

Functional Derivation of Vehicle
Parameters for Dynamic Studies
NRCC, September 1974

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FUNCTIONAL DERIVATION OF VEHICLE
PARAMETERS FOR DYNAMIC STUDIES

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SUMMARY

The primary purpose of this study was to provide vehicle data sets characterizing the subcompact, compact, intermediate and standard size categories of passenger cars. These data sets provide for parametric studies of the vehicle-terrain-cable barrier system using the NAE-Cornell analysis. A secondary objective was to derive parametric functional relationships which could be used to calculate typical values of the required parameters.

The objectives were met by a search of the published literature for vehicle parameter data. These data were then analyzed to establish parametric correlation with wheelbase length or total vehicle weight. This was done for several of the primary vehicle parameters required for parametric studies. Finally the results were used to generate data sets for the required vehicle categories.

RESUME

Le but principal de cette étude a été de produire des ensembles de données permettant la caractérisation de diverses tailles de voitures de série (souscompacte, compacte, intermédiaire et courante). Ces données permettent d'accomplir, au moyen de la méthode d'analyse NAE-Cornell, des études paramétriques du système véhicule-terrain-garde fou à cables. L'un des objectifs secondaires a été de mettre au point des équations paramétriques de façon à calculer des valeurs types des paramètres nécessaires.

Une recherche bibliographique concernant les données paramétriques de véhicules automobiles, a permis d'atteindre ces objectifs. Les données ont été analysées de façon à établir des corrélations entre les paramètres et la distance entre les deux essieux ou encore le poids total du véhicule. Plusieurs des paramètres primaires nécessaires aux études paramétriques ont ainsi été analysés. Les résultats obtenus ont, en dernier lieu, permis de générer des ensembles de données relatifs aux catégories de véhicule étudiées.

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FUNCTIONAL DERIVATION OF VEHICLE PARAMETERS FOR DYNAMIC STUDIES

by

G. L. Basso

1.0 INTRODUCTION

A search for vehicle parameters required for parametric studies of vehicle redirection by highway cable barriers has been carried out. The primary objective was to derive data sets for several vehicle categories. This report presents the results of this investigation.

The NAE analysis of the cable barrier model (Ref. 1) has been programmed for digital computation, and is used in conjunction with the Cornell simulation of vehicle dynamics in single vehicle accidents (Ref. 2).

2.0 BACKGROUND

The Cornell analytical description of the vehicle (valid for a rear drive, front independent suspension and a solid rear axle as shown in Fig. 1) requires numerical values for thirty-two individual parameters. Also required are tabular data for front wheel camber as a function of suspension deflection, driver control tables in the form of wheel torques as a function of time and tire data to cover the complete range of loading conditions. A flow chart listing these parameters is shown in Figure 2. Besides the parameters required in the basic Cornell model as used in the NAE studies, Figure 2 lists additional parameters resulting from extensions of the analysis (Ref. 3).

In addition to the vehicle description, the parametric studies also require parameters identifying roadside terrain features and, of course, the cable barrier configurations. To include this total amount of detail in studies of the type envisaged would render the task most difficult. Accordingly the objectives of the vehicle parameter search were twofold. First to provide a parametric description of that class of vehicles constituting the major percentage of the total population - considered to be the family sedan type of automobile subdivided into subcompact, compact, intermediate and standard size categories. And secondly, to investigate the possibility of reducing the total number of individual parameters required to define the vehicle model by functional relationships with as few

independent variables as possible; e.g., that all vehicle parameters may be functionally related to wheelbase length. This latter step is particularly important in relation to the derivation of simplified design criteria used to assess total vehicle-terrain-barrier system response.

The objectives noted above were met, in effect, by searching the published literature for numerical data typifying the various vehicle parameters apropos to the Cornell simulation. These data were analyzed to uncover the existence of functional relationships that would permit calculation of parameters for all categories of vehicles within acceptable tolerances. A $\pm 10\%$ variation was considered acceptable, based on typical sensitivity response of the vehicle-terrain-barrier system to changes in major system parameters. The absence of a significant amount of data for any particular category of vehicle negated the use of statistical analysis other than the application of best curve fitting by least squares fit. No attempt was made to model any particular ride or handling aspect of the passenger car for purposes of generating data. The approach was to accept typical final production values which, in the automotive industry, are often arrived at by an essentially 'track test' approach.

In total the literature search uncovered the existence of an appreciable amount of data, much of it, however, somewhat fragmentary. To assemble a complete data set for a particular category of vehicle required a composite of several makes and models involving several production years. Thus a particular parameter could possibly reflect production trends if derived from vehicles spanning several production years. For example, for a given overall length and weight present day passenger cars have a smaller pitch moment of inertia than, say, the early 1950 era due to current low profile styles (Ref. 4). The most complete source of data (Ref. 5) was directed towards a compilation of typical vehicle parameters for dynamic studies applicable to conventional domestic (North American) passenger cars. Here again, however, for the most part a range of values were quoted typical of an upper and lower bound. The point to be made is that a valid system response is dependent on a judicious choice of a data set representative of a particular class or category of vehicles. Accordingly, where possible, criteria used in ride and stability response were employed to validate results of the study. Also attempts were made to obtain as complete a data set as possible for the category of vehicles considered herein by direct solicitation to the automotive manufacturers.

The classification of private passenger cars into the subcompact, compact, intermediate and standard size categories as used herein is in conformity with that generally used by the automotive industry as reported in, e.g., the Automotive News.

3.0 VEHICLE POPULATION STATISTICS

As stated previously, the objective of this study was to provide vehicle data characterizing the several categories of vehicles noted above for parametric studies of vehicle redirection by highway cable barriers. The assumption is that these categories comprise the major portion of the total vehicle population as attested by motor vehicle registration statistics.

Such statistics have additional relevancy to barrier design. For example one of the most significant trends noted over the past several years has been the increasing presence of the smaller (overall dimensions and curb weight) size car - subcompact, compact and, to some extent, the intermediate categories. This is illustrated in the bar graph of Figure 3 which shows Canadian registration statistics for the production years 1969 and 1973, arranged according to the vehicle categories used in this study. This shift is dramatized further if the results of Figure 3 are viewed in relation to the more traditional full-size or standard category. There is reason to believe that this trend will continue. Related to highway barriers the message is that for existing installations the more rigid configurations are likely to be, in a structural sense, more punishing. By contrast flexible barriers (e.g. the cable type) are more accommodating. Also vehicle statistical specifications for future barrier design may require a change.

Figure 3 was constructed using the data tabulated in Tables 1 and 2 which, in turn, were compiled from registration statistics arranged, in so far as possible, according to the designated categories. Wheelbase length and curb or unladen weight were derived from manufacturers' specifications.

4.0 FUNCTIONAL DESCRIPTION OF VEHICLE PARAMETERS

The analysis of vehicle parameters as described below was conducted for the specific requirements of the vehicle-terrain-cable barrier system as simulated by the NAE - Cornell analysis. Nevertheless it is anticipated that the results will find general applicability.

The class of vehicle considered in the study was confined to the private passenger car as typified by the two-door or four-door family sedan in its several weight categories. Vehicles classified as specialty cars or station wagons were not considered in so far as specified in the literature.

4.1 Tire Characteristics

As shown in the flow chart of Figure 2 tire parameters are considered as a separate measurable entity. The analytical approach adopted for tire-terrain interaction in the Cornell analysis is fitted empirical relationships to approximate the experimentally derived data. Simply stated this is achieved by adopting, as a function of tire loading, a parabolic distribution for both cornering stiffness for small slip angles and camber stiffness for small camber angles. Tire side-forces are calculated by first approximating camber effects by an equivalent slip angle, and making use of an analytical approach wherein a non-dimensional slip angle variable and a friction circle concept are employed. Aligning torques on the front wheels are simulated by means of a constant pneumatic trail dimension when the optional steer-mode degree of freedom is activated. In this way a complete range of tire loading is accommodated - from a loss of ground contact to conditions of extreme overload. Details of the tire-terrain interaction analysis are given in the Cornell reports (Ref. 2). An example of the approximation achieved is shown in Figure 4 as reproduced from Reference 6. The A constants are those used in the parabolic fit. Table 3 contains a list of data for several tires formulated in accordance with the Cornell analysis, and also reproduced from Reference 6.

Updated versions of the Cornell simulation (Ref. 7) have included a more comprehensive treatment of the tire-terrain interaction analysis, incorporating such details as variation of circumferential friction coefficient with wheel slip speed and vehicle speed, asymmetric tire loading such as that which might occur with one wheel resting on an ice patch, etc. In addition the friction circle concept has been replaced by a more realistic friction ellipse to account for the characteristic variation of tire side-force coefficient with wheel slip speed.

4.2 Curb Weight and Dimensions

Vehicle production characteristics such as curb or unladen weight, total weight distribution, overall body dimensions, wheel track and wheelbase length and tire sizes are

readily available from publications such as Automotive News and Consumer Reports. As an example figures for the production years 1969 and 1974 are shown in Tables 4 and 5 respectively, arranged according to vehicle categories. The subdivision of the standard size category is in accordance with results reported in Consumer Reports. For each category average values have been calculated.

The average values in Tables 4 and 5 have been found to correlate quite well with wheelbase length. For curb or unladen weight a log - log plot using a least squares fit strongly suggests a cubic law - the exponent being 2.94 and 2.77 for the 1969 and 1974 production years respectively. Selecting the cubic relationship and using a least squares fit yield the results shown in Figure 5. In a similar way percent front to rear total weight distribution, overall length, width and height, and front and rear wheel track have been correlated with wheelbase length, Figures 6, 7, 8 and 9 respectively. Linear relationships in the form of $y = a + bx$ have been found adequate. With the exception of front to rear weight distribution the validity of an equation with zero intercept has been verified also. The former is used to calculate typical vehicle values. The latter is used in parametric studies to investigate the possibility of expressing the vehicle contribution to total system response in a simplified form, e.g. using dimensional analysis. Upper limits are shown for overall width and wheel track due to constraints imposed by road size.

By superimposing on Figures 5 to 9 all values for each of the corresponding parameters listed in Tables 4 and 5 one finds that, for the most part, individual values fall within a $\pm 10\%$ band about the least squares fit. Also noted is that North American vehicles tend to have a width to height aspect ratio of approximately $\sqrt{2}$. Imports tend to be somewhat less.

Additional vehicle dimensions are required in barrier analysis to locate the vehicle contact points. For the cable barrier these have been defined as the front and rear corners (Ref. 1). To provide data for the particular needs of the parametric studies, representative values of front and rear overhang, measured relative to the front and rear axle centrelines respectively, have been made on several representative vehicles as listed in Table 6. These have been expressed as percentages of wheelbase length, and again average values calculated for each vehicle category. The average values are shown plotted in Figure 10 and linear functions derived as described above. The footnote at the bottom of Table 6 is relevant to the cable barrier studies and specifies the elevation above

ground at mid - cable height. The sum of front and rear overhang plus wheelbase length will be generally less than the overall vehicle length.

4.3 Weight Distribution

For the analysis the vehicle is idealized as a composite of rigid body masses, namely that corresponding to the sprung weight and the front and rear unsprung weights. The front unsprung weight is considered as two separate masses concentrated at the wheel centres.

Weight distribution data as extracted from several sources are shown tabulated in Table 7. Total vehicle weight distribution has been considered. Total unsprung weight is shown tabulated as a percentage of total vehicle weight and front unsprung, as a percentage of total unsprung.

Total unsprung weight is shown plotted as a function of total vehicle weight with linear correlation in Figure 11. The linear expressions were derived using least squares fit. Reference 9 quotes a typical relationship for the sprung weight (W_s) related to the total vehicle weight (W_t) as

$$W_s \approx \left(0.852 \frac{+ 0.008}{- 0.015} \right) W_t$$

This result is based on data derived from a total of eighteen vehicles. From Figure 11 the corresponding relationship is found to be

$$W_s \approx (1 - 0.144) W_t = 0.856 W_t$$

based on data derived from thirty-six vehicles. Reference 9 also quotes a typical relationship for the front unsprung weight (W_{uf}) related to the total unsprung weight (W_{ut}) as

$$W_{uf} \approx \left(0.379 \frac{+ 0.004}{- 0.003} \right) W_{ut}$$

based on data derived from sixteen vehicles. From Table 7 the corresponding average value is found to be

$$W_{uf} \approx 0.385 W_{ut}$$

using data derived from a total of twenty-four vehicles.

4.4 Centre of Gravity Location

The analysis assumes a vertical plane of symmetry containing the vehicle longitudinal centreline. For the total vehicle the longitudinal location of the centre of gravity, relative to the front and rear axle centrelines, is given by the front to rear weight dis-

tribution and the wheelbase length. The vertical location, on the other hand, is not as readily defined. Reference 5 quotes a range of values of approximately 19 to 24 inches above ground as being representative of the North American passenger car.

There is some evidence to indicate that the vertical centre of gravity location is related to the overall height. Table 8 lists several values for a number of vehicles as derived from several sources. Included is the overall height and the ratio of centre of gravity height to overall height. This ratio appears to be approximately constant with a value of about 40%. Figure 12 shows the correlation of this ratio with vehicle weight using the data obtained from References 8 and 12 (the Mustang and the station wagon are not included). The additional data listed in the table reflect loading conditions other than curb or unladen weight.

The centre of gravity for the sprung mass can be derived using the data obtained for the total vehicle and the vehicle weight distribution. The mass centres for the unsprung weights are assumed to be on the axle centrelines. Their vertical location above ground can be estimated from the tire size, the weight at each wheel and a representative value for the tire stiffness (typically 1000 lb/in).

4.5 Moments of Inertia

Measured moments of inertia, made with respect to a centroidal system of axes as required in the analysis, are shown plotted as a function of total vehicle weight in Reference 5 for total vehicle yaw and pitch, and sprung mass yaw and roll. Linear approximations are derived for each case with estimates of upper and lower bounds. Values given include both station wagons and the relatively low, long hood, short rear deck vehicles. Also the pitch values reflect various loading conditions. Sprung mass pitch moments of inertia are not given.

Relative to the vehicle moments of inertia, the implication of the cubic law relating total vehicle weight and wheelbase length is that the inertia is related to the total weight according to a 1-2/3 power law. To test this hypothesis the data given in Reference 5 were used to obtain the square of the radius of gyration for each case as a function of total vehicle weight (Table 9). The results are shown in Figures 13 and 14 plotted on a log - log scale for total vehicle yaw and pitch, and sprung mass roll and yaw, moments of inertia respectively. Least squares fit has been used in each case. Also shown is the fit

obtained using a 2/3 power law. These results show that for each case the corresponding moment of inertia is approximately proportional to $(W_r)^{1.67}$

The values required in the analysis are the sprung mass inertia parameters relative to a centroidal system of axes located at the sprung mass centre of gravity. For the pitch inertia values can be estimated using the value for the total vehicle and the known weight distribution. The front unsprung weights are considered as point masses. Pitch moment of inertia for the rear axle, about the axle centreline, is sensibly zero. Therefore the rear unsprung mass can also be treated as a point mass for purposes of calculating sprung mass pitch inertia.

The rear unsprung mass roll moment of inertia, i.e. about an axis parallel to the sprung mass reference x - axis and through the axle centre of gravity (Fig. 1), is the additional mass parameter required to define the vehicle. For purposes of the parametric studies this value has been calculated for each vehicle category. To do this the value measured for the test vehicle used in the NRC cable barrier studies (Ref. 1) was taken as a base value. Values for each category were calculated by scaling according to the weight of the rear unsprung mass and the square of the rear wheel track. The value used in Reference 1 (344 lb - sec² - in, 59.28 inch wheel track and 303 lb weight) was measured using an air bearing system (Ref. 13). A value of 600 lb - sec² - in (64 inch track and 345 lb weight) was reported in Reference 3 and 435.6 lb - sec² - in (60.5 inch track and 365 lb weight) in Reference 2.

4.5.1 Dynamic Index

Vehicle inertia parameters are found in the equations of motion governing ride, handling and directional response. In handling analyses a term called the 'dynamic index' is frequently encountered (Ref. 14). This term is defined by the ratio of the square of the yaw radius of gyration to the product of the foreward and rearward location of the centre of gravity of the total vehicle, i.e.

$$\text{dynamic index} = \frac{(k^2)_{\text{yaw}}}{a_r b_r}$$

This term relates the mass distribution to the weight distribution. A typical value is unity.

This dynamic index can be calculated using the results presented herein as follows. From Figure 13 the 2/3 power law for the square of the total yaw radius of gyration is

given by

$$(k^2)_{yaw} \approx 0.103 W_T^{2/3}$$

The cubic law from Figure 5 for 1969 production models is

$$W_T \approx (2.254) 10^{-3} l_w^3$$

whence

$$(k^2)_{yaw} \approx (0.103) \left[(2.254) 10^{-3} \right]^{2/3} (144) l_w^2$$

The value 144 converts square feet to square inches. From Figure 6 an average value between 90 and 130 inch wheelbase length gives, for 1969 production models, a front to rear weight distribution of 54.7/45.3. Thus

$$a_T \approx 0.453 l_w$$

$$b_T \approx 0.547 l_w$$

And hence

$$\frac{(k^2)_{yaw}}{a_T b_T} \approx \frac{(0.103) \left[(2.254) 10^{-3} \right]^{2/3}}{(0.453) (0.547)} (144) = 1.03$$

as compared to the value of 1 previously mentioned.

A similar term is defined for ride response but in this case in terms of the sprung mass pitch moment of inertia (Ref. 15), namely

$$\text{dynamic index} = \frac{(k_s^2)_{pitch}}{a_s b_s}$$

Again from Figure 13 for the total vehicle in pitch

$$(k^2)_{pitch} \approx 0.0788 W_T^{2/3}$$

Using the expressions for total weight and centre of gravity location as a function of wheelbase length as given above for the yaw dynamic index yields

$$\frac{(k^2)_{pitch}}{a_T b_T} \approx 0.79$$

For the sprung mass the product of (ab) is essentially the same as that for the total vehicle. Also the sprung mass pitch moment of inertia is about 14% less than that for the total vehicle (based on Figs. 13 and 14 for yaw values and assuming the same percentage reduction). Hence for the sprung mass

$$\frac{(k_s^2)}{a_s b_s} \text{pitch} \approx (1-0.14) (0.79) = 0.68$$

Reference 9 quotes an average value of

$$\frac{(k_s^2)}{a_s b_s} \approx 0.81 \begin{matrix} + 0.07 \\ - 0.09 \end{matrix}$$

using sprung mass values derived from measurements made on four early 1950 production models. In Reference 15 an average value of 0.8 is quoted for 1940 production models. In both of these cases measurements were made on vehicles which were known to have higher overall production heights, and hence, by comparison to present day passenger cars, for the same overall length and weight a larger pitch moment of inertia.

4.6 Product of Inertia

The assumption of a vertical plane of symmetry containing the vehicle longitudinal centreline implies the existence of a single product of inertia, in this case corresponding to roll - yaw. Very few values have been found in the published literature - too few to establish any correlation for the vehicle categories considered herein. Reference 5 quote an approximate range of values of ± 140 slug-ft², and states that there was no correlation with any measured vehicle properties that would allow this parameter to be estimated without actually measuring it.

The centroidal system of axes used in the analysis (Fig. 1) is not, by definition, a principal system. An angle of inclination relative to the x-axis would define, however, a principal system of axes, and the corresponding moments of inertia about this principal system of axes would be the principal moments of inertia. The assumption that there exists a characteristic value for this angle of inclination, for the category of vehicles considered herein, provides the means for estimating typical values for roll-yaw product of inertia. Thus, given the sprung mass roll (I_x) and yaw (I_z) moments of inertia, the corresponding product of inertia (I_{xz}), all about the centroidal system of vehicle reference axes, and the inclination (λ) of the principal system of axes relative to the x - ax

then

$$I_{xz} = 1/2 (I_z - I_x) \tan 2\lambda$$

Table 10 contains the results of calculated I_{xz} values for three assumed values of λ using the measured values for sprung mass I_x and I_z as reported in Reference 5. The results are shown plotted in Figure 15 correlated with total vehicle weight. Also shown in Figure 15 are the results obtained using the 2/3 power law for sprung mass roll and yaw values as shown in Figure 14, namely

$$(k^2)_{yaw} \approx 0.0869 W_t^{2/3}$$

whence

$$I_z \approx 0.0869 W_t^{2/3} \frac{W_t}{g}$$

For roll

$$(k^2)_{roll} \approx 0.0121 W_t^{2/3}$$

whence

$$I_x \approx 0.0121 W_t^{2/3} \frac{W_t}{g}$$

Therefore

$$I_{xz} \approx 0.0374 W_t^{2/3} \frac{W_t}{g} \tan 2\lambda$$

The upper and lower bounds quoted in Reference 5 (± 140 slug - ft 2) suggest a possible value of $\lambda = 3^\circ$ as being characteristic of the category of passenger cars considered in this study.

4.7 Suspension Characteristics

Many of the vehicles found on the North American highways have one of the following suspension systems. For the front, an independent system with double transverse links using coil springs or torsion bars. For the rear, a solid axle with a multi-control arm system using coil springs, or the conventional Hotchkiss system using semi-elliptic leaf springs. The study of suspension characteristics was confined, therefore, to these systems in so far as specified as such by the data given in the published literature.

4.7.1 Wheel Rates

Wheel rates (suspension rates) for purposes of the Cornell analysis are defined as the suspension load-deflection rate for a single wheel in the quasi-linear range about the curb position, effective at the wheel for the front and at the axle for the rear suspension. Wheel or suspension rates do not include the effect of tire rates. A term called ride rate reflects the effect of the tires (Ref. 16). These terms are used at times interchangeably with resultant confusion.

Wheel rates for several vehicles are tabulated in Table 11. In some cases the references quoted values denoted by ride rates. These were assumed, and therefore entered, as wheel rates however. If such values were indeed ride rates an error of approximately 10% would ensue (assuming a tire stiffness of 1000 lb/in). Reference 5 specifies ranges of ride rate values, namely 80 to 160 lb/in per wheel for the front and 80 to 260 lb/in per wheel for the rear, at 30% to 60% front distribution. Several criteria used to select such values were noted in the literature, and these were invariably related to criteria used to assess vehicle ride quality. The final criteria chosen, as used in this study, was governed by consistency of results. Accordingly, sprung mass bounce natural frequency and percent front distribution were used to determine front and rear wheel rates. Linear correlation with total vehicle weight is shown in Figure 16 for the values tabulated in Table 11. Reference 5 states a range of bounce natural frequencies for light load conditions of 0.9 to 1.3 Hz, with smaller cars typically exhibiting the higher value. The results of Figure 16 give a value of 1.4 Hz at 2000 lb and 0.97 Hz at 5000 lb.

