops to approximately 300 lb-ft at 100 mph.

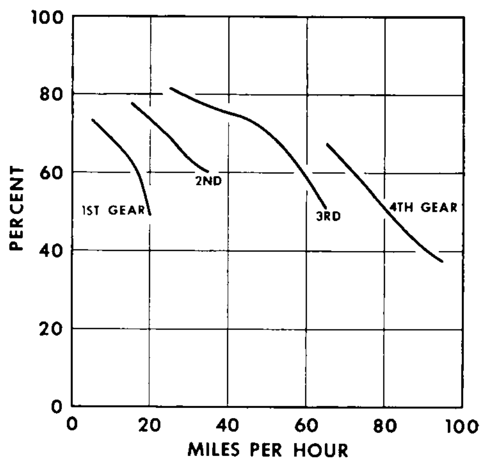

Figure 24. Acceleration torque in percent of transmitted engine torque for each gear ratio.

Figure 24 shows the acceleration torque in percent of the transmitted engine torque through the speed range and in each of the gear ranges. At speeds of about 5 mph, 73 percent of the torque transmitted to the rear wheels is available for acceleration in first gear but this falls to about 35 percent at 95 mph. Only a small proportion of the engine power is available for acceleration in the upper part of the speed range.

High-powered cars require less passing distance than low-powered cars. But, as suggested in Figures 23 and 24, the relative decrease in passing distance falls off as the horsepower is increased. This has been shown elsewhere (*7*).

The trends of fuel economy in miles per gallon under constant speed conditions on a level road at 40 mph are shown in Figure 25. This is a somewhat ideal-

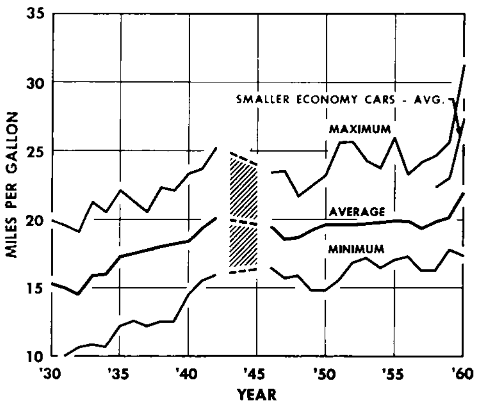

Figure 25. Trend of level road load fuel economy at 40 mph for domestic cars from 1930 to 1960.

ized engineering condition; although it may not be realized by the car owner, it is representative of the design characteristics of the automobiles involved. These curves show a rapid increase in fuel economy up to World War II and a slight decrease in the years immediately afterward, followed by a slow but steady increase up to the current period. The average of the group shows, generally speaking, a steady rise in spite of the added number of optional power-absorbing accessories carried on many of the cars. Fuel economy at 40 mph on the average car has been increased from 15 mi per gal in 1930 to approximately 22 mi per gal in 1960. Smaller economy cars are shown as a special group with an average of approximately 27 mi per gal in 1960.

The conditions of cross-country operation are reflected more accurately in Figure 26, which shows trend data since 1933 measured on a typical highway run on Michigan rural roads covering approximately 300 mi at an average speed of about 45 mph. The route includes some urban and small-town operation.

The cars showing the best economy reached a maximum in 1955; there has been a slight decrease since then, largely because of the increased use of power-absorbing accessories. Smaller economy cars increased the average in 1960. The cars showing the lowest highway economy have been nearly uniform since 1955.

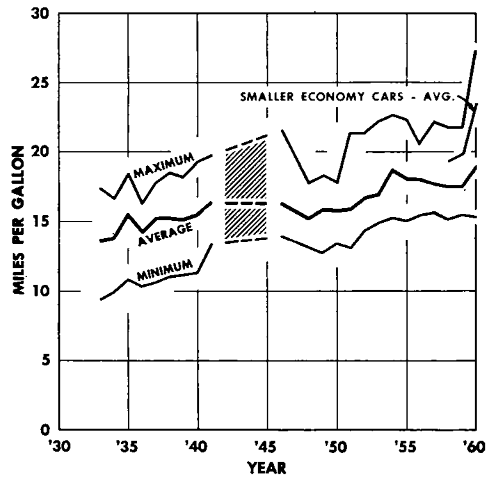

Figure 26. Trend of highway fuel economy for domestic cars from 1933 to 1960.

The average has increased from about 13.5 mi per gal in 1933 to approximately 18.5 mi per gal in 1960. The economy cars have an average of 23.5 mi per gal.

Fuel consumption is related closely to vehicle weight because energy derived from burning fuel is used in performing the work of moving the weight of the car.

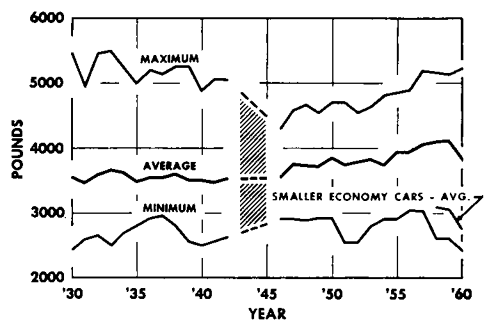

Figure 27. Trend of curb weight for domestic cars from 1930 to 1960.

