Review of Vehicle Dimensions and Performance Characteristics

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The purpose of this paper is to review the trends of dimensions and performance characteristics of American-made passenger cars because there is a close relationship between vehicle and highway design.

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 upon a driver's eye height of 4.5 feet above the ground and an obstacle four inches high, which is presumably the smallest obstacle which a driver would need to avoid. This is illustrated in Figure 1.

In spite of the data shown in Highway Research Board Bulletin 195, there is still growing concern among highway designers that with the increased emphasis on reduction of overall height the driver's eye position may go down and down to the point where the 4.5 feet standard will no longer be applicable and the design criteria for the crest vertical curves will be invalid. The trend of overall height of representative domestic cars from 1927 through 1960 is illustrated 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.

In Bulletin 195 a laboratory test to measure comparative driver visibility in use at the General Motors Proving Ground was discussed. 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.
AASHO DESIGN
HEIGTHS OF EYE AND OBJECT FOR VERTICAL CURVES

Fig. 1. Heights of eye and object for vertical curves—AASHO Design Policy.

Fig. 2. Trend of car overall height with 5-passenger load for domestic cars (and for foreign cars with four-passenger load shown for 1960).
An independent observation on male employees by another division in General Motors, at approximately the same time, checked this value. Based on this observation, a driver's eye height of 28.5 inches above a firm seat was established. Observations showed that the average seat cushion of that day depressed about two inches under the driver's weight, so that the test procedure provided the location of the driver's eye to be 26.5 inches above the undepressed seat cushion. In Bulletin 195 adjustments were made in the driver's eye height to the most recent years when actual depressions of seat cushions in modern automobiles had been measured.

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)*

Fig. 3. Data found in the literature on driver eye height above a firm seat. Included are certain other observations made by the Proving Ground and other General Motors groups. At the left of the chart are some ob-

* Numbers in parentheses refer to list of references.
Fig. 4. Per cent frequency distribution of driver eye height above a firm seat.

Observations on various classifications 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 inches and 30 inches 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 shown on Figure 3 are not given specifically enough 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 two inches or three inches after some extended period of driving on the road. Because the data shown in Figure 3 were 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 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. Our primary interest, however, was in developing a technique by which visibility from representative cars can be compared.
Figure 4 (page 185) shows frequency distributions in per cent 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 show a mean value of 29.4 inches. The lower curve is from a group of 205 males observed as they were driving on a public highway; the mean here is 30.1 inches. These distributions show a relatively wide range of from approximately 26 inches to more than 33 inches.

After extensive study, it was concluded that the best single value representative of the average American driver is 29.1 inches above the depressed seat cushion; this is an average of males and female drivers,
weighted 60:40 in favor of males because of the preponderance of male drivers. Figure 5 (page 186) 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 (page 187) shows percentile distributions of our 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 inches in 1936 to 47.5 inches 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, that must be worked out. Since 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 the 52 inches or 53 inches predicted in Bulletin 195, or that average driver eye heights will fall below the values of 42 inches to 43 inches predicted there.
The reduction in the overall 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 cars of domestic manufacture since 1935 through 1959. The center of gravity height has been reduced from an average of approximately 24.7 inches in 1935 to an average of approximately 21.5 inches in 1959. Thus, it is shown that it has been reduced more or less proportionately with the overall height.

The significance of the affect of the center of gravity height on vehicle stability is discussed in another paper.(5)

The overall length of domestic passenger cars has increased somewhat during the last 30 years, as shown in Figure 8. However, it will be noted that the longest car has not changed appreciably since 1939 and the shortest car has become approximately 15 inches shorter since 1946. A separate curve shows the average of the domestic smaller economy cars.
Figure 9 shows the trend of overall width of domestic passenger cars since 1927. There was a steady increase in width of all cars until the 1942 models when 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 shows the trend in the wheelbase of domestic passenger cars from 1930 through 1960. It may be noted here that the longest post-war car is shorter than several of the pre-war cars, that the average has not changed significantly since 1938, that the minimum car has been 108 inches to 112 inches since approximately 1936, and that the average of the domestic economy cars is about the same as the minimum wheelbase.
To the designer of garage and driveway 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° and the minimum angle has varied from 15° up to 19° and then down to 14°.

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

The ramp break over 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° since 1957.

It should be noted that 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 and it may be noted that the minimum value appears to have stabilized at about five inches.
One of the features which makes the domestic passenger 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 schematically 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 the 1959 domestic production.

In the schematic at the top of the diagram we assume that car "B" is proceeding uniformly at the speed of 40 mph and that the driver of
Fig. 12. Trend of the angle of departure of domestic cars from 1948 to 1959.
Fig. 13. Trend of the ramp breakover angle of domestic cars from 1948 to 1959.
Fig. 14. Trend of the minimum ground clearance of domestic cars from 1951 to 1959.
PASSING DISTANCE
40 MPH START
1959 CARS

Fig. 15. Range of passing distance from a 40-mph start for 1959 domestic cars.
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 we assume 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 right lane at a distance 200 feet ahead. The distance measured is that required to gain 60 feet on car “B,” plus the 200 feet clearance, plus the distance which car “C” would travel in this same length of time.

As shown on the chart, the car with the optimum performance in the 1959 fleet would complete this maneuver in 648 feet and in 3.3 seconds. In contrast, the car with the lowest performance in the 1959
fleet required a distance of 1023 feet and a time of 6.5 seconds. There is considerable variation in the passing distance capacity of 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 feet.