4.7.2 Suspension Stops

Automotive suspension bumpers are used to prevent metal to metal contact with excessive wheel vertical travel, and are designed to minimize and control the effects of impact on the sprung mass (Ref. 18). In the Cornell analysis as used in the NAE studies (Ref. 2) these deflection-limiting stops are assumed to be symmetrically located with respect to the design position of the suspension. They are assumed further to possess constant load-deflection rates. Front and rear suspension stop rates are expressed as a multiple of the front and rear wheel rates, respectively. Some values are quoted in Table 16 and these have been taken as representative data for the various vehicle categories.

4.7.3 Damping

The Cornell analysis considers both coulomb and viscous damping, both effective at the wheel for the front and at the axle for the rear. Coulomb damping would be probably characteristic of the suspension system and possibly depend on vehicle size. Few values were available with which to characterize this parameter. The values quoted in Reference 13 were measured using an air bearing system. Those reported in Reference 3 are comparable. The data in Reference 2 include shock absorber 'blow-off' force.

Viscous damping is provided by the shock absorbers. It would appear that shock absorber rates are selected primarily to provide ride quality. Damping rates are higher in the extension direction and usually higher in the rear suspension. Reference 5 states that ride damping is difficult to specify parametrically because it is nonlinear and quite variable with different vehicles. A gross approximation of 20% critical bounce damping is suggested.

For the Cornell analysis values of viscous damping are derived from force-velocity measurements made directly on the shock absorber (Ref. 15) and then factored to account for installation ratios (Refs. 2 and 3). For the cable barrier parametric studies viscous damping is not a sensitive parameter. Therefore values have been calculated as a percentage of critical damping, where the percentage values have been determined using the data presented in Table 14 as follows. Critical damping (C_c) per wheel was calculated using the corresponding wheel rate (K) and the sprung weight (W_s) at each wheel. The shock absorber rates quoted in the table were then expressed as a percentage of this value and the results averaged.

Thus for the front

$$C_f \approx 12.3\% (C_c)_f$$

and the rear

$$C_r \approx 20.8\% (C_c)_r$$

Critical damping is calculated using

$$C_c = 2 \sqrt{K W_s / g}$$

4.7.4 Roll Stiffness

Roll stiffness comprises two parts, namely that corresponding to the wheel rates and an auxiliary quantity. The auxiliary roll stiffness is that due to the linkage elements of the suspension system and, if employed, a roll or anti-sway bar. Thus for the front the total roll stiffness $(R_T)_f$ is defined by

$$(R_T)_f = \frac{T_f^2}{2} K_f + R_f$$

and for the rear $(R_T)_R$

$$(R_T)_R = \frac{T_s^2}{2} K_R + R_R$$

In these equations R_f and R_R are the front and rear auxiliary roll stiffnesses, respectively, K_f and K_R , the front and rear wheel rates, respectively, T_f the front wheel track and T_s the effective spring spacing at the axle. In the Cornell analysis the auxiliary quantity is required as input data.

Table 12 lists values of roll stiffness for several vehicles itemized as described above. This was done in so far as the data given in the references permitted. In all cases the suspension was one of the types specified previously. Values listed for the front roll stiffness would appear to indicate that in some instances the vehicle was fitted with a roll bar. The auxiliary values given for the 1963 Pontiac were measured by the author (Ref. 13). In this case the suspension was equipped with coil springs, with the rear suspension being a three control arm system with a lateral track bar. The values extracted from Reference 8 are listed in Table 12 but no calculations performed due to the absence of required data. With the exception of the 1969 Ford the rear suspension was of the Hotchkiss type. For the Ford a system with three control arms and a lateral track bar, using coil springs, was specified. In all cases the front suspension was equipped with a stabilizer.

Reference 5 quotes for front roll stiffness a range of values from 200 to 700 lb - ft/deg, for rear roll rates, 100 to 400 lb - ft/deg, with 50% to 80% front distribution. An assessment of the data in Table 12 indicates the following possible parametric relationships; and these have been used for the cable barrier parametric studies. For the front suspension with no roll bar the auxiliary roll stiffness is taken as the average of Ref. 13

and the 1974 Pinto (20 lb - ft/deg). Thus for the front roll stiffness with no roll bar

$$(R_T)_F = \frac{T_f^2}{2} K_F + 20$$

The increased roll stiffness due to the installation of a roll bar is dependent on material type and size. There is, however, some evidence (Ref. 19) to suggest that as a minimum a roll bar is sized to give a 100% increase in front roll stiffness. Therefore, on this assumption, for front roll stiffness with roll bar

$$(R_T)_F = 2 \left(\frac{T_f^2}{2} K_F \right) + 20$$

where the auxiliary value now becomes

$$R_F = \frac{T_f^2}{2} K_F + 20$$

For rear roll stiffness two cases are distinguished, namely a Hotchkiss system with semi-elliptic leaf springs and a multi-control arm system with coil springs. This has been done to account for differences in auxiliary roll stiffness. Also, total roll stiffness depends on the effective rear spring spacing (T_s) as measured at the axle; and this is considered to be different for each of the two cases. The data in Table 12 distinguish rear roll stiffness and rear spring spacing for each of these types with the following results. For the leaf spring system the average auxiliary value is 87.4 lb - ft/deg. Rear spring spacing expressed as a percentage of rear wheel track gives an average value of

$$T_s \approx 76.4\% T_R$$

For the coil spring system the corresponding values are

$$R_R \approx 58 \text{ lb - ft/deg}$$

$$T_s \approx 64\% T_R$$

Thus for the total rear roll stiffness

$$(R_T)_R = \frac{T_s^2}{2} K_R + 87.4$$

$$T_s \approx 0.764 T_r$$

for the semi-elliptic leaf spring system. And for the coil spring type

$$(R_t)_r = \frac{T^2}{2} K_r + 58$$

$$T_s \approx 0.640 T_r$$

Using these results front and rear total and auxiliary roll stiffnesses have been calculated for each vehicle listed in Table 12. The results are shown tabulated in Table 12a. A reasonable degree of approximation is evident.

4.7.5 Rear Roll Centre Height

The concept of a roll axis has been abandoned in the Cornell analysis. For the front unsprung masses the degrees of freedom are the vertical motion of the wheel centres and the optional steer mode. For the rear unsprung mass two degrees of freedom are assumed, namely vertical motion and roll, the latter about a roll centre (i.e. the virtual centre about which axle motions take place in roll). The roll centre is assumed to remain a fixed distance from the rear unsprung mass centre of gravity (positive for roll centre above the C.G.).

The absence of sufficient data precludes the possibility of establishing any definitive parametric relationship for this parameter. Data tabulated in Tables 14, 15 and 16 show several values for rear roll centre heights measured relative to ground. Values range from 4.3 inches above the wheel centre height to 3.9 inches below, with most values negative, i.e. below the wheel centre. Reference 5 quotes a range of values from 8 to 20 inches as measured above ground. A value of -2 inches was used in Reference 2 and -0.6 for the NRC test vehicle (Ref. 13). In the absence of more definitive data a value of 0 has been assumed for the parametric studies. Sensitivity studies have shown this not to be a sensitive parameter. It has also been assumed that the rear unsprung mass centre of gravity coincides with the geometric centre.

4.7.6 Rear Roll-Steer Coefficient

The lack of data precludes the possibility of establishing any parametric relationship for rear roll-steer (positive for roll understeer). In addition to the values listed in Tables 14, 15 and 16, Reference 5 quotes a range of values from 10% oversteer to 25% understeer. Values of 5.9%, 5.62% and 3.7% were used in References 2, 3 and 13

respectively. A value of 5% has been used for the cable barrier studies, again a secondary parameter in terms of response sensitivity.

4.7.7 Wheel Vertical Travel

Maximum suspension deflections, from the positions of static equilibrium relative to the vehicle, in both jounce (compression) and rebound (extension) are required for both front and rear unsprung masses. The version of the Cornell analysis used in the barrier studies assumes symmetry of travel in both directions. This restriction has been removed in a more recent version (Ref. 7). Values are normally determined during measurements of suspension load-deflection characteristics. Some representative magnitudes are listed in Tables 14 and 16. The description full wheel travel in Table 14 has been assumed to mean travel to contact of the suspension bumpers. In Reference 16, Section 6 (suspension geometry) the term metal-to-metal position (compression and rebound) is used to define the point of maximum travel limited by interference of substantially rigid members. The description given in Table 16 is assumed to convey this meaning.

Values for both rebound and jounce are probably dependent on suspension type and vehicle category. In the absence of more definitive data the values listed in Table 14 have been taken as characteristic of this parameter for the various vehicle categories. Corrections were applied to account for passenger load, i.e., jounce values were increased by the same amount that rebound values were decreased. This was done using the listed wheel rates and estimates of passenger load distribution. For the latter a 47% front to 53% rear weight distribution was used for front seat passengers, and 17% front to 83% rear for rear seat passengers (Ref. 8). Passenger weight was taken as 175 lb per person.

4.7.8 Wheel Camber

Tabular values of wheel camber angle versus wheel vertical travel relative to the vehicle are required for the right and left front wheels. For a solid rear axle the rear suspension is assumed to have zero camber. Figure 17 shows some representative values plotted for a double transverse linkage, front independent suspension, typical of many North American cars. The data extracted from Reference 20 exhibit camber change only. Positive values of camber angle are defined as being clockwise when viewed from the rear.

4.8 Steering and Drive Line System

Values of the parameters used to describe the steering and drive line system found in the literature are shown tabulated in Table 13. This is one area of vehicle dynamics where there is indeed a lack of data. Reference 21 represents one of the earliest studies of the dynamics of the steering system. The importance of friction was clearly demonstrated. References 3 and 13 are both related to the Cornell analysis. In the former additional degrees of freedom were added to detail more completely the steering-drive line system. Reference 13 is related to the NRC cable barrier studies wherein the Cornell analysis of Reference 2 is used directly. In all of these cases the analyses are made effective at the front wheels.

Values measured on the NRC test vehicle (Ref. 13) using an air bearing system were related to the cable barrier test configurations. In this case the steering wheel was secured against rotation. Steering flexibility was measured, therefore, for this condition. The magnitude of the coulomb friction was determined also. Since all values are made effective at the front wheels, the effective magnitude of the moment of inertia was assumed to be essentially that due to the steering wheel. This would be very nearly the case since steering wheel inertia reflected at the front wheels is proportional to the square of the overall steering ratio. In view of the absence of more definitive data steering system parameters were assumed to be the same for all vehicle categories. It is recognized that steering system flexibility and friction are likely dependent on vehicle category.

4.9 Data Sheets

Vehicle data were requested from the major American automotive manufacturers. The parameters requested for each of the vehicle categories were in relation to the Cornell analysis. These data are reproduced in Tables 14, 15 and 16. For purposes of this study ride rates given in Tables 15 and 16 were interpreted as being wheel rates. Also, corrections were applied to approximate values for the curb weight condition in cases where data reflected contrary load conditions.

5.0 APPLICATION OF THE RESULTS

The results of this study have been used to calculate representative values of the several parameters considered herein. These are shown in Table 17 for the vehicle categories used to describe the passenger class of vehicles. Table 17 has been used in

turn to generate the data sets required for vehicle-terrain-cable barrier parametric studies, and these are shown tabulated in Table 18.

For the parametric studies rear axle roll centre has been assumed to coincide with the axle centre of gravity, which is considered, in turn, to coincide with the geometric centre. It is anticipated that this will have minimal effect on system response. Also suspension travel to the suspension stops has been assumed to be the same for jounce and rebound in compliance with the Cornell analysis (Ref. 2) used in the study. Values given are the average of jounce and rebound, calculated using the results of Table 14 as described in the text (pg. 17). Coulomb damping values are the average of those reported in References 3 and 13 (Table 13).

Sprung mass centre of gravity location and sprung mass pitch moment of inertia were calculated by parts, using the total vehicle values and the mass distribution in Table 17. Since both values of yaw moment of inertia are listed in Table 17, a check was made by calculating the total value using the rigid body mass distribution. Values compared within 7% or better.

In the absence of more definitive data steering system parameters have been assumed to be the same for all vehicles. This assumes the same steering wheel moment of inertia and overall gear ratio for each category. Although front wheel size is different for the various vehicles listed in Table 18, their contribution to the total system moment of inertia is considered small. These assumptions are quite likely reasonable ones. Steering compliance, on the other hand, is likely a function of vehicle size as well as transmission type. The value given for steering stiffness is taken, therefore, as representative with the anticipation that this parameter is of secondary importance to the vehicle-cable barrier response. Finally the values of the auxiliary roll stiffness were derived as described in the footnote to Table 12a.

6.0 CONCLUDING REMARKS

The primary objective of this study was to derive vehicle parameter data sets for vehicle-terrain-cable barrier parametric studies. A secondary objective was to evaluate the possibility of formulating parametric relationships which could be used to calculate typical values of the required parameters. In the main both of these objectives have been made. An implication of the latter aspect of this study is that vehicle dynamic response will scale in a dimensional sense..

One observation noted during the course of this investigation is that the generation of vehicle parameter data tends to lag analytical development. The steering-drive line system is a case in point. Very few values of the parameters characterizing this vehicle subsystem have been found. Also vehicle data reported in the literature tend to be propagated from author to author with the result that there comes a time when its relevancy becomes questionable.

These deficiencies could be remedied by a systematic program of parametric measurements carried out by interested agencies, and made on a few selected vehicles representative of a given class. These data could then be used to derive parametric relationships as outlined in this study. This, in turn, could provide the basis for generating relevant vehicle data sets apropos to vehicle dynamic studies. Facilities for the accurate and reliable measurements of vehicle parameters exist. For example, Reference 22 describes an extensive laboratory facility designed for vehicle parameter measurements affecting understeer and brake steer. This facility can accommodate a variety of vehicles. In addition the Structures and Materials Laboratory here at the National Research Council has an air bearing system which forms the basis for a vehicle parameter measuring system; and has been used, in fact, to measure the data set for the NRC test vehicle (Ref. 13).

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TABLE I

NEW MOTOR VEHICLE REGISTRATIONS BY MAKE AND PROVINCE - 1969*

Make	Typical [†] wheelbase Length (in)	Typical Curb [†] or Unladen Weight (lb)	0 Canada	1 Ont.	2 Que.	3 Alta.	4 B.C.	5 Man.	6 Sask.	7 N.B.	8 N.S.	9 Nfld.	10 P.E.I.	Comments
Volkswagen	91.5	1,898 to 2,116	35,137	16,155	7,755	2,427	4,271	795	344	1,254	1,580	645	211	
British G.M.	80 to 93.5	1,512 to 2,355	13,370	4,224	3,098	920	2,212	666	316	605	913	574	42	no specs found
British Leyland	98 to 100.8	1,926 to 2,123	12,275	5,591	2,606	709	1,803	682	53	133	513	158	27	
British Ford	89 to 105.8	1,825 to 2,249	11,367	2,901	3,174	679	2,536	262	150	636	692	263	69	
Renault	89.3 to 95.3	2,050 to 2,265	8,523	1,655	5,869	226	333	151	51	28	125	84	1	
Datsun	90 to 95.3	1,637 to 2,260	18,135	4,700	3,868	2,228	6,431	290	290	441	314	95	73	
Toyota			17,232	4,703	5,292	1,048	5,182	98	61	403	285	91	59	
Total			117,135	39,929	31,662	8,237	22,768	2,944	1,265	3,500	4,432	1,916	482	smallest size category
Mustang	108	2,835 to 3,085	16,261	8,157	4,052	1,109	1,506	491	281	211	325	119	19	specialty car
Valiant	108	2,865 to 3,095	11,908	4,597	3,378	781	1,461	464	160	217	501	316	33	specialty car
Camaro	108	3,005 to 3,125	6,303	2,988	1,800	479	573	156	167	69	202	61	8	specialty car
Dart	111	2,885 to 3,035	19,104	8,624	4,724	1,123	1,663	916	345	440	760	414	95	
Chvy Nova	111	2,910 to 3,165	12,122	5,615	3,115	663	1,073	325	257	213	379	433	19	
Falcon	111	2,852 to 3,037	6,601	2,248	1,637	486	861	216	148	227	417	327	34	specialty car
Cougar	111	3,358 to 3,534	6,891	3,239	1,221	699	1,043	248	177	76	141	43	4	
Maverick	103	2,487	19,573	8,183	5,187	1,184	2,121	565	490	548	922	261	107	
Total			98,963	43,656	25,114	6,315	10,301	3,381	2,025	2,031	3,647	1,974	319	compact category
Chevelle	112 and 116	3,140 to 3,265	27,870	12,554	6,813	1,811	2,292	847	700	796	1,357	563	137	
Fairlane	116	3,154 to 3,225	22,069	9,245	5,713	1,538	2,049	795	731	606	804	432	155	
F-55	116	3,300 to 3,489	18,745	9,173	5,033	1,241	1,471	507	417	205	508	160	30	
Buick Special	116	3,304	13,831	6,371	3,609	831	1,445	265	238	323	417	100	52	
Belvedere	116	3,170 to 3,300	13,327	4,801	3,941	1,060	1,216	605	429	302	560	343	70	
Couonet	117	3,195 to 3,325	12,039	4,665	3,483	950	791	577	367	394	478	253	92	
Montego	116	3,202 to 3,302	10,427	3,937	2,715	927	961	464	437	329	603	130	24	
Tempest	116	3,379 to 3,564	6,931	3,476	1,436	603	672	237	172	164	131	42	18	
Beauford	116	2,715 to 3,546	12,932	5,342	3,271	914	1,241	384	297	579	615	271	68	
American Motors	97 to 122	18,948	8,967	5,041	1,087	1,363	610	338	397	518	513	114	no breakdown given	
Total			157,220	68,531	41,255	10,862	13,591	5,292	4,126	4,095	5,991	2,807	760	intermediate category
Chevrolet	119	3,660 to 3,890	72,843	31,661	17,272	6,427	4,571	3,354	3,350	1,954	2,441	1,555	248	
Ford	121	3,853 to 3,917	55,135	25,064	11,843	4,903	4,921	2,748	1,345	1,509	720	186		
Plymouth	120	3,705 to 3,895	25,375	10,160	6,140	2,372	1,719	1,699	1,597	536	699	333	76	similar to Ford
Meteor	121	3,853 to 3,917	22,597	8,609	5,913	2,367	1,309	1,234	1,356	592	851	319	47	
Dodge	122	3,925 to 4,045	22,217	8,942	5,426	2,026	1,284	1,462	992	792	720	516	87	
Total			203,197	84,280	46,594	18,095	12,904	10,555	10,043	5,219	6,220	3,643	644	full-size, low-price category
Pontiac	122	4,144	54,713	24,977	13,359	4,662	3,385	2,578	1,878	1,537	1,349	798	199	
Chrysler	124	4,165 to 4,390	24,290	9,125	7,692	1,424	1,175	957	425	475	264	68		
Buick	123.2	4,118 to 4,254	22,196	10,160	5,987	2,146	1,262	800	722	443	402	189	85	
Oldsmobile	124	4,164 to 4,255	20,179	8,757	6,032	1,943	1,121	766	689	339	369	113	50	
Marquis	124	4,335	10,997	4,544	2,899	1,139	798	469	602	207	255	62	22	
Total			132,375	57,563	35,969	12,575	7,990	5,788	4,348	2,951	2,850	1,426	415	full-size, medium-and high-price category

* Table 31 Facts and Figures of the Automotive Industries, 1969 (Motor Vehicle Manufacturers' Association)