Figure 27 shows the trend of curb weights from 1930 to 1960. Although the average of the cars in the fleet has increased from about 3,500 to 4,100 lb, the weight of the heaviest car has fallen since the early 1930's by nearly 500 lb and the weight of the lightest car, except for the economy cars, has increased about 500 lb. Therefore, even though the average curb weight of the cars has increased more or less steadily through the 30-year period, the constant-speed fuel economy average has increased approximately 30 percent and the average highway economy has increased by about 25 percent.

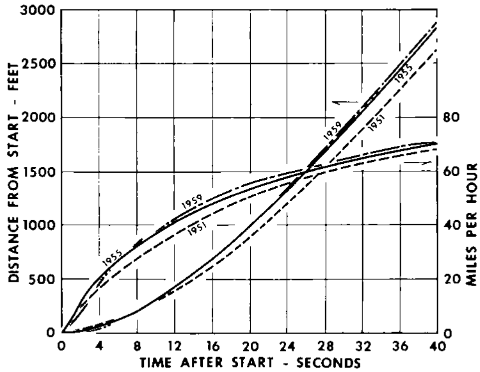

Figure 28. Time-distance and time-speed comparison of the poorest performing cars for three model years.

Figure 28 shows the time-distance and time-speed relationships of the car with the lowest performance for the years 1951, 1955 and 1959. There has been only a small increase in performance for cars at this level; for example, at 40 sec after the start, the 1951 car had traveled slightly over 2,600 ft, while the 1959 car had traveled approximately 2,900 ft. At the same time, the speed attained by the 1951 car was 68 mph, while the 1955 and 1959 cars attained 70 mph.

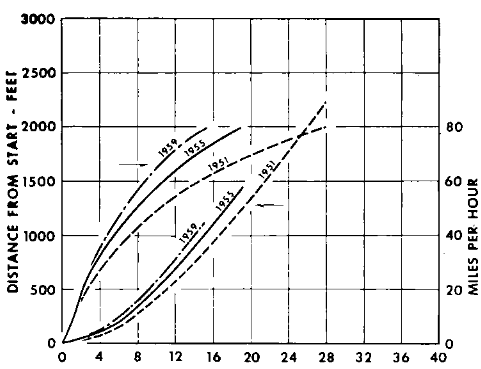

Figure 29. Time-distance and time-speed comparison of the best performing cars for three model years.

Figure 29 shows time-distance and time-speed relationships for the best-performing car for the same years. The 1951 car attained a speed of 80 mph in 28 sec while traveling 2,250 ft; the 1959 car attained this same speed in 15 sec and 1,120 ft. These charts can be used to determine approximately the time required and distances required to accelerate from one speed to another, or to determine the speed change developed and the distance traveled through a given length of time of full-throttle acceleration.

No paper on automobile characteristics would be complete without a chart showing the trend of the number of vehicles in operation and the number of miles operated. Figure 30 indicates that by the

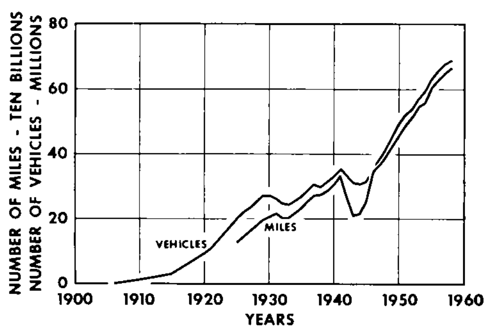

Figure 30. Trend of number of vehicles on the highway from 1906 to 1958 and number of miles driven each year from 1925 to 1958.

end of 1960, there will be about 70 million vehicles on the road and that about 700 billion miles will be traveled during 1960. This is an increase of approximately 40 million vehicles and a yearly rate of travel of nearly 400 billion miles in the last 15 years.

ACKNOWLEDGMENT

The extensive contributions of Mrs. Arline Marshall in the preparation of this paper are acknowledged gratefully.

REFERENCES

1. Stonex, K. A., McConnell, W. A., and Nagler, L. H., "Relation Between Vehicle Characteristics

and Highway Design." HRB Bull. 195 (1958).
2. STONEX, K. A., "Relation Between Automobile and the Highway." *HRB Proc.* 33:91-103 (1954).
3a. McFARLAND, R. A., ET AL., "Human Body Size and Capabilities in the Design and Operation of Vehicular Equipment." Harvard School of Pub. Health, Boston (1953).
3b. WOODSON, W. E., "Human Engineering Guide for Equipment Designers." Univ. of California Press, Berkeley (1956).
3c. Armored Medical Research Laboratory (Source: Office of Surgeon General), "Percentile Dimensions of Human Beings (Male) 1944."
3d. DREYFUSS, H., "Designing for People." Simon & Schuster (1955).
4. LEE, C. E., "Driver Eye Height and Related Highway Design Features." *HRB Proc.,* Vol. 39 (1960).
5. STONEX, K. A., "Roadside Design for Safety." *HRB Proc.,* Vol. 39 (1960).
6. CARMICHAEL, T. J., "Motor-Vehicle Performance and Highway Safety." *HRB Proc.* 32:414-421 (1953).
7. STONEX, K. A., "Lessons Learned by the Proving Ground Engineer in Highway Design and Traffic Control." *Proc. Instit. of Traffic Eng.* (1955).