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 per cent. This gives a curve beginning with a minimum passing distance of 600 feet and a maximum distance of 1050 feet, as noted on Figure 16, and a median distance of 775 feet.

Figure 18 shows the percentile passing distance curves from 40 mph start for the successive model years from 1952 through 1959. This
Fig. 18. Percentile distribution of passing distance from a 40-mph start for successive model years from 1952 to 1959.
shows a steady reduction in median passing distance until 1957. Since the passing distances required by the current economy cars are generally greater than those of the larger, higher-powered cars, it may be anticipated 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 10-60 mph is more useful than the passing distance as a measure of relative performance.

Figure 20 shows the trend of time to accelerate from 10-60 mph for car models 1933 through 1959. In this chart 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 seconds to accelerate through this speed range consistently.
Figure 20. Trend of time to accelerate from 10 to 60 mph for 1933 through 1959.

Figure 21 shows the trend of rated horsepower 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.

The trend of the average curve continued the rise indicated since World War II up 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 on one of the larger 1959 cars. The engine of this car had a rated horsepower which we need not discuss here since it was measured under special laboratory conditions; essentially these cover a bare engine, which is entirely
appropriate because of development and design considerations. However, with the engine installed in a car and carrying certain accessories such as a fan, a generator, and other power-absorbing components, it developed and “as-installed” power of 230 hp as shown in Figure 22. In the first range of this transmission, the 230 hp was developed at about 25 mph; in third gear, this was developed at about 65 mph; and in the top gear of the transmission, 230 hp would be developed at about 105 mph.

When the power required to accelerate the rotating parts of the power train is taken into account, we find that 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 approxi-
HORSEPOWER

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

mately 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. This is shown in Figure 23. We note four pairs 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 or wind and rolling resistance is subtracted. In first gear the effect of road load, wind and rolling resistance is almost negli-
Fig. 23. Comparison of engine torque transmitted to rear wheels and torque available for acceleration.

gible, as wind resistance is low at low speed: in fourth gear there is a considerable difference between the curves amounting to approximately 50 per cent of the transmitted engine torque at 100 mph, near the practical top speed of this car. The residual torque available for acceleration, as measured on the road, is also shown. This reaches a maximum of 3200 lb-ft at about 11 mph and drops to approximately 300 lb-ft at 100 mph.

Figure 24 shows the acceleration torque in per cent of the transmitted engine torque through the speed range and in each of the gear ranges. Seventy-three per cent of the torque transmitted to the rear wheels is available for acceleration in first gear at speeds of about five mph, but in the upper part of the speed range this falls to something like 35 per cent at 95 mph. It is clear that 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 those of low-powered cars but, as suggested in Figures 23 and 24, the relative
ACCELERATION TORQUE
IN PERCENT OF
TRANSMITTED ENGINE TORQUE

Fig. 24. Acceleration torque in per cent of transmitted engine torque for each gear ratio.

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 on Figure 25. This is a somewhat idealized engineering condition. While 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
Fig. 25. Trend of level road load fuel economy at 40 mph for domestic cars from 1930 to 1960.

Accessories carried on many of the cars in this fleet. Fuel economy at 40 mph on the average car has been increased from 15 miles per gallon in 1930 to approximately 22 miles per gallon in 1960. Current smaller economy cars are shown as a special group and the average of this group was approximately 27 miles per gallon in 1960.

The conditions the owner experiences on cross-country operation is reflected much more accurately in Figure 26. Here are trend data since 1933 measured on a typical highway run on Michigan rural roads covering approximately 300 miles 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. Additional smaller economy cars increased the average in 1960. The cars showing the lowest highway economy have given nearly uniform economy since 1955.
Fig. 26. Trend of highway fuel economy for domestic cars from 1933 to 1960.

The average of the fleet of cars has increased from about 13.5 miles per gallon in 1933 to approximately 18.5 miles per gallon in 1960. The smaller economy cars, shown separately, have an average highway economy of 23.5 miles per gallon.

Fuel consumption is related closely with the vehicle weight because the energy derived from burning the fuel is used in performing work of moving the weight of the car. Figure 27 shows the trend of curb weights from 1930 to 1960. While we find that the average of the cars in the fleet has increased from about 3500 to 4100 lbs., the weight of the heaviest car has fallen since the early 1930's by nearly 500 lbs. and the weight of the lightest car, except for the smaller economy cars, has increased about 500 lbs. Thus, we find that, even though the average curb weight of the cars in the fleet has increased...
more or less steadily through this 30-year period, the constant speed fuel economy average has increased approximately 30 per cent and the average highway economy has increased by about 25 per cent.

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 in this level. For example, at 40 seconds after the start the 1951 car had travelled slightly over 2600 feet while the 1959 car had travelled approximately 2900 feet. 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 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 seconds while travelling 2250 feet; the 1959 car attained this same speed in 15 seconds and 1120 feet. 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 travelled 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 a number of vehicles in operation and the
Fig. 28. Time-distance and time-speed comparison of the poorest performing cars for three model years.

Number of miles operated. Figure 30 indicates that by the end of 1960 there will be something like 70 million vehicles on the road and that about 700 billion miles will be travelled 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.
Fig. 29. Time-distance and time-speed comparison of the best performing cars for three model years.
Fig. 30. Trend of number of vehicles on the highway from 1906 to 1958 and number of miles driven each year from 1925 to 1958.
REFERENCES


   c. Armored Medical Research Laboratory, Source: Office of Surgeon General—“Percentile Dimensions of Human Beings (Male) 1944.”