† Specifications: Domestic and Imports. Automotive News, March 31, 1969

TABLE 2
NEW MOTOR VEHICLE REGISTRATIONS BY MAKE AND PROVINCE - 1973*

Make	Typical [†] Wheelbase Length (in.)	Typical Curb [‡] or Unladen Weight (lb.)	0 Canada	1 Ont.	2 Que.	3 Alta.	4 B.C.	5 Man.	6 Sask.	7 N.B.	8 N.S.	9 Nfld.	10 P.E.I.	Comments
Dodge Colt	95	2,012 to 2,130	4,939	1,195	1,214	398	870	251	206	221	228	82	19	
Plymouth Cricket	98	1,961 to 2,160	4,897	1,117	1,136	440	705	240	209	162	212	83	30	
Ford Pinto	94.2	2,216	25,270	11,164	6,636	1,376	3,956	579	389	521	521	349	52	
Chevrolet Vega	97	2,268	29,312	13,081	7,088	1,519	2,700	1,298	881	619	1,161	838	61	
Pontiac Astre	97	2,165	8,479	4,677	1,290	216	670	315	671	818	309	91		
Brit. Ley. Austin	96	2,103	5,877	2,568	1,187	187	934	212	36	112	561	87	20	Similar to Vega
MG	90 and 91	1,512 to 2,190	2,490	1,631	358	385	611	121	22	81	32	4		
Triumph	94 and 98	1,708 to 2,156	1,745	886	322	128	275	76	11	53	3	1		
Fiat	79.8 to 96.4	1,580 to 2,147	6,704	2,556	1,881	341	1,279	161	129	39	67	73	6	
Ford Capri	100.8	2,333 and 2,410	8,163	3,313	1,092	628	1,613	241	187	137	205	89	23	
Cortina			6,619	1,896	1,316	542	1,718	216	249	221	252	113	23	
G.M. Foreign	85.7	2,120 to 2,227	731	242	215	128	33	43	15	19	20	4		Similar to Capri
Mazda	91 and 97	2,000 to 2,355	11,473	3,250	2,568	1,034	2,679	367	426	439	529	334	66	Opel
Datsun	90.6 to 98.4	1,630 to 2,300	42,067	13,929	10,301	3,616	7,299	1,817	1,083	1,136	1,820	731	312	
Renault	96	2,093 to 2,392	5,710	995	3,498	236	576	127	56	50	181	51	4	
Toyota	91.0 to 100.8	1,725 to 2,700	16,879	15,131	11,760	3,040	8,877	1,942	1,719	1,463	1,807	759	260	
Audi	105.3	2,379	3,428	1,123	623	249	529	93	22	70	88	19	12	
Porsche	98.5 and 96.5	1,809 and 2,250	937	451	211	79	110	30	10	8	12	6		
Volkswagen	94.5 to 98.4	1,426 to 2,460	26,103	10,311	7,306	914	4,144	502	172	1,065	1,314	337	107	
A. M. C. Gremlin	96	2,702 and 2,959	6,902	4,300	931	257	521	192	106	71	261	29		
Corvette	98	3,407	2,252	1,185	563	191	153	79	39	15	38	4	2	not included in totals
Total			251,111	91,071	61,092	17,128	49,503	9,088	6,312	7,002	10,305	4,118	1,115	
A. M. C. Hornet	108	2,494 and 3,127	10,771	5,665	2,415	391	935	357	151	166	291	392	65	
Javelin	110	2,895 and 3,134	2,553	918	922	169	215	115	36	22	36	65	8	
Dodge Dart	111	2,095 and 3,195	29,593	11,019	9,105	1,380	2,326	1,277	602	1,073	1,816	918	134	
Ply. Barracuda	108	3,230	2,218	1,030	632	136	190	120	61	10	48	29	2	
Valiant	108	2,418 and 3,068	38,165	15,752	13,321	1,214	2,170	1,322	568	1,020	1,585	941	210	
Ford Maverick	103 and 109.9	2,681 and 2,736	22,599	6,155	1,295	2,110	736	551	811	895	773	97		
Mustang	106	3,128 and 3,232	11,175	4,895	2,891	790	1,179	396	283	237	303	165	27	
Mercury Comet	103 and 109.9	2,782 and 2,877	26,291	7,821	5,919	1,121	1,759	639	745	956	1,309	651	14x	
Buick Apollo	111	3,354 and 3,410	3,113	1,201	915	191	318	121	69	114	192	71	8	
Chev. Camaro	108	3,295 and 3,435	5,200	2,281	1,558	281	511	207	86	60	135	62	13	
Nova	111	3,169 and 3,289	22,493	7,869	6,365	1,515	2,371	968	658	705	1,073	868	74	
Olds. Omega	111	3,293 and 3,356	3,939	1,322	1,109	229	431	121	137	166	172	162	11	
Firbird	104	3,218	2,892	1,312	849	294	290	92	11	37	56	21	7	
Ventura	111	3,171 and 3,234	13,793	4,719	4,694	857	1,948	576	299	571	681	369	113	
Pengon	108 and 114	2,759 and 2,912	1,029	343	535	35	36	2	7	38	11	2		
Volvo	96.5 to 107	2,548 to 2,999	10,557	4,292	2,763	802	1,582	292	119	227	333	75	24	
Total			290,499	78,711	60,250	19,846	17,354	7,301	1,168	6,251	8,767	5,549	919	
A. M. C. Matador	118	3,310 and 3,453	3,569	1,653	725	111	361	215	107	78	155	93	32	
Charger/Coronet	115 and 118	3,505 to 3,590	14,936	5,696	4,765	550	816	600	329	451	576	352	65	
Challenger	119	3,215	3,139	1,213	925	290	232	156	91	59	84	45	6	
Satellite	115 and 117	3,480 and 3,625	17,271	6,169	5,485	1,175	1,111	708	103	471	592	436	95	
Torino	114 and 118	3,674 to 3,838	39,804	12,190	9,085	2,062	2,175	1,180	888	1,020	1,073	611	141	
Montego	114 and 118	3,790 and 3,851	13,181	5,098	3,731	957	1,197	512	616	129	621	311	59	
Cougar	112.1	3,516	6,359	2,811	1,716	518	618	266	235	195	159	70	16	
Buick Century	112 and 116	3,802 and 3,922	25,216	9,236	7,126	1,502	1,982	1,314	813	775	1,261	1,042	147	
Chev. Malibu	112 and 116	3,533 to 3,788	17,819	8,319	4,896	1,169	996	766	582	312	562	185	21	
Monte Carlo	116	3,823	2,818	1,202	723	1,618	1,857	854	683	496	986	291	79	
Cutlass	112 and 116	3,828 to 3,920	26,972	12,802	1,109	1,227	1,311	722	302	704	711	335	84	
Pontiac LeMans	112 and 116	3,698 and 3,715	20,717	8,831	6,159	1,327	1,311	722	302	311	311	1,188	210	
Grand Prix	116	3,117	1,856	2,211	1,770	301	258	117	56	31	37	13	3	
Mercedes-Benz	86.8 to 116.5	3,070 to 4,030	1,818	861	437	111	253	53	12	13	27	44		
Total			291,135	81,138	56,067	12,733	11,650	7,947	5,713	5,613	7,313	4,068	855	Intermediate category
A. M. C. Ambassador	122	3,841	2,385	1,112	572	222	327	150	292	31	36	23	7	
Dodge	122	3,940 and 4,140	16,976	5,791	3,008	1,171	980	938	582	720	638	465	57	
Plymouth	120	3,940	19,938	8,098	5,177	1,652	1,019	930	931	629	574	536	79	
Ford	121	4,282	41,333	16,685	10,391	4,102	2,930	2,078	1,813	1,496	1,175	638	152	
Ford Thunderbird	120.4	1,742	3,984	2,339	968	273	319	97	67	55	46	11	5	
Mercury Meteor			13,513	1,963	4,971	1,005	782	682	1,001	508	567	259	43	
Chevrolet	121.5	4,011 to 4,322	53,225	21,665	14,036	3,979	3,211	2,161	3,176	1,569	1,700	1,188	210	
Pontiac	121	4,326	21,755	10,973	6,702	1,829	1,099	1,215	1,122	792	582	306	103	
Total			173,746	69,580	46,169	14,031	10,377	8,501	9,163	5,648	5,272	3,157	703	
Chrysler New Yorker	124	4,170	3,971	1,308	1,378	313	236	181	162	192	61	63	11	
Newport/Wagons	124	4,345	21,505	8,267	8,121	1,617	705	1,029	837	532	170	269	71	Specs. for Newport
Imperial	127	5,020	6,056	227	190	844	36	46	22	12	26	12	2	
Mercury Marquis	123	3,739	9,070	3,680	2,111	1,012	518	362	310	201	171	60	28	
Lincoln	127	5,210	3,122	1,799	937	298	281	158	60	15	31	7	2	
Buick Riviera/Electra	122/127	4,617 to 4,721	3,398	1,715	960	183	161	76	85	52	55	9	9	
LeSabre	124	3,199	11,311	6,391	4,251	1,252	185	619	613	387	251	81	65	
Cadillac	130	4,096	6,211	3,357	3,684	2,037	143	129	112	79	75	17	9	
Olds. Delta 88 Royale	121	3,368	16,703	7,256	3,986	1,206	806	697	843	315	312	163	58	
Toronto/88	122/127	1,740 to 1,811	5,302	2,120	3,907	2,062	269	128	205	74	86	23	5	
Total			81,975	36,157	26,755	6,725	4,064	3,121	3,190	1,819	1,576	698	266	full-size, medium- and high-price category

*Private communication from R. L. Polk and Co., Toronto.

†Specifications: Domestic and Imports. Automotive News, April 2, 1973.

TABLE 3
TIME DATA

Size	Test Pressure (psi)	Lateral Force Coefficients				Aligning Torque Coefficients			Comments	
		A0	A1	A2	A3	A4	Coefficient of Friction	A	B	
A-3-13	28	5.200	3.8	1.800	1.9	3.400	0.8	-1.47	18	-6
C73-14	24	5.200	3.1	1.800	1.8	4.600	0.8	-1.5	18	-6
D73-14	32	5.500	3.6	2.600	1.8	4.600	0.8	-1.1	13	-7
E73-14	24	4.000	3.7	2.400	2.2	5.000	0.8	-1	14	-6
G73-14	32	4.000	4.6	2.600	1.8	4.600	0.8	-1.5	15	-8
H73-14	24	4.099	7.0	2.400	2.3	4.000	0.8	-2	22	-9
F78-14	32	5.500	4.7	2.800	2.1	4.800	0.8	-1.3	16	-8
S-55-15	24	3.000	5.5	2.800	1.5	6.900	0.8	-1.3	14	-10
J78-15	32	3.000	8.6	2.800	1.5	5.600	0.8	-1.45	16.56	-10
F70-14	24	6.000	5.1	2.200	1.9	4.000	0.8	-2	16.5	-8
H73-14	32	6.000	5.1	3.000	2.2	5.200	0.9	-2.4	24	-12
F70-14	24	6.000	5.2	2.600	2.6	4.600	0.9	-2.7	24.5	-12
H73-15	32	7.000	5.5	3.000	2.7	4.800	0.9	-2.7	24.5	-12
F70-14	24	6.000	6.8	2.400	1.8	4.600	0.8	-2.3	15	-9
H73-15	32	7.000	5.0	3.200	2.0	4.000	0.8	-2.4	24	-15
225R-15	24	5.000	4.6	2.500	2.1	7.600	1.0	-	-	-
S-55-15	32	7.000	6.0	3.000	2.6	5.600	1.0	-	-	-
J78-15	24	5.000	7.7	2.600	3.8	4.800	0.8	-2.7	24.5	-12
H73-15	32	3.800	10.8	3.300	5.4	4.200	0.8	-1.0	11.8	-4
H73-15	24	5.000	5.87	3.200	2.2	4.800	0.8	-	-	-
F70-15	28	3.750	6.5	3.150	2.6	3.730	0.7	-	-	-
S-55-15	32	7.000	3.0	3.700	2.05	4.100	0.8	-1.23	10.8	-5
J78-15	36	-652	11.1	3.800	2.29	4.924	0.7	-	-	-
G-0-15	24	3.000	8.9	3.000	2.8	3.400	0.8	-2.08	20.8	-16.7
H70-15	26	4.000	5.6	3.500	2.8	4.200	1.0	-1.0	32.5	-20
S-55-15	32	5.000	8.5	3.200	2.5	4.200	0.8	-2.41	19.5	-15
J78-15	36	5.000	7.1	3.500	3.4	3.200	1.0	-5.6	33.3	-20
G-0-15	28	6.900	7	3.000	2.5	4.400	0.9	-	-	-
H70-15	36	-4.620	22.4	3.175	3.53	3.500	0.9	-2.05	21.1	-15
H70-15	24	6.000	5.9	3.000	3.1	5.400	0.8	-3.7	25.7	-15
H69-15	32	0	17	3.600	3.7	6.000	0.8	-3.64	30.5	-24
H69-15	24	9.000	6.27	3.000	3.4	5.000	1.0	-5.37	34.38	-20
215R-15	32	10.500	5.9	3.600	3.4	5.000	1.0	-	-	-
215R-15	28	10.727	2.36	1.600	2.71	3.800	0.7	-	-	-
225-15	36	9.000	9.0	3.000	3.4	3.200	1.0	-6	36	-36
225-15	26	7.500	10	2.400	2.1	5.600	1.0	-6.4	44.6	-35
J78-15	26	4.000	5.6	3.500	2.8	4.200	1.0	-2.9	23	-15
J78-15	36	5.000	7.1	3.500	3.4	3.200	1.0	-3.1	18.7	-14

TABLE 4
SPECIFICATIONS FOR PASSENGER VEHICLES - 1969*

Make and Model	Unladen or Curb Weight (lb)	Distribution/ Front/Rear (%)	Wheelbase (in)	Overall Dimensions			Wheel Track		Width to Height Ratio	Tire Size	Comments
				Length (in)	Width (in)	Height (in)	Front (in)	Rear (in)			
Datsun PL510 4-door Sedan	2,094	54/46	95.3	162.2	61.4	56.3	50.4	50.4	1.11	5.60 x 13	
2-door Sedan	2,050		95.3	160.2	61.4	56.1	50.4	50.4	1.11	5.60 x 13	
Toyota Corona Sedan	2,260	58/42	95.3	162.4	61.9	56.9	50	50	1.09	6.00 x 13	
British Ford Cortina 4-door	1,978	55/45	98	168.5	61.0	54.7	52.5	51	1.18	6.00 x 13	
2-door	1,926		98	166.5	61.9	54.7	52.5	51	1.18	6.00 x 13	
Volkswagen 1600 Fastback	2,116		94.5	160.3	63.2	57.9	51.6	51	1.09	6.00 x 13	
Opel Kadett 2-door Sedan	1,691		95.1	161.6	61.9	55	49.2	50.2	1.17	5.55 x 13	
Renault 10	1,825		98	167.5	60	55.5	49	48	1.08	5.5 x 13	
Averages	1,992	55.6/44.4	95.0	164.6	62.0	55.2	50.7	50.5	1.13		
A.M.C. Rambler 6	2,715	57/43	106	181	70.84	51.24	54.24	55.0	1.50	6.45 x 14	
Rambler V-8	2,956	57/43	106	181	70.81	51.21	56.85	55.27	1.30	6.95 x 14	
Chevrolet Chevy Nova 4	2,910		111	189.4	72.1	52.4	50.0	58.9	1.38	7.35 x 14	
Chevy Nova 6	3,028	58/47	111	189.4	72.4	52.4	50.6	58.9	1.38	7.35 x 14	
Chevy Nova 8	3,165	57/46	111	189.4	72.4	52.4	50.0	58.9	1.38	7.35 x 14	
Dodge Dart 6	2,886	55/45	111	185.4	69.6	53.6	57.4	55.6	1.30	6.50 x 13	
Dart V-8	3,036	55/45	111	185.4	69.6	53.6	57.4	55.6	1.30	6.50 x 13	
Ford Falcon 6	2,852	55/45	111	181.3	73.2	54.9	58.8	58.5	1.33	6.95 x 14	
Falcon V-8	3,057	57/43	111	181.3	73.2	54.9	58.8	58.5	1.33	7.35 x 14	
Maverick	2,187	55/45	103	170.4	70.6	52.9	55.6	55.5	1.35	6.00 x 13	
Plymouth Valiant 6	2,855	54/46	108	188.4	69.6	53.7	57.4	55.6	1.29	6.50 x 13	
Valiant V-8	3,005	55/45	108	188.4	69.6	53.7	57.4	55.6	1.29	7.00 x 13	
Volvo 164	2,928	54/46	106.3	185.6	68.3	56.7	53.1	53.1	1.20	6.85 x 15	
Averages	2,913	55.1/41.3	104.8	187.0	70.8	53.8	57.3	56.5			
A.M.C. Rebel 6	3,178	53/47	111	197	77.21	55.0	58.81	60.0	1.40	7.35 x 14	
Rebel V-8	3,359	55/45	111	197	77.21	55.0	60.0	60.0	1.40	7.35 x 14	
Buick Special Deluxe 6	3,304	52/48	116	204.7	75.6	51.1	58.0	58.0	1.10	7.75 x 14	
Skylark Custom V-8	3,519	54/46	116	204.7	75.6	51.1	58.0	58.0	1.10	7.75 x 14	
Chevrolet Chevelle 6	3,140	54/46	116	206.0	76.6	53.5	58.0	58.0	1.12	7.35 x 14	
Chevelle 2-door	3,265		112	196.9	76.8	53.5	58.0	58.0	1.12	7.35 x 14	
Chevelle V-8	3,263	55/45	116	200.9	76.6	53.5	58.0	58.0	1.12	7.35 x 14	
Dodge Coronet 6	3,135	53/47	117	206.6	76.7	51.8	58.5	58.5	1.42	7.35 x 14	
Coronet V-8	3,325	54/46	117	206.6	76.7	51.8	58.5	58.5	1.42	7.35 x 14	
Ford Fairlane 6	3,151	51/46	116	201.1	71.6	51.1	58.4	58.4	1.39	7.35 x 14	
Fairlane V-8	3,235	51/46	116	201.1	71.6	51.1	58.4	58.4	1.38	7.35 x 14	
Mercury Montego 6	3,292	53/47	116	206.2	76.0	51.1	58.4	58.4	1.38	7.35 x 14	
Montego V-8	3,302	55/45	116	206.2	76.0	51.1	58.4	58.4	1.38	7.35 x 14	
Oldsmobile F-85 Cutlass 6	3,309	51/46	116	205.9	76.8	53.5	59.9	59.9	1.10	7.75 x 14	
F-85 Cutlass V-8	3,495	57/43	116	205.9	76.8	53.5	59.9	59.9	1.10	7.75 x 14	
Plymouth Belvedere 6	3,170	58/47	116	202.7	76.8	53.5	59.0	59.0	1.43	7.75 x 14	
Belvedere V-8	3,300	53/47	116	202.7	76.4	53.7	59.5	59.5	1.39	7.35 x 14	
Pontiac Tempest 6	3,379	56/45	116	205.5	75.8	52.7	61	60	1.41	7.35 x 14	
Tempest V-8	3,568	56/44	116	205.3	75.8	52.7	61	60	1.41	7.35 x 14	
Averages	3,206	54.1/55.9	115.7	202.0	76.1	51.0	59.3	59.4			
A.M.C. Ambassador 6	3,357	54/46	122	206.5	77.24	55.0	60.0	60.0	1.10	7.75 x 14	
Ambassador V-8	3,516	55/45	122	206.5	77.24	55.0	60.0	60.0	1.10	7.75 x 14	
Chevrolet Impala 6	3,660	56/50	119	215.9	79.8	55.9	62.5	62.1	1.43	8.25 x 14	
Impala V-8	3,800	51/49	119	215.9	79.8	55.9	62.5	62.1	1.43	8.25 x 14	
Dodge Polara 500 V-8	3,925	56/47	122	220.8	79.2	55.8	62.5	62.1	1.43	8.25 x 14	
Monaco V-8	4,045		122	220.8	79.2	55.8	62.1	60.7	1.42	8.25 x 15	
Ford Custom Galaxie 6	3,752	53/47	121	219.8	79.2	55.8	62.1	60.7	1.42	8.25 x 15	
XL 6	3,917		121	214	79.8	55.1	63.0	61.9	1.45	8.25 x 15	
LTD V-8	3,853	53/47	121	216	79.4	55.1	63.0	61.0	1.45	8.15 x 15	
Mercury Marauder V-8	4,186		121	219.1	79.7	54.2	63.0	63.0	1.47	8.25 x 15	
Oldsmobile Vista Cruiser V-8	4,098		121	217.6	77.2	58.6	63.0	63.0	1.42	8.25 x 15	
Plymouth Fury 6	3,705	52/48	120	214.5	79.6	55.8	62.1	60.7	1.42	7.75 x 15	
Fury V-8	3,805	53/47	120	214.5	79.6	55.8	62.1	60.7	1.42	7.75 x 15	
Pontiac Catalina V-8	4,141	53/47	122	217.5	79.8	54.8	61	61	1.45	8.25 x 15	
Averages	4,212	52.7/47.3	120.9	215.4	79.1	55.4	62.0	61.8			
Buick LeSabre V-8	4,118	53.47	129.2	218.2	80.0	55.3	63.0	63.0	1.41	8.25 x 15	
Wildcat V-8	4,254	54/46	129.2	218.2	80.0	55.3	63.0	63.0	1.41	8.25 x 15	
Electra 225 V-8	4,395	53.47	126.2	218.6	80.0	55.8	63.5	63.0	1.41	8.25 x 15	
Chrysler Newport	4,161	56/54	124	221.7	79.1	56.1	62.1	60.7	1.43	8.25 x 15	
266	4,335	53.45	124	221.7	79.1	56.1	62.1	60.7	1.43	8.25 x 15	
Mercury Monterey V-8	4,110	57/43	121	221.8	79.1	56.1	62.1	60.7	1.43	8.25 x 15	
Marquis V-8	4,233	58/42	121	221.8	79.8	55.2	63.0	61.0	1.41	8.25 x 15	
Oldsmobile Delta 88	4,161	55/46	121	221.3	79.8	55.8	63.0	61.0	1.41	8.25 x 15	
Delta 88, Royale V-8	4,235	55/45	121	218.6	79.9	55.5	62.5	63.0	1.41	8.25 x 15	
98 V-8	4,436	55/45	127	218.6	79.9	55.5	62.5	63.0	1.41	8.25 x 15	
Pontiac Bonneville V-8	4,379	53/47	125	221.1	80.0	55.8	62.5	63.0	1.41	8.25 x 15	
Averages	4,276	54.9/45.1	121.4	222.0	79.7	55.3	62.0	62.0			
Cadillac Calais de Ville	4,740	51/46	129.5	225.0	79.9	51.4	63	63	1.47	9.00 x 15	
Imperial	4,925	55/45	127	229.7	79.4	56.3	62.1	61.1	1.40	9.15 x 15	
Lincoln Continental	5,208	54/46	126	221.2	79.7	51.9	63.0	61.0	1.45	9.15 x 15	
Averages	4,971	51.3/45.7	127.5	226.3	79.5	55.2	62.6	62.6			

* Specifications: Domestic and Imports. Automotive News, March 31, 1969.

† Consumer Reports April, Sept., Oct., 1969

full-size category no. 2

full-size category no. 3

TABLE 5
SPECIFICATIONS FOR PASSENGER VEHICLES - 1974*

Make and Model	Unladen or Curb Weight (lb)	Distribution [†] Front/Rear (%)	Wheelbase (in)	Overall Dimensions			Wheel Track		Width to Height Ratio	Tire Size	Comments
				Length (in)	Width (in)	Height (in)	Front (in)	Rear (in)			
A. M. C. Gremlin 6	2,739	58/42	96	170.3	70.6	52.6	57.5	57	1.34	6.45 x 14	
A. M. C. Gremlin V-8	2,990	54/46	96	170.3	70.6	52.6	57.5	57	1.34	6.95 x 14	
Chevrolet Vega	2,446	52/48	97	175.4	65.4	51.9	55.2	54.1	1.26	A78 x 13B	
Dodge Colt	2,219	94.2	64	172	64	53.1	50.6	50.6	1.20	6.00 x 13	
Ford Pinto	2,443	56/44	94.2	169	69.4	50.3	55.0	55.8	1.38	6.00 x 13	
Audi Fox	2,102	61/39	97.2	172	64.7	53.6	52.7	52.5	1.21	1.55SR13	
Dateun B210 - 2 door	1,960	54/46	92.1	160	60.8	53	50.2	49.8	1.15	6.15 x 13	
610 - 2 door	2,400	98.4	174	63	54.5	51.6	52	52	1.15	6.45 x 13	
710 - 4 door	2,315	56/44	96.5	170.9	62.2	55.5	51.6	52	1.12	6.45 x 13	
Fiat 124 Special TC	2,199	56/44	95.3	165.6	64.9	55.9	52.4	51.2	1.16	1.55SR13	
128 - 4 door	1,920	62/38	96.4	157.2	63.9	55.9	51.3	51.7	1.14	1.45SR13	
Honda Civic 2 door	1,605	60/40	86.6	146.9	59.25	52.2	51.2	50.4	1.13	6.00S12	
Mazda RX-2	2,540	55/45	97	173	62	56	51	51	1.11	1.55SR13	
Opel Manta	2,335	58/42	91	165	63	53	51	51	1.19	1.55SR13	
Subaru DL - 4 door	2,035	54/46	95.7	176.1	64.3	51.8	52.4	52	1.24	1.65 x 13	
Toyota Corolla 1200	1,815	61/39	96.6	164.4	59.2	54.5	50.2	48	1.08	1.55SR13	
Volkswagen Dasher - Super Beetle	2,530	55/45	91.9	163.5	59.3	53	49.4	49	1.12	6.00 x 12	
	1,994	56/44	98.4	171.9	63.8	54.1	52.9	52	1.18	B78 x 14	
	61/39	97.2	172.8	63	52.7	52.6	52	52	1.18	1.55SR13	
	95.3	164.9	62.4	59.1	54.9	53.1	53.1	53.1	1.05	6.00 x 15L	not applicable
Averages	2,248	57/43	95.2	168.0	63.8	53.5	52.4	52.1	—	—	subcompact category
A. M. C. Hornet 6	2,827	58/42	108	187	71	52.4	57	57	1.35	6.95 x 14	
	3,061	59/41	108	187	71	52.4	57	57	1.35	6.95 x 14	
Buick Apollo 6	3,254	53/47	111	200.3	72.7	52.8	59.1	59.7	1.37	E78 x 14	
	3,149	53/47	111	200.3	72.7	52.8	59.1	59.7	1.37	E78 x 14	
Chevrolet Nova 6	3,254	53/47	111	196.7	72.4	53.9	59.8	59.8	1.34	E78 x 14B	
	3,792	53/47	111	196.7	72.4	53.9	59.8	59.8	1.34	E78 x 14B	
Dodge Dart 6	3,135	56/44	111	201.7	69.6	54.1	59.1	55.4	1.28	6.95 x 14	
	3,230	57/43	111	203.2	69.6	54.1	59.1	55.4	1.28	D78 x 14	
Ford Maverick 2-door 6	2,552	103	157	70.5	53	56.5	56.5	56.5	1.33	6.45 x 14	
	2,964	54/46	109.9	193.9	70.5	52.8	56.5	56.5	1.33	6.45 x 14	
Maverick 4-door 6	3,025	56/44	103	167	70.5	53	56.5	56.5	1.33	6.45 x 14	
Maverick 2-door V-8	2,874	103	190	70.5	53	56.5	56.5	56.5	1.33	6.45 x 14	
Mercury Comet 2-door 6	2,950	55/45	109.9	196.9	70.5	52.8	56.5	56.5	1.33	C78 x 14	
Comet 4-door 6	3,153	56/44	109.9	196.9	70.5	52.8	56.5	56.5	1.33	C78 x 14	
Comet 4-door V-8	3,153	56/44	111	199.5	72.8	52.4	59.1	58.8	1.39	E78 x 14	
Oldsmobile Omega 2-door 6	3,334	52/48	111	199.5	72.8	52.4	59.1	59.8	1.39	E78 x 14	
	3,524	103	194.1	71.8	53.1	59.1	55.4	55.4	1.35	6.95 x 14	
Plymouth Valiant Duster 6	3,115	55/45	111	197.6	71	54.3	59.1	55.4	1.31	6.95 x 14	
	3,215	56/44	111	197.6	71	54.3	59.1	55.4	1.31	D78 x 14	
Pontiac Ventura 6 2-door Coupe	3,254	52/48	111	199.4	72.5	53.1	59.9	59.6	1.40	E78 x 14B	
	3,305	54/46	111	199.4	72.5	53.1	59.9	59.6	1.36	E79 x 14B	
Plymouth Valiant Scamp 6	2,569	62/38	105.3	187.2	69	55.7	56.1	56.1	1.24	1.65SR14	
	2,500	62/38	97.4	174	66.5	56.7	54.7	55.3	1.17	1.65SR15	
Scab 99-L Sedan	2,820	59/41	101.8	179.3	64	55.1	53.5	53	1.16	6.45 x 14	
Toyota Corona Mark II	2,738	52/48	103	188	67.1	56.5	53.1	53.1	1.19	1.65SR15	
Volvo 144 4-door Sedan	—	—	—	—	—	—	—	—	—	—	compact category
Averages	3,088	55.4/44.6	108.1	193.6	70.6	53.5	57.6	56.9	—	—	—

TABLE 5 (cont'd)

Make and Model	Unladen or Curb Weight (lb)	Distribution ^f Front/Rear (%)	Wheelbase (in)	Overall Dimensions			Wheel Track		Tire Size	Comments	
				Length (in)	Width (in)	Height (in)	Front (in)	Rear (in)			
A. M. C. Matador 2-door 6	3,518	114	209.3	77.2	51.8	60	60	1.49	E78 x 14		
Matador 2-door V-8	3,745	114	209.3	77.2	51.8	60	60	1.49	E78 x 14		
Matador 4-door 6	3,548	54/46	118	216	77.2	55.4	60	60	E78 x 14		
Matador 4-door V-8	3,743	55/45	118	216	77.2	55.4	60	60	E78 x 14		
Buick Century 350 V-8	4,101	56/44	116	213.5	79.0	54.1	61.5	60.7	E78 x 14		
Century Regal 2-door V-8	4,146	112	212.0	79.0	53.3	61.5	60.7	1.46	G78 x 14		
Chevrolet Chevelle 2-door 6	3,653	112	206.3	76.6	53.1	61.5	60.7	1.48	E78 x 14		
Chevrolet Chevelle 4-door V-8	3,863	56/44	116	201.3	76.6	53.8	61.5	60.7	E78 x 14B		
Dodge Coronet 4-door V-8	3,685	55/45	118	212.4	77.8	53.6	61.9	62	G79 x 14B		
Charger V-8	3,650	115	214	77	52.5	61.9	62	1.45	F78 x 14		
Ford Torino 2-door V-8	3,954	114	211.4	79.3	52.8	63.4	63.5	1.47	G79 x 14B		
Torino 4-door V-8	4,039	57/43	118	213.4	79.3	53.5	63.4	63.5	G78 x 14B		
Mercury Montego 2-door V-8	3,977	114	215.5	78.6	52.8	63.4	63.5	1.48	G78 x 14B		
Montego 4-door V-8	4,062	54/43	118	219.5	78.6	53.5	63.4	63.5	G79 x 14B		
Oldsmobile Cutlass 2-door V-8	3,984	112	210.6	76.5	53.4	61.4	60.7	1.47	G78 x 14B		
Cutlass 1-door V-8	4,040	56/44	116	211.6	76.5	56.1	61.4	60.7	F78 x 14		
Plymouth Satellite 2-door V-8	3,610	115	212.4	79.1	52.2	61.9	62	1.36	F78 x 14		
Satellite 4-door V-8	3,690	55/45	117	213.3	78.6	53.7	61.9	62	F78 x 14		
Pontiac LeMans 2-door 6	3,665	112	208	77.9	52.3	61.5	60.7	1.46	F78 x 14		
LeMans 4-door V-8	3,957	56/44	116	212	77.9	52.9	61.5	60.7	F78 x 14B		
Averages	3,834	55.4/44.6	115.2	212.6	77.8	53.4	61.6	61.4	G79 x 14B		
A. M. C. Ambassador V-8	3,965	56/44	122	219.4	77.2	55.5	60	60	1.39	F78 x 14	
Buick LeSabre V-8	4,431	56/44	124	223.9	79.9	54.0	63.6	64	1.48	H78 x 15	
Chevrolet Bel Air, Impala V-8	4,281	54/46	121.5	222.7	79.5	54.5	64.1	64	1.46	G79 x 15B	
Caprice Classic V-8	4,427	121.5	222.7	79.5	54.5	64.1	64	1.46	G78 x 15B		
Chrysler Newport V-8	4,560	56/44	124	223	79.5	55.3	64.0	63.4	1.46	G78 x 15B	
New Yorker V-8	4,690	56/44	124	225	79.5	55.6	64.0	63.4	1.44	H78 x 15B	
Dodge Monaco V-8	4,300	55/45	122	220.5	79.3	54.8	64.0	63.4	1.43	JR78 x 15B	
Ford	4,302	57/43	121	222.5	79.5	54.9	64.2	64.4	1.45	JR78 x 15	
Mercury Monterey V-8	4,518	57/43	124	226.8	79.6	54.7	64.1	64.3	1.45	G79 x 15	
Marquis V-8	4,773	58/42	124	226.8	79.6	54.7	64.1	64.3	1.45	HR78 x 15	
Oldsmobile Delta 98 V-8	4,515	53/47	124	226.9	79.8	53.5	63.7	64.0	1.45	HR78 x 15	
Plymouth Fury V-8	4,315	54/46	122	219.9	79.9	54.8	64	63.4	1.49	H79 x 15	
Pontiac Catalina V-8, 2-door H/T	4,419	55/45	124	223.2	79.6	53.3	64.1	64.0	1.46	G78 x 15	
Bonneville V-8, 4-door H/T	4,584	55/45	124	226	79.6	54	64.1	64.0	1.49	H78 x 15B	
Grand Ville V-8, 4-door H/T	4,655	124	226	79.6	54	64.1	64.0	1.47	H78 x 15B		
Averages	4,450	55.5/44.5	123	221.0	79.4	54.5	63.7	63.6			
Buick Electra V-8	4,842	55/45	127	231.5	79.9	55.0	63.6	64.0	1.45	J79 x 15	
Cadillac Calais de Ville	5,174	54/46	130	230.7	79.8	54.4	63.3	63.3	1.46	L78 x 15B	
Lincoln Continental V-8	5,361	57/43	127.2	232.6	80	55.5	64.3	64.3	1.44	235 x 15	
Oldsmobile Custom Cruiser V-8	5,296	127.0	231.2*	80.0	54.0	63.3	63.7	63.7	1.48	L78 x 15	
Ninety-Eight V-8	4,778	52/48	127.0	232.4	79.8	54.2	63.7	64.0	1.47	J78 x 15	
Averages	5,078	54.5/45.5	127.6	231.7	79.9	54.6	63.6	63.8			
										full-size category no. 1	
										full-size category no. 2	

* Specifications: Domestic and Imports, Automotive News, Nov. 19, 1973 and April 1, 1974.

† Consumer Reports, April 1974

TABLE 6
FRONT AND REAR OVERHANG FOR VEHICLE - CABLE CONTACT*

Make and Model	Wheelbase Length (in)	Measured Overhang (in)		Percent of Wheelbase		Comments
		Front	Rear	Front	Rear	
1968 Datsun	94-1/4	21-1/4	34-3/4	22.5	36.9	
Toyota Corona	96-3/8	24	34-5/8	24.9	35.9	
1971 Ford Capri	100-7/8	26-7/8	32-3/8	26.6	32.1	
1970 Renault 12	96-1/4	25	35-3/8	25.6	36.7	
Averages	96-15/16	24-9/16	34-1/4	24.9	35.4	typical of subcompact category
1968 Beaumont	111-3/4	27-1/2	43-3/4	24.6	39.1	
Dodge Dart	111	32	42-1/4	28.8	38.0	
1970 Buick Skylark	111-7/8	33	48-1/8	33.9	43.0	
1968 504 Peugeot	107-1/2	23-1/2	35-3/8	21.8	32.9	
1968 Ford Falcon	110-1/2	28-1/2	49-5/8	25.8	36.7	
1970 Plymouth Duster	108	27-5/8	47	25.6	43.5	
Averages	110-5/16	28-7/8	42-15/16	26.7	38.8	typical of compact category
1973 Buick Skylark	115-7/8	29-7/8	49-3/4	25.8	42.9	
1972 Plymouth Satellite	117-3/4	32-1/2	52-1/2	27.5	44.6	
1970 Ford Torino	117-1/4	34-1/2	48	29.4	40.9	
1969 Pontiac Strato Chief	118-3/4	37-1/4	56-1/8	31.4	47.2	
1968 Ford Fairlane	116-1/4	26-7/8	46-3/8	23.1	40.2	
1972 Oldsmobile Cutlass	112	34	47-1/4	30.3	42.2	
1970 Ford Torino	117-3/8	34-3/4	47-1/2	29.6	40.5	
1974 Pontiac LeMans	116-3/4	31-3/4	48-5/8	27.2	41.6	
Averages	116-9/16	32-3/4	49-9/16	28.0	42.5	typical of intermediate category
1970 Meteor	123-5/8	36	56-7/8	29.1	46.0	
1970 Meteor LeMoyne	123-3/8	37-5/8	56-3/4	30.5	46.0	
1968 Oldsmobile Delta 88	124-1/2	33-3/4	52-3/4	27.1	42.4	
1971 Chevrolet Impala	121-1/4	29	52-1/8	23.9	43.0	
1973 Ford LTD	121	32-1/2	52	26.8	43.0	
1968 Lincoln Continental	125-3/4	35-1/8	56	27.3	44.5	
Averages	123-5/16	33-13/16	54-5/8	27.4	44.1	typical of full-size category

* Overhang measurements made relative to wheel axle centerlines at a vertical height of 24" to 27" above ground

TABLE 7
VEHICLE WEIGHT DISTRIBUTION

Make and Model	Division or Curb Weight (lb)	Total Vehicle Distribution			Suspension Weight			Suspension Distribution			Comments
		Front Axle (lb)	Rear Axle (lb)	Front/Rear <th>Front (lb)</th> <th>Rear (lb)</th> <th>Total (lb)</th> <th>Total (lb)</th> <th>Total (\%)</th> <th>Front/Rear<br (\%)<="" th=""/><th data-kind="ghost"></th></th>	Front (lb)	Rear (lb)	Total (lb)	Total (lb)	Total (\%)	Front/Rear <th data-kind="ghost"></th>	
not specified	2,400				171	288	459	17.0	37.2		
	2,700				172	286	458	16.4	37.5		
	2,910				182	292	474	16.2	38.3		
	3,100				171	293	464	14.9	36.8		
	3,220				186	289	475	14.7	39.1		
	3,500				194	329	522	14.5	37.3		
	3,770				224	328	552	14.6	36.5		
	4,150				244	390	634	15.2	38.4		
	4,180				230	316	576	13.7	39.9		
	4,370				262	361	626	12.9	35.6		
	4,470				232	322	654	11.6	35.4		
	4,600										Individual measured points. Figure 3 Reference 5
1969 Chevrolet Biscayne 4-door Sedan, 327 V-8	3,855	1,915	1,940	50.4/49.6				366	11.6		Reference 8
	3,870	1,810	1,530	51.5/48.5				484	11.3		Reference 8
	3,990	1,735	1,555	51.3/48.7				485	15.2		Reference 8
	4,120	1,715	1,285	55.6/44.4				503	16.1		specialty car Reference 8
	4,610	930	1,680	55.6/44.4				356	13.4		specialty car Reference 8
	4,885	2,090	1,795	53.7/46.3				329	13.6		specialty car Reference 8
	5,218	1,860	1,115	56/44				523	16.2		specialty car Reference 8
	5,325	1,728	1,597	51.9/48.1				513	15.4		Reference 8
	4,194	2,181	2,013	52/48				632	15.0		Reference 8
	4,164	2,215	1,919	53.1/46.8				579	13.9		Reference 8
	3,489	1,940	1,519	55.6/44.4				492	13.8		Reference 8
	4,780	2,337	2,333	59/41				671	11.1		Reference 8
	4,286	2,354	1,926	55/45	217	345	562	13.1	38.6	Reference 3	
	3,620	1,919	1,671	53.4/46.2	212	343	555	15.3	39.1	Reference 8	
	3,143	1,871	1,569	51.4/45.6	201	351	554	16.1	36.7	Reference 9	
	4,165	2,245	1,880	51.8/45.2	226	381	610	14.6	37.0	Reference 9	
	(4,390) [†]	2,406	1,992	51.7/45.3	(226)*	(381)*	610	13.8	37.0	Reference 9	
1973 Ford Galaxie-1 dr. Sedan 1973 Villain Sedan 6 cyl. engine (225CID)	4,122	2,203	1,929	53.3/46.7	235	365	600	11.5	39.4	Reference 2	
	3,120	1,780	1,310	57/43	195	280	475	15.2	41.0	Reference 10	
	3,750	2,100	1,650	56/44	210	350	560	11.9	37.5	Reference 10	
	4,600	2,480	2,120	53.9/46.1	255	415	670	11.5	38.0	Reference 10	
	2,925	1,504	1,421	51.1/48.6	117	249	366	12.5	40.2	Reference 11	
	3,370	1,711	1,665	50.7/49.3	151	284	475	11.1	40.2	Reference 11	
	4,694	2,314	1,915	51.5/45.6	257	355	612	12.0	37.0	Reference 11	
	5,065	2,611	2,154	51.5/48.5	241	365	616	12.8	33.8	Reference 11	
									38.51	average value	

[†] suspension weight measured

estimated

TABLE 8
CENTRE OF GRAVITY HEIGHT

Make and Model	Unladen or Curb Weight (lb)	Wheelbase Length (in)	Overall Height (in)	C. G. Height [†] (in)		C. G. Height /Overall Height (%)	Comments
				Sprung Mass	Total Vehicle		
1969 Mustang 2-door H/T, V-8	3,085	108	51.2	19.8	38.6	Reference 8	
1969 Falcon 2-door Sedan, 6 cyl. eng.	2,865	110, 9	54.9	23.0	41.8	Reference 8	
1969 Mercury-Marquis Colony Park 4-door Station Wagon	4,639	121	56.8	22.0	38.7	Reference 8	
Lincoln Continental 4-door Sedan	5,208	126	54.9	23.2	42.2	Reference 8	
1969 Chevy Nova 4-door Sedan, 250 L-6	3,182	111	52.4	21.2	40.4	Reference 8	
1969 Chevelle 2-door H/T, 307 V-8	3,469	112	53.5	22.9	41.1	Reference 8	
1969 Impala 4-door H/T, 350 V-8	4,126	119	55.9	22.9	40.9	Reference 8	
1973 Valiant Sedan, 223 CID6	3,120	111	52.4	21.3*	40.3	Reference 10	
1973 Dodge Coronet Sedan, V-8	3,750	117, 5	53.6	22.1*	41.2	Reference 10	
1973 Chrysler New Yorker, V-8	4,600	123, 5	56.4	22.3*	39.5	Reference 10	
1974 Subcompact	2,450	97	51.9	20	38.5	Reference 12	
1974 Compact	3,200	111	53.0	22	41.5	Reference 12	
1974 Intermediate	4,200	112	53.3	20.5	38.1	Reference 12	
1974 Standard	4,450	121	54.5	21.7	39.8	Reference 12	
1974 Pinto (subcompact)	2,925 [‡]	94, 2	50.3	20.6 [†]	40.9	Reference 11	
1974 Maverick (compact)	3,379 [‡]	103	53	20.73 [†]	39.2	Reference 11	
1974 Torino (intermediate)	4,694 [‡]	118	53.5	20.4 [†]	38.1	Reference 11	
1974 Ford (standard)	5,065 [‡]	121	54.9	20.5 [†]	37.3	Reference 11	

[†] Measured relative to ground

* At 3 passenger load (2 front, 1 rear)

[‡] Design load condition = 1 less than maximum number of passengers

TABLE 9
VEHICLE MOMENT OF INERTIA PARAMETERS

Make and Model	Unladen or Curb Weight (lb)	Vehicle Sprung Mass						Total Vehicle						Comments	
		I_x (slug-ft ²)	k_x^2 (ft ³)	I_y (slug-ft ²)	k_y^2 (ft ³)	I_z (slug-ft ²)	k_z^2 (ft ³)	Roll	I_x (slug-ft ²)	k_x^2 (ft ³)	Pitch	I_y (slug-ft ²)	k_y^2 (ft ³)	I_z (slug-ft ²)	k_z^2 (ft ³)
	2,555	217	2.69			1,425	17.65			1,025	12.92				
	2,600	212	2.12			1,635	16.38			1,600	16.02				
	3,215									1,575	15.44				
	3,285									1,725	16.81				
	3,305									1,825	17.28				
	3,360											2,560	21.03		
	3,400											2,730	20.23		
	3,450											3,030	24.80		
	3,545	310	2.91			2,130	20.00								
	3,720	315	2.86			2,280	20.71								
	3,920	344	2.98			2,613	22.64								
	3,930											2,650	21.77		
	3,950											2,360	18.84		
	3,995											2,475	20.18		
	4,025											2,450	19.75		
	4,045	408	3.25			2,859	22.69					2,200	17.60		
	4,060											2,525	20.10		
	4,120	403	3.15			3,105	24.27					2,700	21.41		
	4,175	405	3.12			2,915	22.48								
	4,260	467	3.53			3,350	25.32								
	4,315														
	4,340											2,725	20.33		
	4,375											3,000	22.26		
	4,380											2,860	20.61		
	4,475											3,025	22.24		
	4,480											3,175	22.84		
	4,530	486	3.45			3,270	23.24					2,925	21.02		
	4,565	403	2.84			2,930	20.67								
	4,605											3,275	22.90		
	4,635											3,425	23.79		
	4,690	548	3.76			3,470	23.82								
	4,710	521	3.56			3,795	25.94								
	4,795	453	3.04			3,250	21.82								
	4,895											3,400	22.36		
	4,950	512	3.33			3,865	25.14					3,575	23.52		
	5,090											3,725	23.99		
	5,075											3,775	23.95		
	5,160											3,625	22.62		
	5,220											3,975	24.52		
	5,330											3,775	22.80		
	5,395											4,225	25.22		
	5,410											4,350	25.97		
	5,620											4,625	26.50		
	5,840											4,600	25.36		
	5,900											4,875	26.60		
	6,040											4,800	25.59		

Figures 2, 4, 5, 6
Values reflect
measurements
made on sports
cars, station
wagons and
various loading
conditions

TABLE 10
VEHICLE SPRUNG MASS ROLL - YAW PRODUCT OF INERTIA

Vehicle Weight (lb)	Sprung Mass Moment of Inertia Yaw (slug - ft ²)	Roll (slug - ft ²)	Yaw - Roll (slug - ft ²)			Comments
			$\lambda = 1^\circ$	$\lambda = 3^\circ$	$\lambda = 5^\circ$	
2,600	1,425	217	1,208	21	63	106
3,215	1,635	212	1,423	24	75	125
3,430	2,130	310	1,820	32	95	160
3,545	2,280	315	1,965	34	103	173
3,720	2,615	344	2,271	39	119	200
4,045	2,850	408	2,442	42	128	215
4,120	3,105	403	2,702	47	142	238
4,175	2,915	405	2,510	44	132	221
4,260	3,350	467	2,883	50	151	254
4,530	3,270	486	2,784	48	146	245
4,565	2,930	403	2,527	44	133	223
4,690	3,470	548	2,922	51	153	257
4,710	3,795	521	3,274	57	172	288
4,795	3,250	453	2,797	49	147	246
4,950	3,865	512	3,353	58	176	295

TABLE 11
SUSPENSION CHARACTERISTICS

Make and Model	Weight Distribution (lb)				Wheel Rate [†] (lb/in)		Ratio (%)		Damping		Sprung Weight Bounce Natural Frequency (c/s)				Comments		
	Total Vehicle		Sprung Mass		Coloumb [‡] (lb)		Viscous [‡] Coefficient (lb-sec/in)		Front		Rear		Front		Rear		
	Front	Rear	Front	Rear	Front	Total	Front	Rear	Front	Rear	Front	Total	Front	Rear	Front	Rear	
1969 Ford 4-door Sedan, 302 V-8 engine	2,039	1,766	(1,828)	(1,421)	96	123	43.8						1.01	1.29	1.15		Reference 8
1969 Mustang 2-door H/T, 302 V-8 engine	1,777	1,428	(1,592)	(1,125)	74	103	41.8						0.88	1.34	1.13		Reference 8
1969 Fairlane 500 4-door Sedan, 302 V-8 engine	1,749	1,510	(1,562)	(1,203)	76	93	44.9						0.98	1.23	1.09		Reference 8
1969 Lincoln 4-door Sedan, 460 V-8 engine	2,771	2,437	(2,500)	(1,994)	105	100	51.2						0.91	0.99	0.95		Reference 8
1963 Ford Galaxie 4-door	2,203	1,929	1,968	1,564	131	194	40.3	58.0	97.0	1.30	1.75	1.14	1.56	1.34		Reference 2	
1969 Ford Galaxie 500 4-door H/T, 390 V-8 engine	2,354	1,926	2,137	1,581	105	114	47.9	35	13.75	0.633	0.125	0.98	1.19	1.07		Reference 3	
1970 Torino 4-door H/T, 351 V-8 engine	2,220	1,580	(2,009)	(1,236)	100	95	51.2						0.99	1.23	1.09		Reference 17
1963 Pontiac Strato Chief	2,123	2,176	1,927	1,873	124.7	121.1	50.7	29.5	11				1.12	1.12	1.12		Reference 13
1973 Valiant Sedan, 225 6 cyl. engine	1,730	1,340	1,585	1,060	95	110	46.3						1.08	1.43	1.23		Reference 10
1973 Dodge Coronet Sedan, V-8 engine	2,100	1,650	1,890	1,300	105	125	45.6						1.04	1.37	1.19		Reference 10
1973 Chrysler New Yorker, V-8 engine	2,460	2,120	1,925	1,705	115	120	48.9						1.08	1.17	1.13		Reference 10
Subcompact	1,309	1,150	(1,147)	(900)	110	125	46.8						1.37	1.65	1.50		Reference 12
Compact	1,700	1,500	(1,515)	(1,197)	90	100	47.4						1.08	1.28	1.14		Reference 12
Intermediate	2,400	1,800	(2,172)	(1,427)	100	105	48.8						0.95	1.20	1.06		Reference 12
Standard	2,450	2,000	(2,212)	(1,610)	105	115	47.7						0.96	1.18	1.06		Reference 12
1974 Pinto (subcompact)	1,372	1,078	1,225	859	111	110	50.4						1.33	1.58	1.44		Reference 11
1974 Maverick (compact)	1,758	1,382	1,567	998	86	119	41.9						1.03	1.53	1.25		Reference 11
1974 Torino (intermediate)	2,360	1,780	2,103	1,425	105	130	44.7						0.99	1.33	1.14		Reference 11
1974 Ford (standard)	2,625	1,980	2,341	1,615	112	122	47.8						0.97	1.21	1.07		Reference 11

[†] Wheel rate (does not include tire) = suspension load-deflection rate for a single wheel in the quasi-linear range about the curb position, effective at the wheel for the front and at the axle for the rear

[‡] Estimated using the results of Figure 11 and Table 7

* Shock absorber rates given in Table 14

¹ Values effective at the wheel for the front and at the axle for the rear. Reference (2) includes an estimated average shock absorber "blow-off" force in jounce and rebound velocities and approximate installation ratios

² From average slopes of shock absorber force vs. velocity data for jounce and rebound

TABLE 12

SUSPENSION ROLL STIFFNESS

Make and Model	Unladen or Curb Weight (lb)	Wheel Track		Rear Spring Spacing at Axle (in)	Wheel Rate		Roll Stiffness				Comments		
		Front (in)	Rear (in)		Front (lb/in)	Rear (lb/in)	Front (lb-ft/deg)		Rear (lb-ft/deg)				
							Total	Auxiliary	Total	Auxiliary			
1970 Ford Torino 4-dr. H/T	3800	60.6	60.3		100	95	867		382(L)		Reference 17		
1969 Ford Galaxie 500 4-dr. H/T, 390 V-8	4280	63	64	38.44	105	114	418	115	234(C)	112	Reference 3		
1963 Ford Galaxie 4-dr. Sedan	4132	61.2	60.5	46.52	131	194	744	387	391(L)	86	Reference 2		
1973 Valiant Sedan, 225 CID 6 cyl. engine	3120	59.1	55.6	43.02	95	110	241 (95)	0	225(L) (100)	77	Reference 10		
1973 Dodge Coronet Sedan, 8 cyl. engine	3750	61.9	62.0	47.3	105	125	557 (200)	292	335(L) (120)	132	Reference 10		
1973 Chrysler New Yorker, 8 cyl. engine	4600	62.1	63.4	47.3	115	120	617 (220)	294	292(L) (100)	97	Reference 10		
1963 Pontiac Strato Chief 2-dr. Sedan, 6 cyl. engine	4299	60.34	59.28	42.0	124.7	121.1	353	23	182(C)	25	Reference 13		
1974 Pinto (subcompact)	2450	55.1	55.0	42.2	111	110	262	17	187(L)	45	Reference 11		
1974 Maverick (compact)	3140	56.4	56.5	42.8	86	119	395	199	226(C)	68	Reference 11		
1974 Torino (intermediate)	4140	63.6	62.9	33.7	105	130	782	473	138(C)	31	Reference 11		
1974 Ford (standard)	4605	64.0	64.3	38.44	112	122	560	227	185(C)	54	Reference 11		
Subcompact	2450	55	54		110	125	320		245(C)		Reference 12		
Compact	3200	60	60		90	100	460		170(C)		Reference 12		
Intermediate	4200	62	61		106	107	517		160(C)		Reference 12		
Standard	4150	54	54		105	115	329		140(C)		Reference 12		
1969 Ford 4-dr. Sedan, 302 V-8 engine	3805	63	64		96	123		*	(C)		Reference 8		
1969 Mustang 2-dr. H/T, 302 V-8 engine	3205	58.5	58.5		74	103		*	(L)		Reference 8		
1969 Fairlane 500 4-dr. Sedan, 302 V-8 engine	3259	60.5	60		76	93		*	(L)		Reference 8		
1969 Lincoln 4-dr. Sedan, 460 V-8 engine	5208	62.4	61		105	100		*	(L)		Reference 8		

() Wheel rate in roll (lb/in)

* Front suspension equipped with stabilizer bar in all cases

$$(R_T)_F = \frac{(T_F)^2}{2} K_F + R_F - \text{for front}$$

R_F and R_R are the auxiliary roll stiffnesses, that is, the roll stiffness in excess of that corresponding to the wheel rates in ride motions

$$(R_T)_R = \frac{(T_S)^2}{2} K_R + R_R - \text{for rear}$$

(L) Indicates rear suspension using semi-elliptic leaf springs

(C) Indicates rear suspension using coil springs

 $T_S \approx 0.764 T_R$ for (L) $T_S \approx 0.640 T_R$ for (C)

TABLE 12A
CALCULATED ROLL STIFFNESS

Make and Model	Wheel Track (in)		Wheel Rate (lb/in)		Rear Spring Spacing at Axle (in)		Front Roll Stiffness (lb-ft/deg)	Rear Roll Stiffness (lb-ft/deg)						
							No Roll Bar	With Roll Bar	Coil Springs	Leaf Springs				
	Front	Rear	Front	Rear	Leaf	Coil	Total	Auxiliary	Total	Auxiliary	Total	Auxiliary	Total	Auxiliary
1970 Ford Torino	60.6	60.3	100	95	46.07		287	20	554	287			234	87
1969 Ford Galaxie 500	63	64	105	114		40.96	323	20	626	323	197	58		
1963 Ford Galaxie	61.2	60.5	131	194	46.22		377	20	733	377			389	87
1973 Valiant Sedan	59.1	55.6	95	110	42.48		261	20	502	261			232	87
1973 Dodge Coronet	61.9	62.0	105	125	47.37		312	20	605	312			291	87
1973 Chrysler New Yorker	62.1	63.4	115	120	48.44		342	20	665	342			292	87
1963 Pontiac	60.34	59.28	124.7	121.1		37.93	350	20	680	350	184	58		
1974 Pinto	55.1	55.0	111	110	42.02		265	20	510	265			228	87
1974 Maverick	56.4	56.5	86	119		36.16	219	20	418	219	171	58		
1974 Torino	63.6	62.9	105	130		40.25	329	20	638	329	211	58		
1974 Ford	64.0	64.3	112	122		41.15	353	20	687	353	208	58		
Subcompact	55	54	110	125		34.56	261	20	504	261	166	58		
Compact	60	60	90	100		38.40	255	20	491	255	165	58		
Standard	64	64	105	115		40.96	333	20	645	333	198	58		
1969 Ford Sedan	63	64	96	123		40.96	297	20	574	297	208	58		
1969 Mustang	58.5	58.5	74	103	44.69		204	20	388	204			237	87
1969 Fairlane 500	60.5	60	76	93	45.84		222	20	424	222			229	87
1969 Lincoln	62.4	61	105	100	47.67		317	20	614	317			252	87

For front roll stiffness:

$$1) \text{ No roll bar} \quad (R_T)_F = \frac{T_F^2}{2} K_F + 20$$

$$2) \text{ With roll bar} \quad (R_T)_F = T_F^2 K_F + 20$$

For rear roll stiffness:

$$1) \text{ Coil spring} \quad (R_T)_R = \frac{T_S^2}{2} K_R + 58$$

$$T_S = 0.64 T_R$$

$$2) \text{ Leaf spring} \quad (R_T)_R = \frac{T_S^2}{2} K_R + 87.4$$

$$T_S = 0.764 T_R$$

TABLE 13
STEERING AND DRIVE LINE SYSTEM

Parameter	Description and Typical Value	Comments
Moment of inertia of the steering wheel (I_{SW}) (lb-sec ² -in)	0.6 (about its own axis of rotation) 446.4 (effective about the kingpin axis - I'_{SW})	Reference 3 Reference 21
Moment of inertia of one front wheel (I_{FW}) (lb-sec ² -in)	effective about kingpin axis } 8 } 17.64	Reference 3 Reference 21
Coulomb friction (C'_ψ) (lb-in)	600 (effective at the wheel both sides included)	References 21 and 13
Viscous damping derivative (lb-in/rad/sec)	1608 (total system about kingpin axis) } (H_δ) 400 (front wheel) } 2.2 (for steering wheel) (K_δ)	Reference 21 } Reference 3
Flexibility (lb-in/rad)	6000 (steering column and gear box (K_{SC})) 28600 (steering linkage (K_{SL})) 75900 (total system (K_{SS})) 51000 (total system (K_ψ))	} Reference 3 Reference 21 Reference 13
Drive line inertia (lb-sec ² -in)	0.6 (for rear drive (I_D))	Reference 3

Test Vehicles:

Reference 3: 1969 Ford Galaxie 500 4-dr. H/T, 390 C.I.D. 2v, V-8 engine, automatic transmission, power steering and power drum brakes

Reference 21: 1953 Buick

Reference 13: 1963 Pontiac Strato Chief, 6 cyl. engine, standard transmission

TABLE 14

REPRESENTATIVE DATA FOR CHRYSLER PRODUCTION MODELS

Parameter	Units	1973 Valiant Sedan 225 CID 6 Cyl. Eng.	1973 Dodge Coronet Sedan 8 Cyl. Eng.	1973 Chrysler New Yorker 8 Cyl. Eng.
Wheelbase	in	111	117.5	123.5
Track: Front	in	59.1	61.9	62.1
Rear	in	55.6	62.0	63.4
Rear Spring Spacing at Axle	in	43.02	47.3	47.3
Wheel Centre Height	in	12.1	12.5	13.4
Curb Weight: Front	lb	1780	2100	2480
Rear	lb	1340	1650	2120
Unsprung Weight: Front	lb	195	210	255
Rear	lb	280	350	415
*Vertical C.G. Height	in	21.3	22.1	22.3
Moment of Inertia: Roll	slug-ft ²	215	295	415
Pitch	slug-ft ²	1450	1980	2800
Yaw	slug-ft ²	2220	3030	4250
Wheel Rate: Front	lb/in	95	105	115
Rear	lb/in	110	125	120
Roll Rate: Front	lb/in	95	200	220
Rear	lb/in	110	120	100
*Full Wheel Travel: Jounce—Front	in	3.73	4.00	4.00
Rear	in	3.89	3.20	3.94
Rebound—Front	in	3.98	3.84	4.00
Rear	in	5.55	5.60	4.77
*Rear Roll Steer	%	5	5	0
*Rear Roll Centre Height	in	10.4	10.3	11.3
Shock Absorber Rate: Front	lb-sec/in	3	4	5
Rear	lb-sec/in	5	6	7
8-1/4 axle, 2.71 ratio with 10 in brake and drum assembly				
Moment of Inertia: Fore and Aft Plane	slug-ft ²	16.092	16.092	
Vertical Plane	slug-ft ²	16.159	16.159	
Lateral Plane	slug-ft ²	0.624	0.624	

* At 3 passenger load (2 front, 1 rear)

TABLE 15

REPRESENTATIVE DATA FOR GENERAL MOTORS PRODUCTION MODELS

Parameter	Units	Subcompact	Compact	Intermediate	Standard
Wheelbase	in	97	111	112	121
Track: Front	in	55	60	62	64
Rear	in	54	60	61	64
Rear Spring Spacing		*	*	*	*
Wheel Height	in	11	12.5	12.7	13.0
Total Weight	lb	2450	3200	4200	4450
Front Weight	lb	1300	1700	2400	2450
Unsprung Front Weight		**	**	**	**
Rear Weight	lb	1150	1500	1800	2000
Unsprung Rear Weight		**	**	**	**
C.G. Height	in	20	22	20.5	21.7
Moment of Inertia: Roll	slug-ft ²	220	310	430	490
Pitch	slug-ft ²	1200	1900	2700	3100
Yaw	slug-ft ²	1200	1900	2700	3300
Roll-Yaw Product of Inertia	slug-ft ²	-3	32	-13	-3
Rear Axle Moment of Inertia		N/A	N/A	N/A	N/A
Ride Rate (both wheels): Front	lb/in	220	180	200	210
Rear	lb/in	250	200	210	230
Rear Roll Steer	%	0	5	7	3
Roll Rate: Front	lb-ft/deg	320	460	515	620
Rear	lb-ft/deg	245	170	110	140
Wheel Travel to Stops		*	*	*	*
Rear Roll Centre	in	11	9	17	17
Damping		**	**	**	**
Suspension Stop Spring Rates		N/A	N/A	N/A	N/A

* Not routinely tabulated for current General Motors' vehicles

** Can be approximated as per General Motors' Report A-2542 (Ref. 5)

N/A Not available

TABLE 16

REPRESENTATIVE DATA FOR FORD PRODUCTION MODELS

Parameter	Units	1974 Pinto Subcompact	1974 Maverick Compact	1974 Torino Intermediate	1974 Ford Standard
Dimensions:					
Wheelbase	in	94.2	103	118	121
Track: Front	in	55.1	56.4	63.6	64.0
Rear	in	55.0	56.5	62.9	64.3
Rear Spring Spacing	in	42.2	42.8	33.7	38.44
Wheel Centre Height	in	10.7	11.1	11.8	12.4
Mass Parameters: (Design Load = 1 less than max. no. of passengers)					
Total Weight	lb	2925	3379	4694	5065
Weight Distribution: Front	lb	1504	1714	2318	2611
Unsprung Weight: Front	lb	147	191	257	284
Rear	lb	219	284	355	365
Vertical C.G. (above ground)	in	20.6	20.78	20.4	20.5
Moment of Inertia: Roll	lb-sec ² -in	—	3886	—	—
Pitch	lb-sec ² -in	—	24282	—	—
Yaw	lb-sec ² -in	—	25534	—	—
Suspension:					
Wheel Spring Rate: Rear	lb/in	95	95	130	130
Front	lb/in	280	225	270	300
Rear Roll Steer	%	9.5	6.8	5.7	0
Roll Stiffness: Front	lb-ft/deg	262	395	782	560
Rear	lb-ft/deg	187	226	138	185
Wheel Travel (metal to metal)					
Front: Jounce	in	3.37	4.5	4.24	4.10
Rebound	in	3.63	4.5	4.11	4.50
Rear: Jounce	in	3.51	3.67	3.07	3.91
Rebound	in	3.26	4.2	5.72	6.09
Rear Roll Centre	in	9.4	8.85	7.90	14.30
Suspension Stop Spring Rate:					
Front	lb/in	1200	865	500	500
Rear	lb/in	210	285	625	375
Ride Rate: Front	lb/in	111	86	105	112
Rear	lb/in	110	119	130	122

TABLE 17

TABLE 18

VEHICLE PARAMETERS FOR VEHICLE - TERRAIN - CABLE BARRIER PARAMETRIC STUDIES

Parameter (Symbol) (Units)	Vehicle Category					
	Subcompact	Compact	Intermediate	Standard		
				Weight Category No. 1	Weight Category No. 2	Weight Category No. 3
Sprung mass (M_s) (lb-sec ² /in)	4.117	6.350	7.704	8.835	9.655	10.421
Unsprung mass { front (M_{UF}) lb-sec ² /in } rear (M_{UR})	0.339 0.543	0.417 0.714	0.512 0.817	0.566 0.905	0.605 0.967	0.641 1.027
Sprung mass C.G. relative { front (a) to wheel centres (in) } rear (b)	38.031 56.068	45.931 62.868	49.591 66.108	52.198 68.701	54.081 70.318	55.787 71.712
Wheel track (in) { front (T_f) rear (T_R) }	50.8 50.4	56.7 56.3	59.6 59.3	61.9 61.6	63.0 62.0	63.0 62.0
Static vertical distance between sprung mass C.G. and front wheel centres (z_f) (in)	11.290	10.406	10.655	9.724	9.868	10.052
Static vertical distance between sprung mass C.G. and rear axle roll centre (z_R) (in)	11.180	10.266	10.505	9.554	9.698	9.872
Sprung mass moment of inertia (lb-sec ² /in) { roll (I_x) pitch (I_y) yaw (I_z) }	1344 6542 9708	2664 13558 19128	3624 18721 26016	4512 23555 32412	5208 27325 37380	5880 31035 42288
Rear unsprung mass moment of inertia in roll (I_R) (lb-sec ² /in)	172	282	358	428	464	493
Sprung mass yaw-roll product of inertia (I_{xy}) (lb-sec ² /in)	432	864	1176	1464	1692	1908
Vertical distance between rear axle C.G. and rear axle roll centre (ρ) (in)	0	0	0	0	0	0
Undeflected radius of wheel (R_w) (in)	13	14	14	15	15	15
Suspension load { front (K_f) deflection rate (lb/in) } rear (K_R)	73 91	94 112	102 117	105 118	106 117	105 114
Effective distance between { coil spring springs at rear axle (T_S) (in) } leaf spring	32.25 38.50	36.03 43.01	37.95 46.30	39.42 47.06	39.68 47.37	39.68 47.37
Auxiliary roll stiffness (lb-in/rad) { front (R_f) no roll bar } front (R_f) with roll bar rear (R_R) coil springs rear (R_R) leaf springs	13751 107945 39878 60092	13751 165012 39878 60092	13751 194577 39878 60092	13751 214516 39878 60092	13751 224142 39878 60092	13751 224142 39878 60092
Rear axle roll-steer coefficient (K_{RS}) (%)	5	5	5	5	5	5
Coulomb damping (lb) { front (C_f) rear (C_R) }	32.25 12.37	32.25 12.37	32.25 12.37	32.25 12.37	32.25 12.37	32.25 12.37
Viscous damping coefficient (lb-sec/in) { front (C_f) rear (C_R) }	2.32 3.64	3.23 5.09	3.69 5.78	4.00 6.24	4.19 6.52	4.32 6.70
Suspension stop spring rate { front rate (lb/in) } rear	1200 210	865 285	500 625	500 375	500 375	500 375
Suspension stop spring rate { front as a multiple of wheel rate } rear (λ_R)	16.44 2.31	9.20 2.54	4.91 5.34	4.76 3.18	4.72 3.20	4.76 3.29
Vertical wheel travel to suspension stops (in) { front (Ω_f) jounce and rebound } rear (Ω_R)	3.85 4.71	3.85 4.71	3.91 4.39	4.00 4.35	4.00 4.35	4.00 4.35
Steering system - values effective at the wheels, both sides included						
Moment of inertia (I_v) (lb-sec ² /in)	490	490	490	490	490	490
Coulomb friction (C_v) (lb-in)	600	600	600	600	600	600
Total stiffness (K_v) (lb/in/rad)	51000	51000	51000	51000	51000	51000
Angular deflection to stops (Ω_v) (rad)	0	0	0	0	0	0
Front wheel camber angle vs. front wheel vertical deflection (ϕ_c) (deg) vs. (δ) (in)				See Figure 17		
Cable contact co-ordinate points (in)						
right front corner A X_A Y_A	62.53 31.05	74.63 35.60	80.00 37.85	85.70 39.55	88.98 40.00	88.98 40.00
right rear corner C X_C Y_C	88.77 31.05	105.47 35.60	114.21 37.85	121.10 39.55	125.72 40.00	129.81 40.00

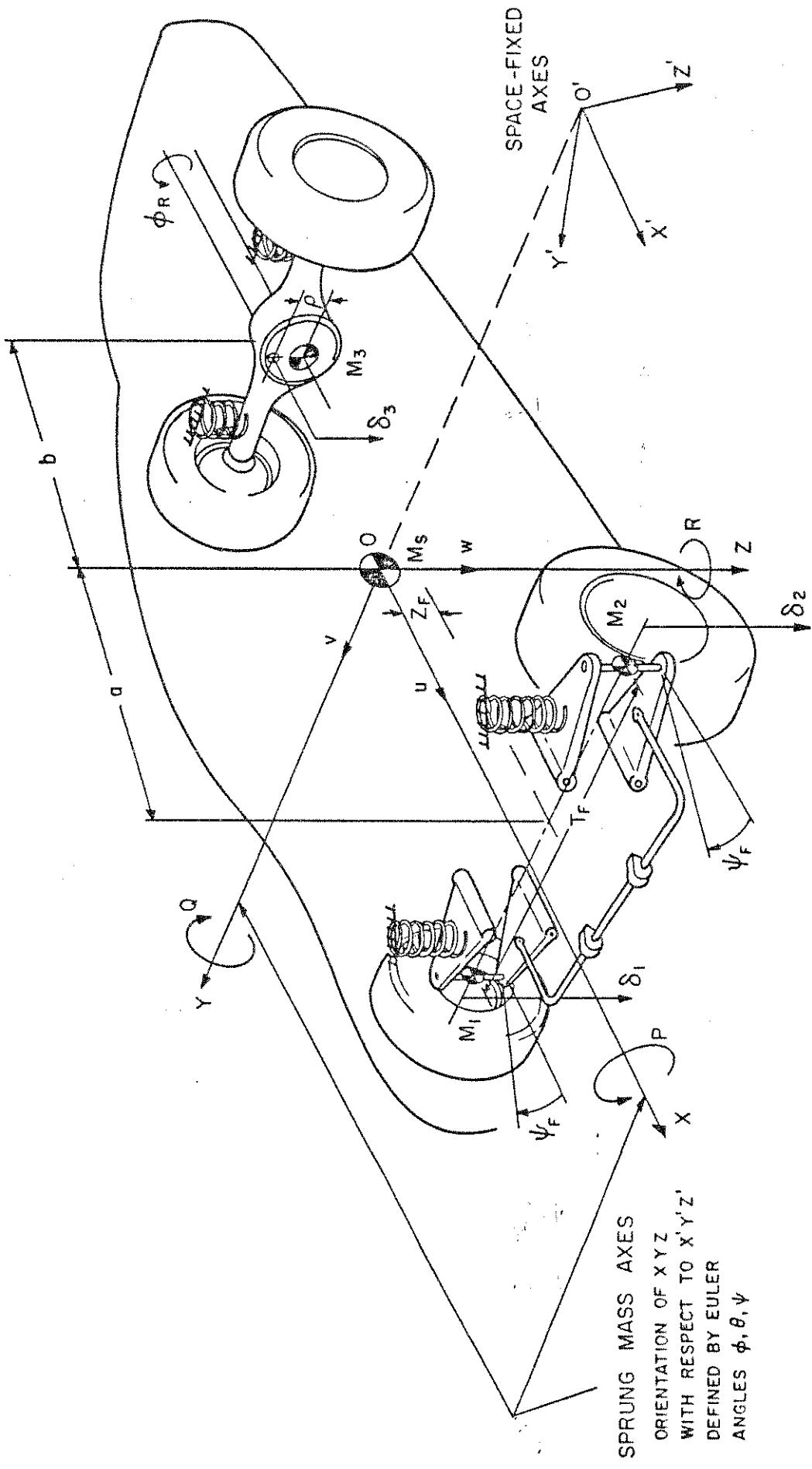


FIG. I

VEHICLE PARAMETERS
(MODEL FOR SOLID REAR AXLE - REAR DRIVE SYSTEM)

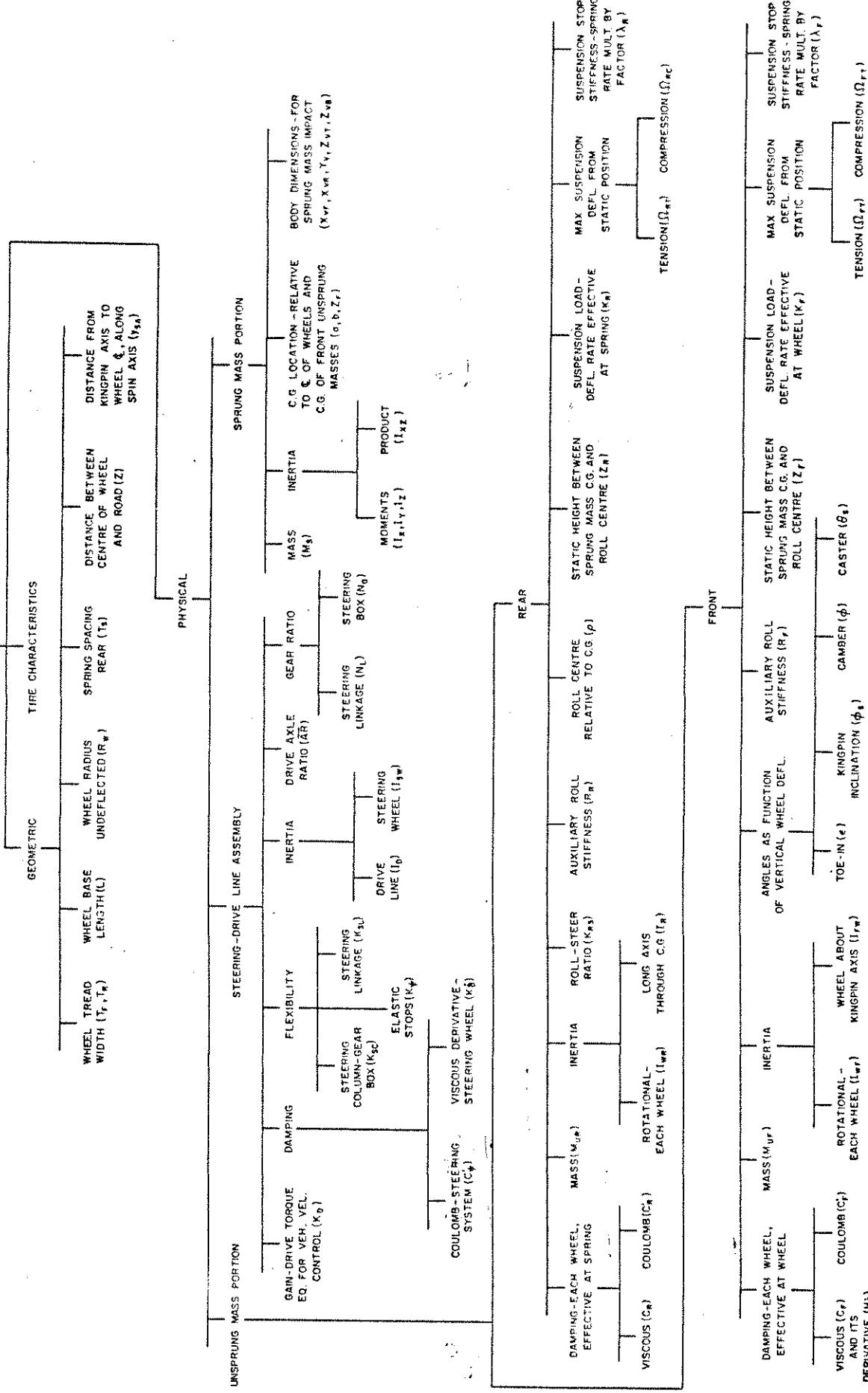


FIG. 2 FLOW CHART OF VEHICLE PARAMETERS REQUIRED FOR VEHICLE DYNAMIC STUDIES

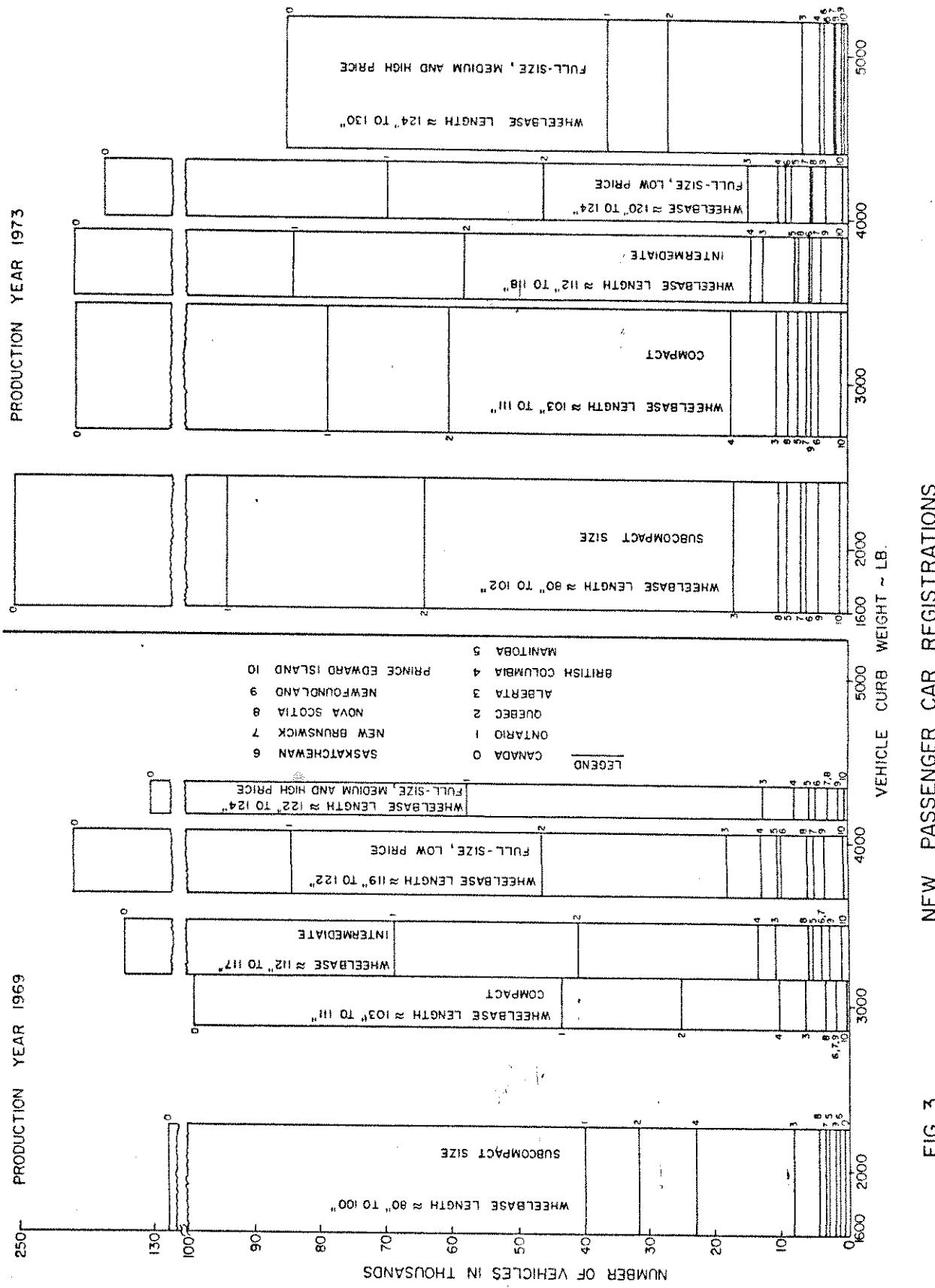


FIG. 3

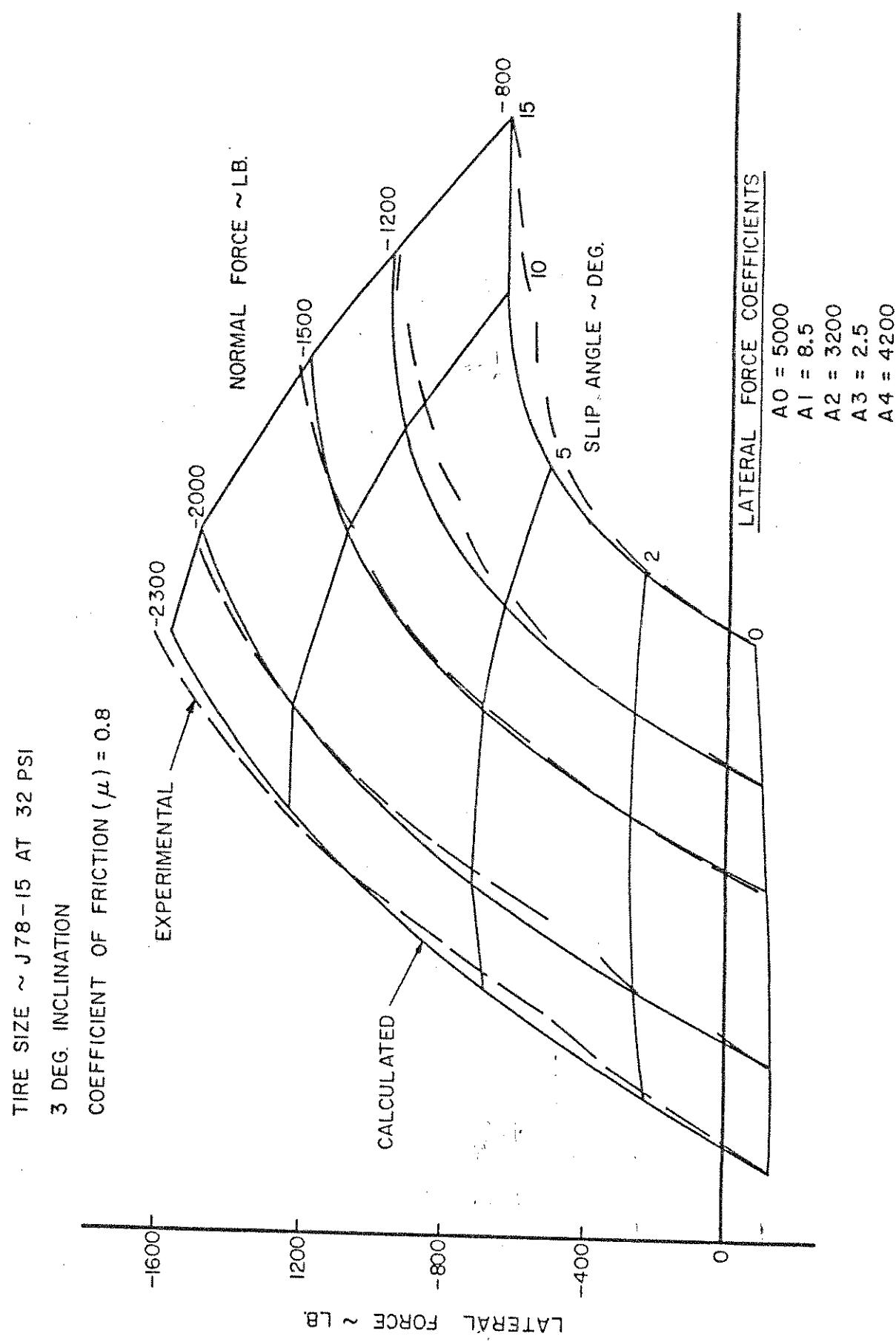


FIG. 4 TYPICAL COMPARISON OF EXPERIMENTAL AND CALCULATED TIRE CHARACTERISTICS

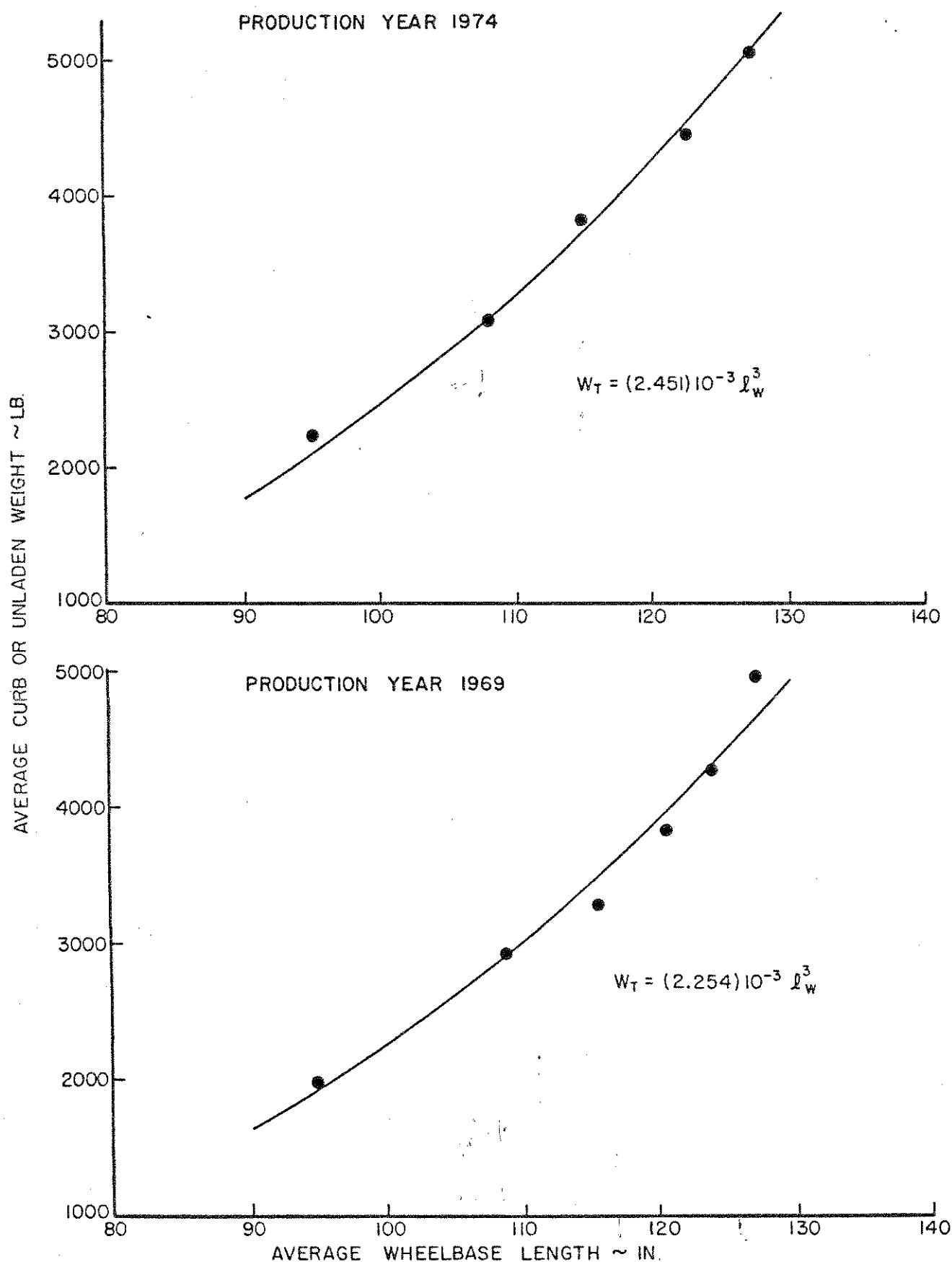


FIG. 5

TOTAL WEIGHT AS A
FUNCTION OF WHEELBASE LENGTH

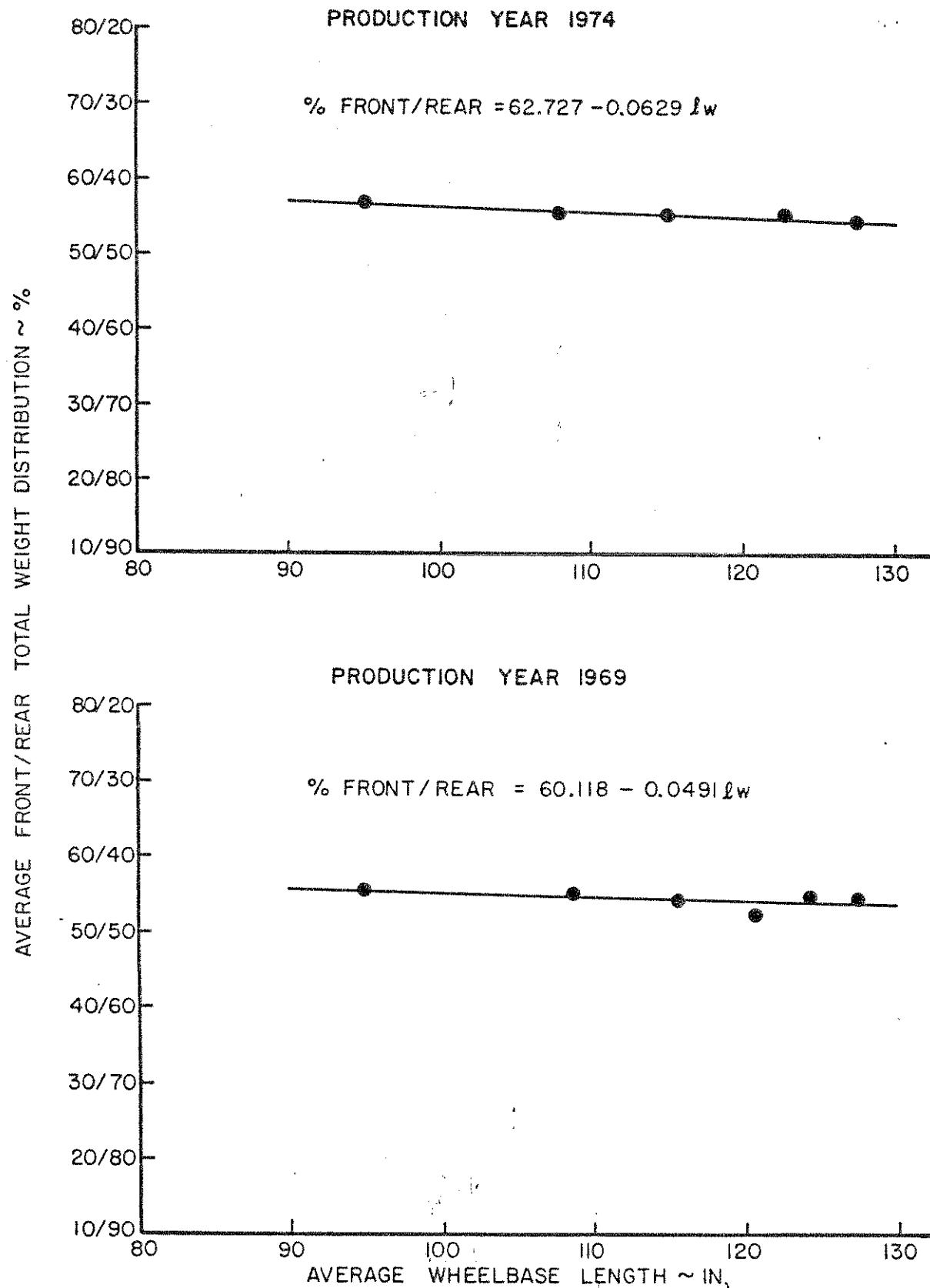


FIG. 6

TOTAL WEIGHT DISTRIBUTION
AS A FUNCTION OF WHEELBASE LENGTH

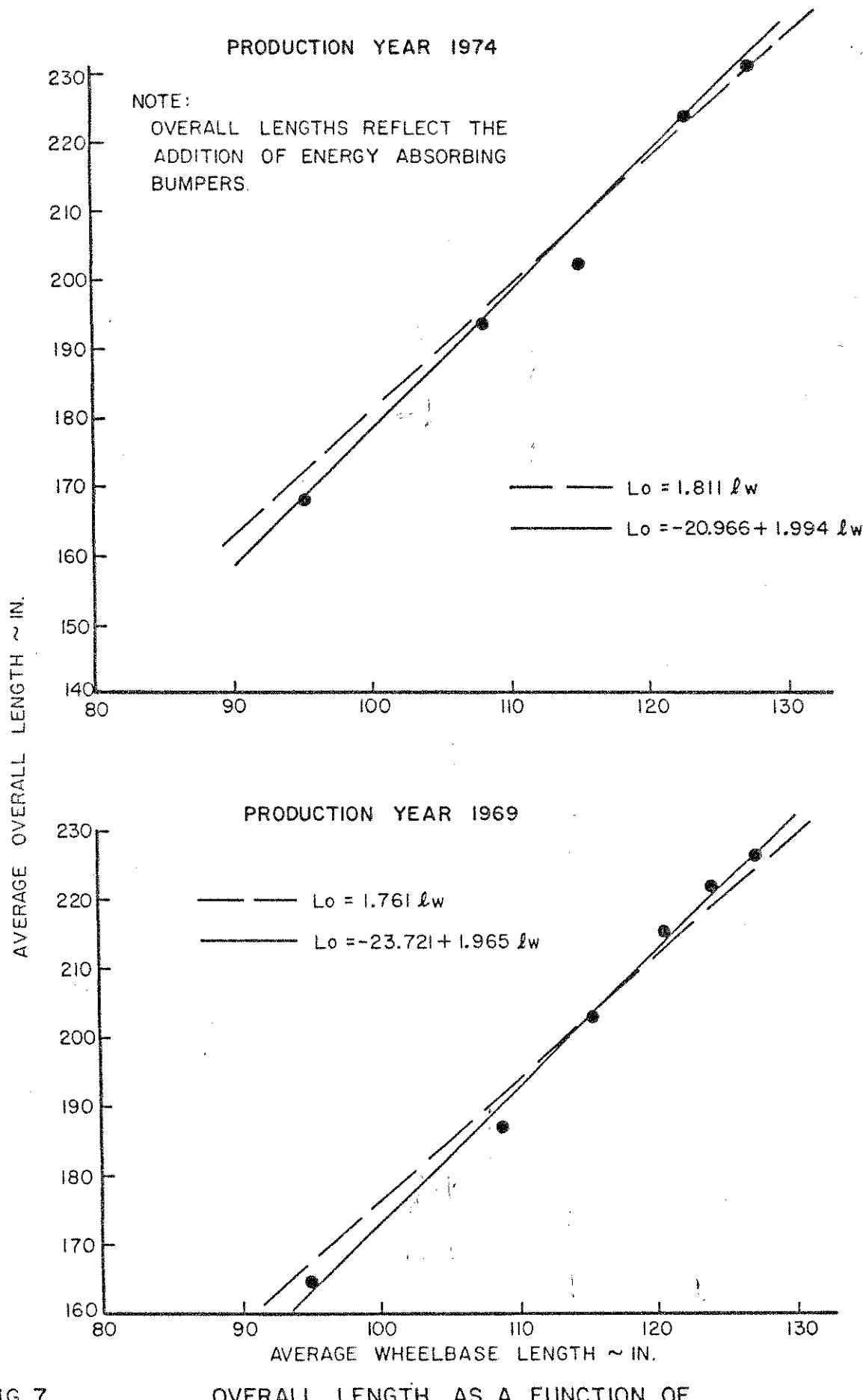


FIG. 7

OVERALL LENGTH AS A FUNCTION OF
WHEELBASE LENGTH

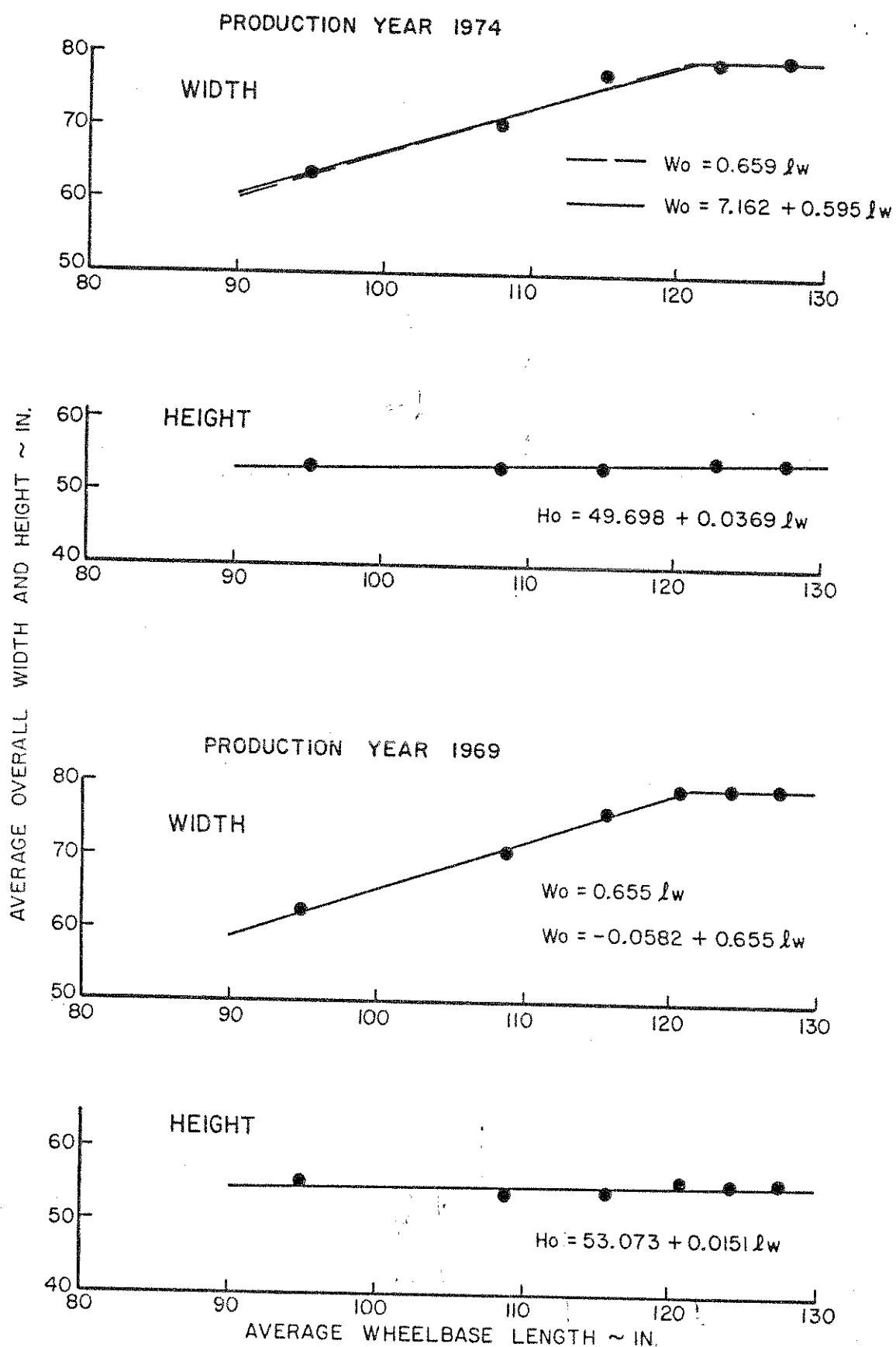


FIG. 8

OVERALL WIDTH AND HEIGHT
AS A FUNCTION OF WHEELBASE LENGTH

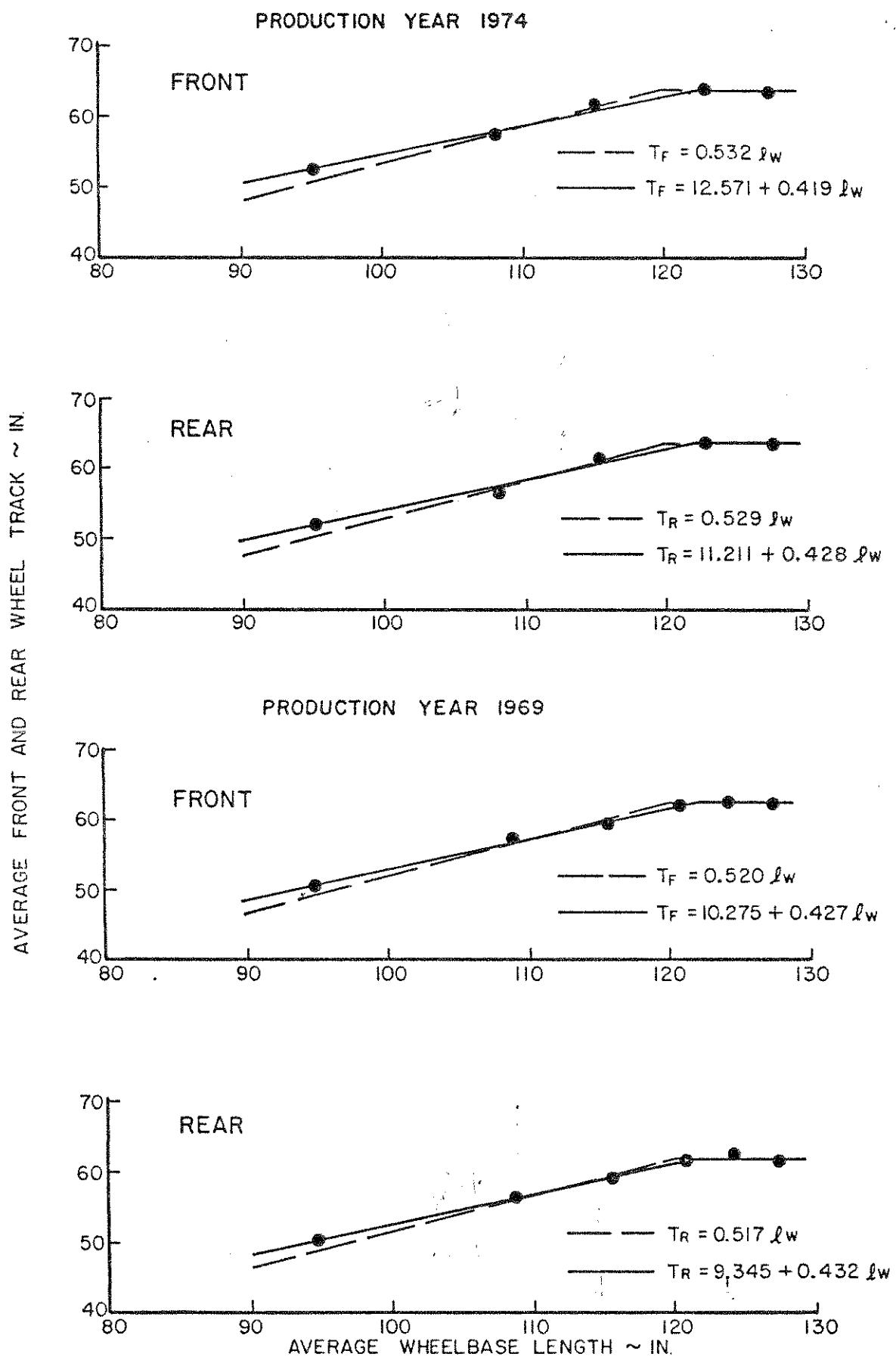


FIG. 9

FRONT AND REAR TRACK AS A
FUNCTION OF WHEELBASE LENGTH

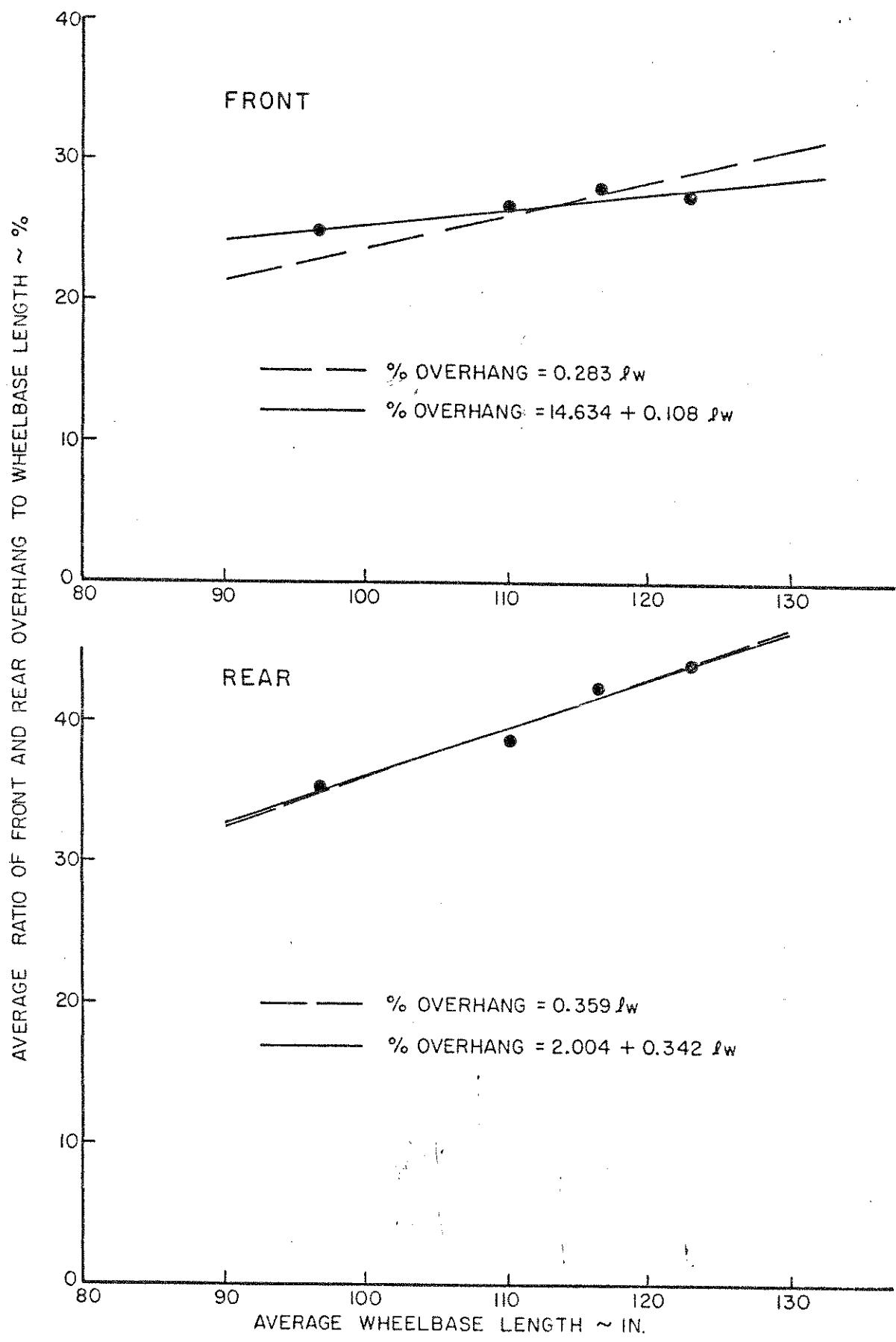


FIG. 10

FRONT AND REAR OVERHANG AS A
FUNCTION OF WHEELBASE LENGTH

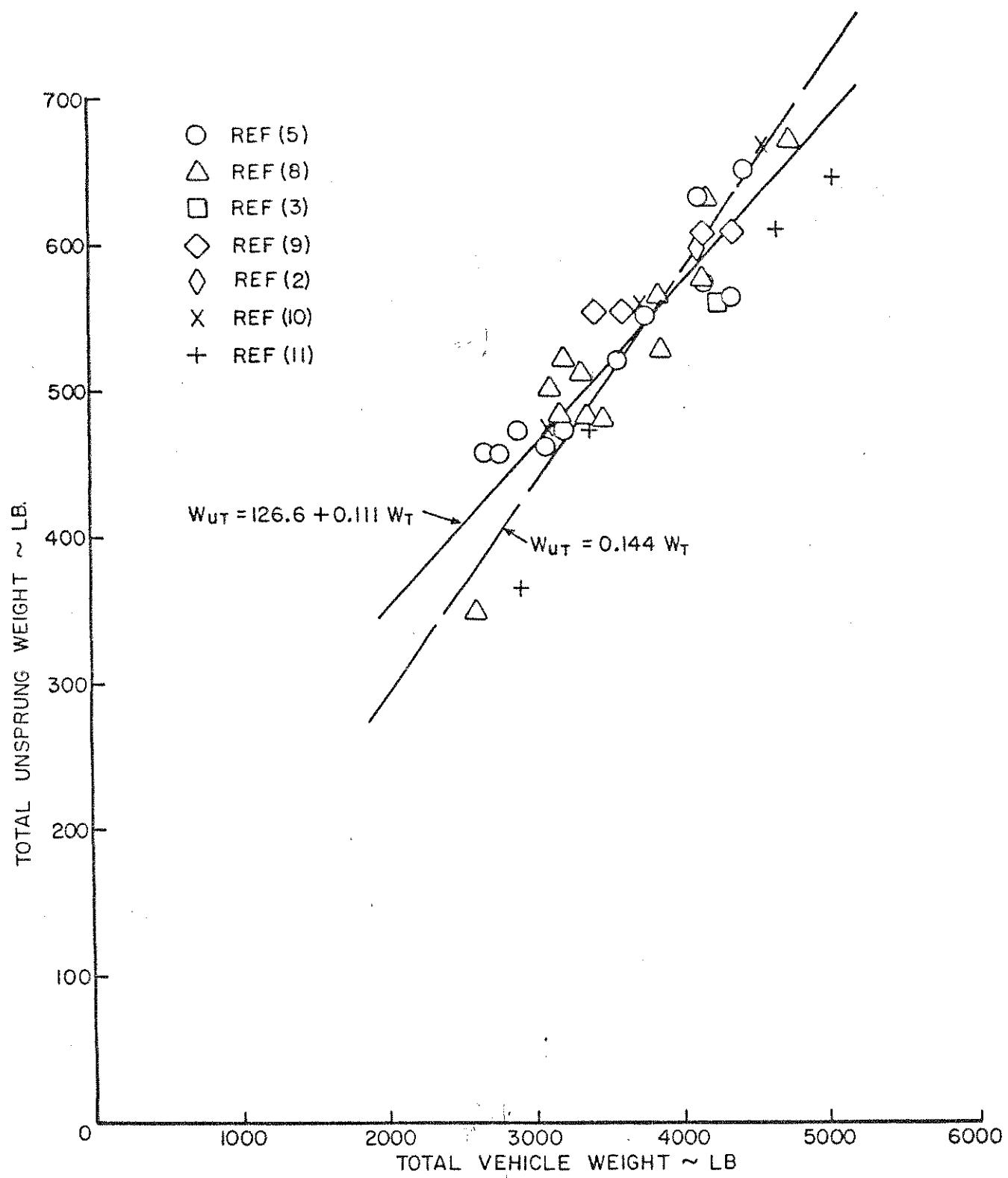


FIG.11 UNSPRUNG WEIGHT AS A FUNCTION OF TOTAL WEIGHT

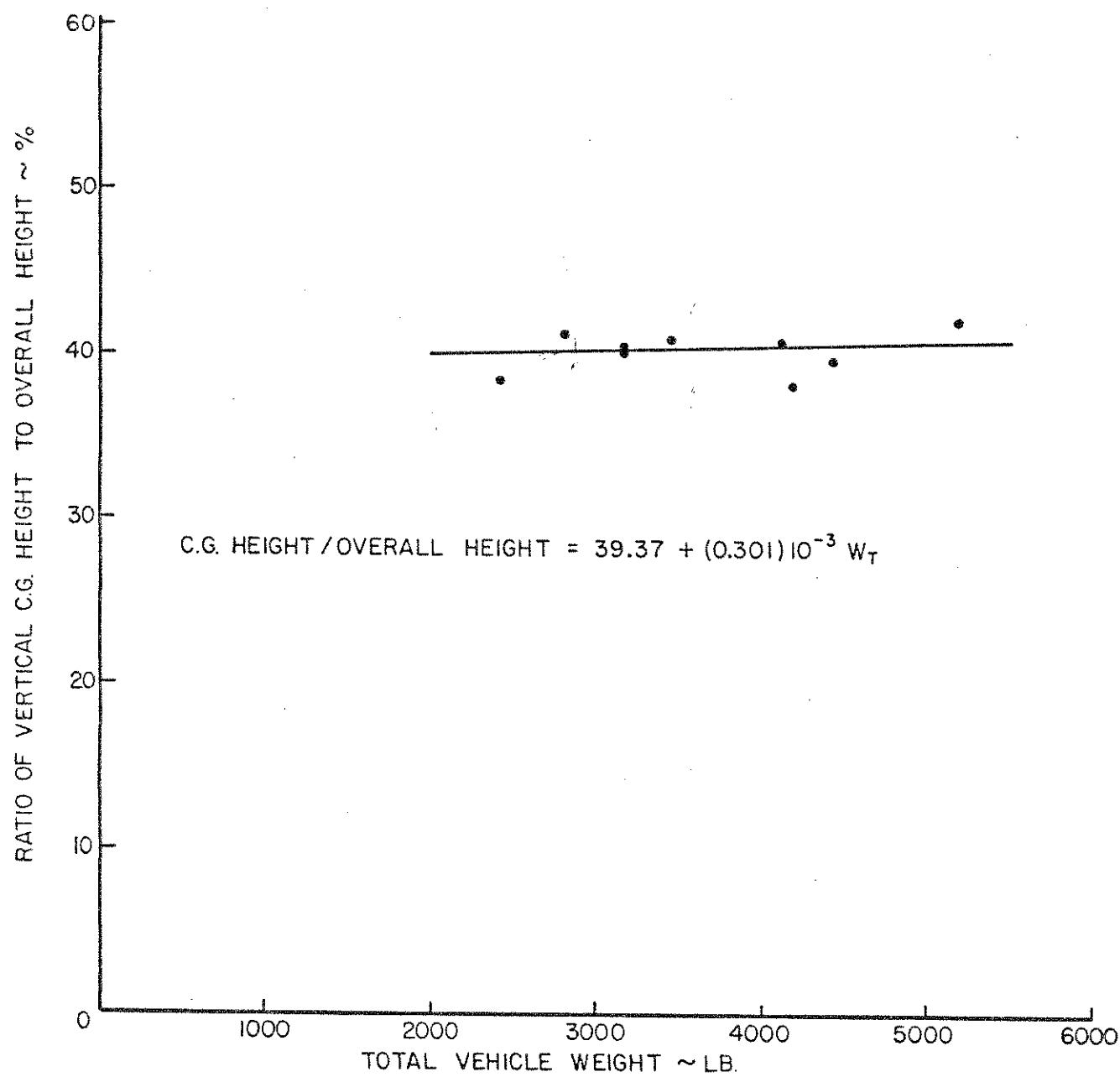


FIG. 12

TOTAL VEHICLE C.G. HEIGHT AS
A FUNCTION OF TOTAL WEIGHT

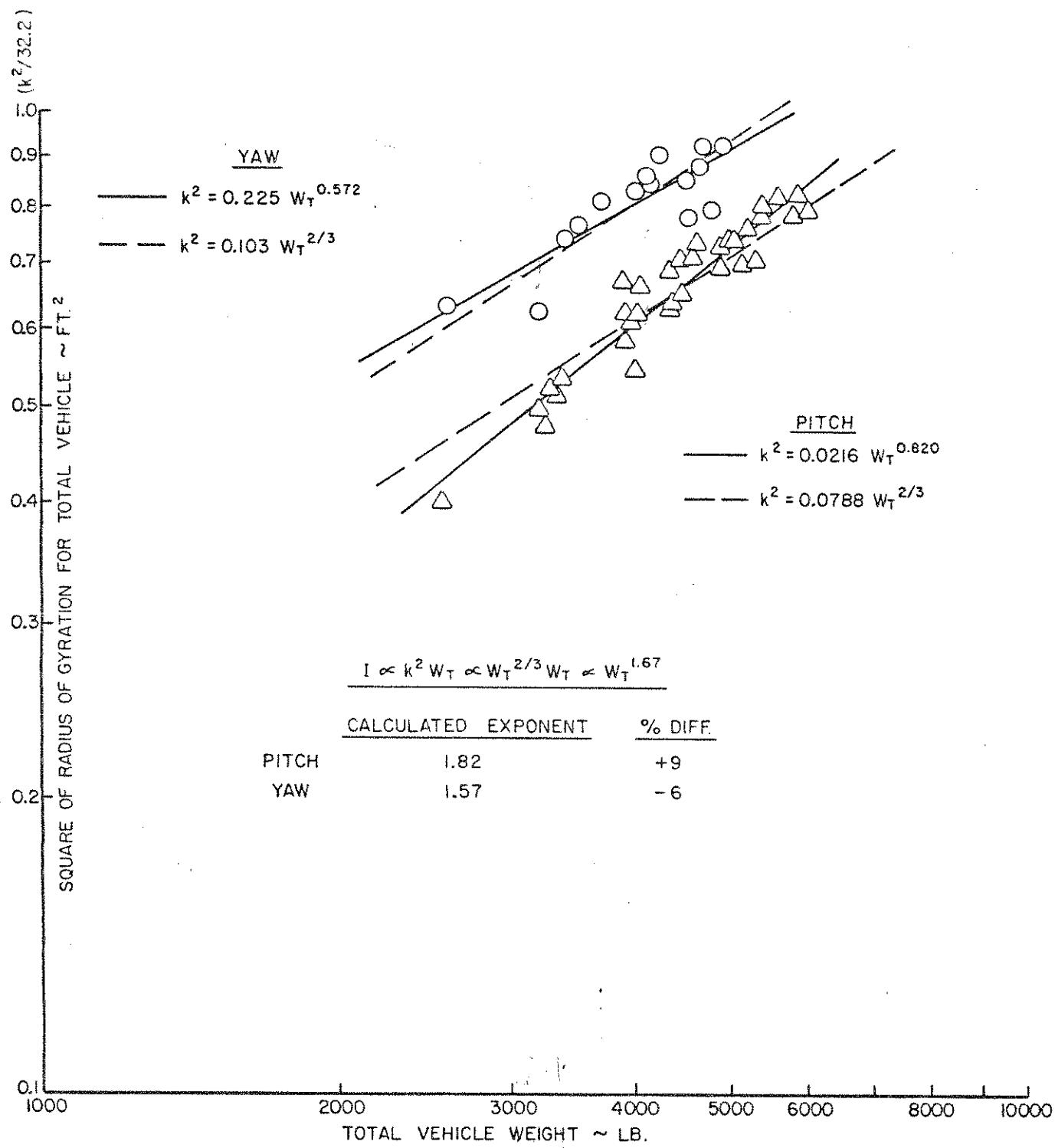


FIG. 13 TOTAL YAW AND PITCH RADII OF GYRATION AS A FUNCTION OF TOTAL WEIGHT

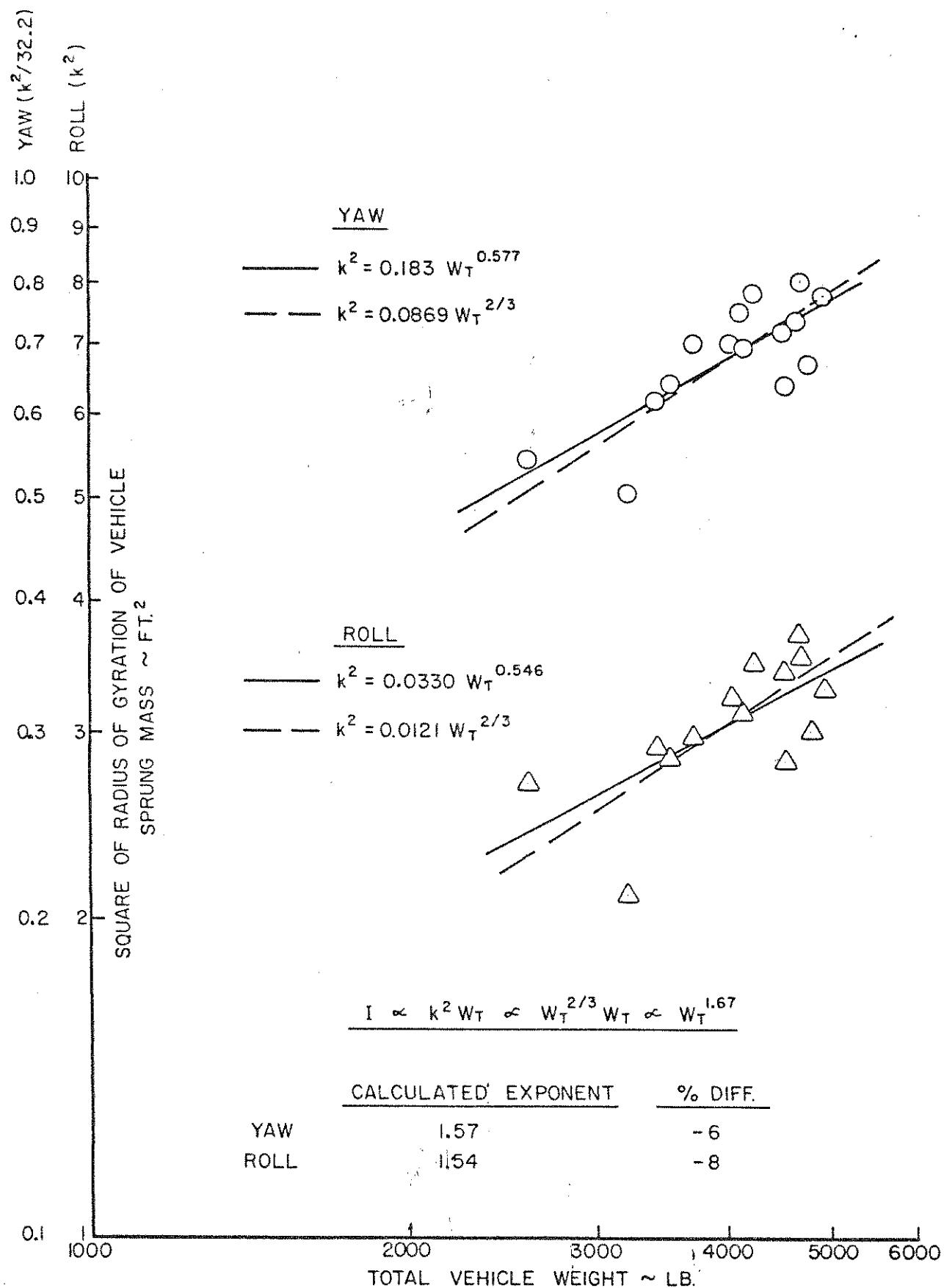


FIG. 14 SPRUNG MASS YAW AND ROLL RADII OF GYRATION AS A FUNCTION OF TOTAL WEIGHT

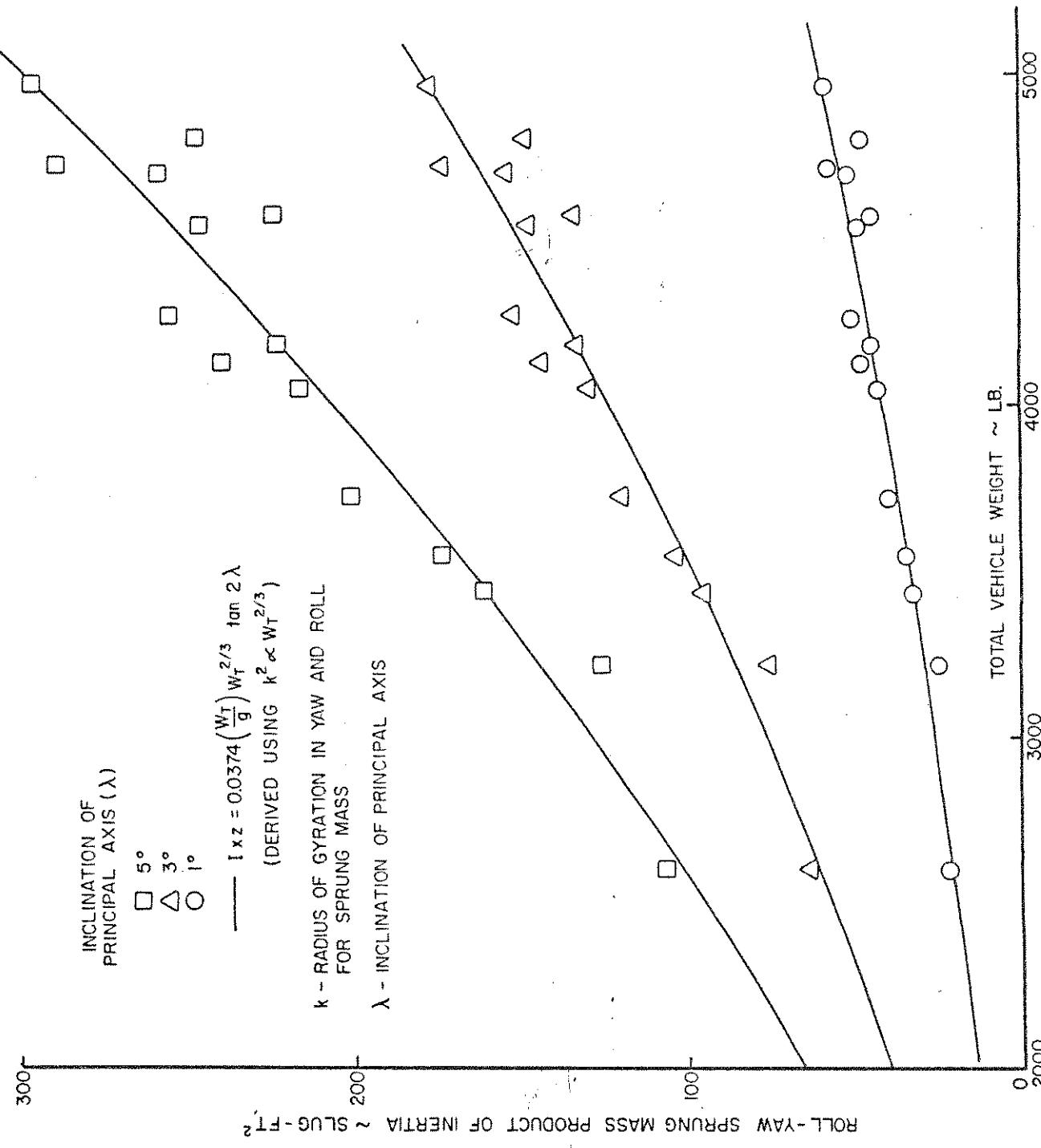


FIG. I5

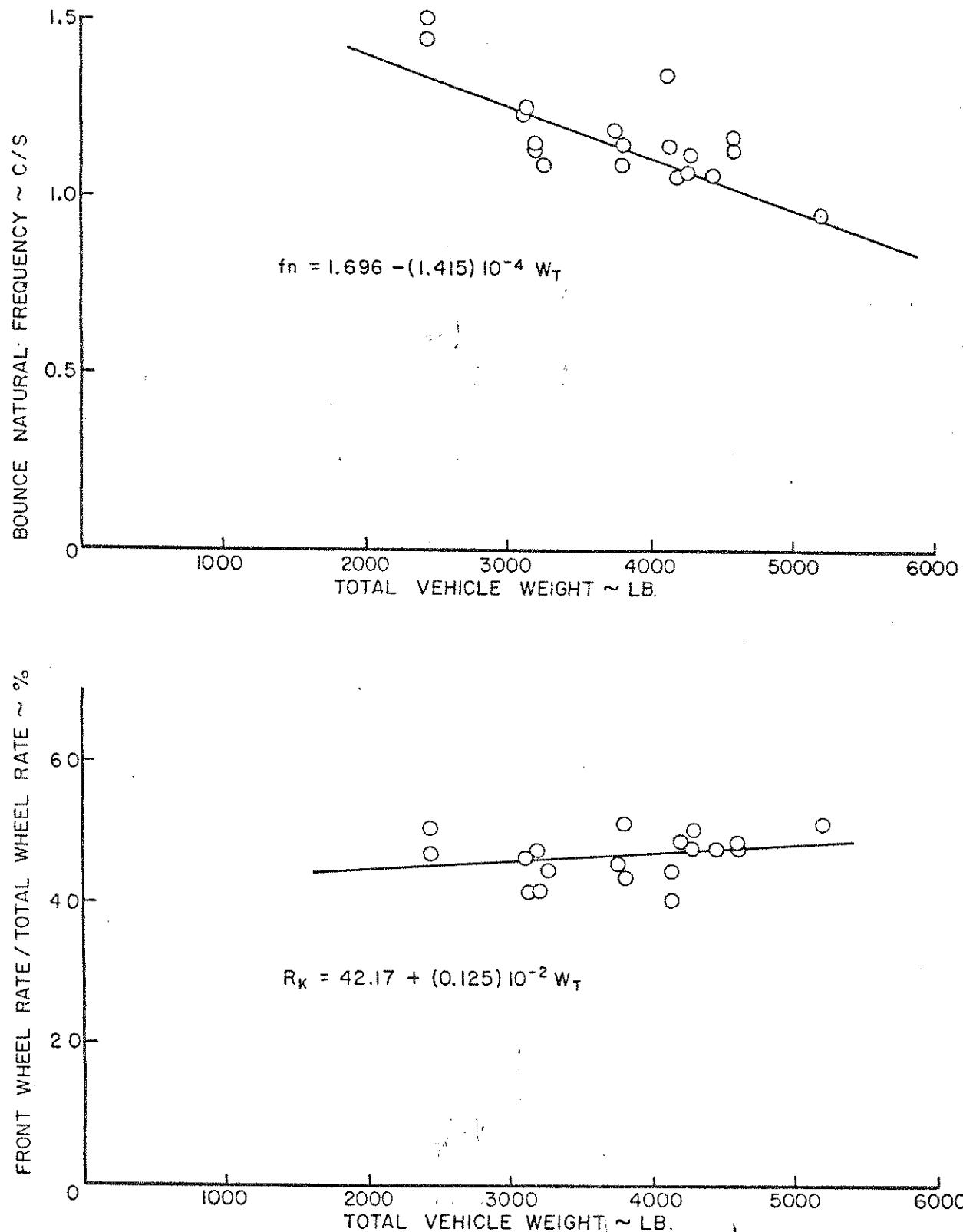


FIG. 16 SPRUNG MASS BOUNCE NATURAL FREQUENCY AND WHEEL RATE DISTRIBUTION AS A FUNCTION OF TOTAL WEIGHT

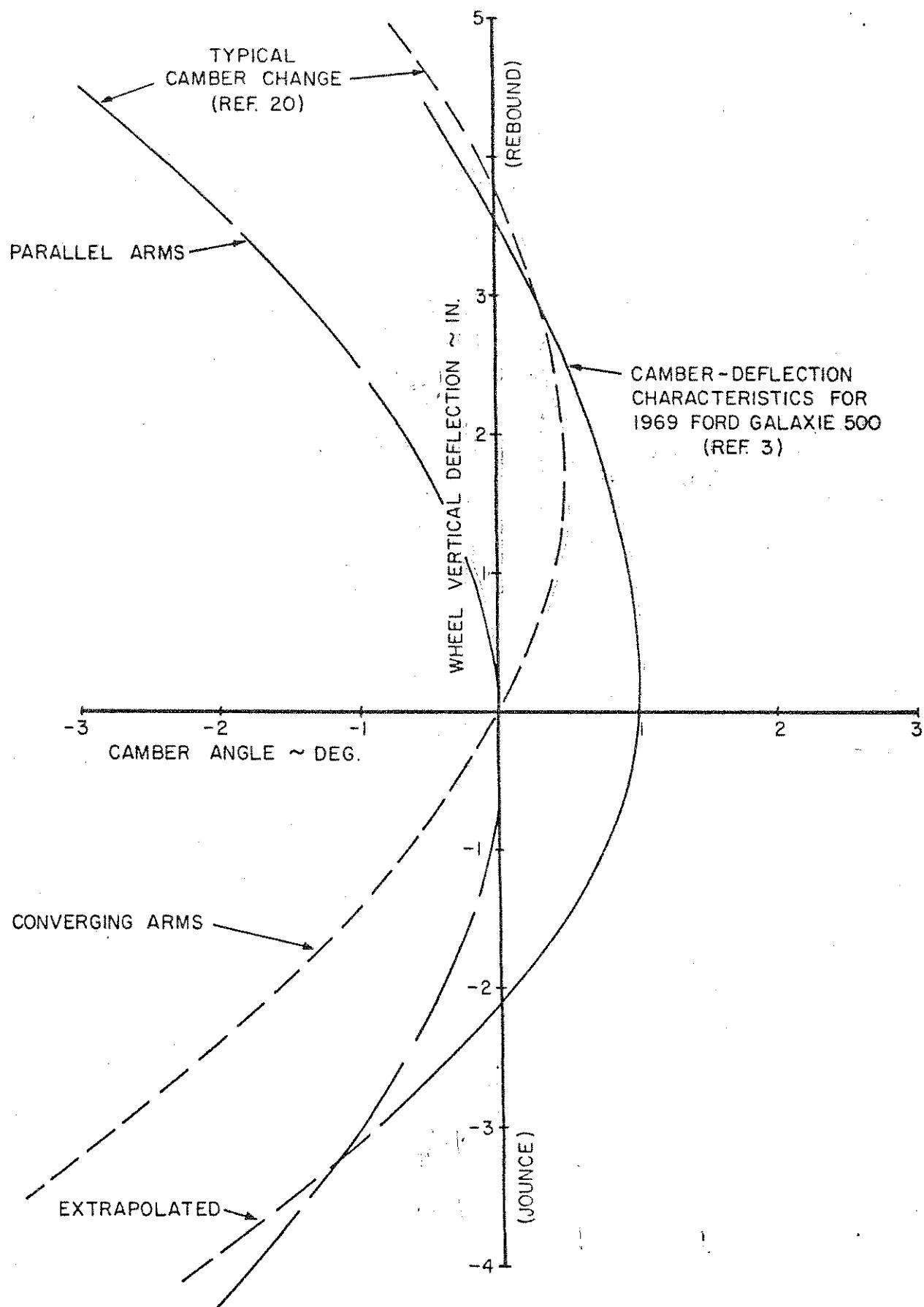


FIG. 17 TYPICAL CAMBER - WHEEL VERTICAL TRAVEL CHARACTERISTICS FOR TRANSVERSE LINK INDEPENDENT SUSPENSION