Technical Support Report for Regulatory Action

Comparison of Dynamometer Power Absorption Characteristics and Vehicle Road Load Measurements

by

Glenn D. Thompson
and
Myriam Torres

July 1977

Standards Development and Support Branch
Emission Control Technology Division
Office of Mobile Source Air Pollution Control
Office of Air and Waste Management
U.S. Environmental Protection Agency

Abstract

If dynamometer measurements are to accurately reflect the on-road operation of a vehicle, the dynamometer must supply the appropriate load; that is, the force required to drive the vehicle on a level surface as a function of the vehicle speed.

The dynamometers currently in use at the EPA for emission certification and fuel economy measurements have a single adjustable load parameter. Therefore, the load at any single speed, typically 50 mph, can be adjusted. Currently, for most vehicles, the dynamometer power absorption at 50 mph is predicted by EPA, based on previous measurements of a large class of vehicles. The regulations do, however, provide an opportunity for manufacturers to submit road load data and to request the dynamometer adjustment be based on these empirical results. In this instance no systematic error should occur at 50 mph. However, since the dynamometer loads at all speeds other than the 50 mph set point are subsequently determined by the load versus speed curve of the dynamometer, errors may occur at other speeds.

This report presents vehicle road load force versus speed curves and Clayton dynamometer force versus speed curves. The vehicle road load force data were collected in the recent road load project, where the vehicle road load, as a function of speed, was determined for sixty-three light-duty vehicles. These vehicles were chosen to represent the sales distribution of light-duty vehicles. The dynamometer data were obtained from the six EPA certification dynamometers. These data were collected and made available by the EPA Quality Control Development Section.

The dynamometer data is first used to generate an equation to represent an average emission dynamometer. The variations of the individual dynamometers about this average dynamometer curve are discussed. Subsequently, each vehicle curve is compared to this average dynamometer curve. Variations between different vehicles are discussed, and the possible intrinsic error caused by differences between the shape of the dynamometer force versus speed curve and the typical vehicle road load curve is investigated.

It is concluded that:

1. Variations among different EPA dynamometers exist and are statistically significant.

2. Differences exist among the appropriate dynamometer road load simulation curves for different vehicles. The observed variations among the vehicles are greater than the dynamometer variations.

3. The current EPA dynamometers appear to supply insufficient load at low speeds to correctly simulate the average vehicle road experience. This conclusion is, however, very dependent on the tire-twin roll dynamometer interaction i.e., the assumption that two tires dissipate as much power on the dynamometer as four tires dissipate on the road.

I. Purpose

This report presents vehicle road load force versus speed curves and Clayton dynamometer force versus speed curves. These curves are compared, and the possible intrinsic error caused by differences between the shape of the dynamometer force versus speed curve and the vehicle road load curve is investigated.

II. Introduction

When vehicle exhaust emission tests or vehicle fuel consumption measurements are performed on a chassis dynamometer, the dynamometer is usually adjusted to simulate the road experience of the vehicle. Specifically, if the dynamometer measurements are to accurately reflect the on-road operation of the vehicle, the dynamometer must supply the appropriate load; that is, the force required to drive the vehicle on a level surface as a function of the vehicle speed.

The dynamometers currently in use at the EPA for emission certification and fuel economy measurements have a single adjustable load parameter. That is, the load at any single speed, typically 50 mph, can be adjusted. Currently, for most vehicles, the dynamometer power absorption at 50 mph is predicted by EPA, based on previous measurements of a large class of vehicles. The regulations do, however, provide an opportunity for manufacturers to submit road load data and to request the dynamometer adjustment be based on these empirical results. In this instance no systematic error should occur at 50 mph. However, since the dynamometer loads at all speeds other than the 50 mph set point are subsequently determined by the load versus speed curve of the dynamometer, errors may occur at other speeds. The possible systematic nature of these errors and their magnitude are discussed.

Errors can also occur because of variations in the characteristics of different dynamometers. The magnitude of these errors are discussed, and their effect on fuel economy is considered.

III. Discussion

This report is based on the data collected in the recent road load project and on dynamometer data from the EPA Quality Control Development Section. The dynamometer data is first used to generate an equation to represent an average emission dynamometer. The curve of this "average dynamometer" is then compared with each of the vehicle curves.

A. The Dynamometer Characterization

The purpose of this section is to develop an equation to represent the average emission dynamometer. In the process of developing this equation the variations between dynamometers can be observed and will be discussed. All dynamometer data were supplied by the EPA Quality Control Development Section. Two data sets were supplied, the first was speed versus time data during dynamometer coast downs. These data were analyzed to give the total power absorbed by the dynamometer. Dynamometer power absorber torque versus speed was the second data set. These data were used to calculate indicated dynamometer torques and then, by subtraction from the total torque calculated from the coast down data, the dynamometer residual friction could be obtained.

1. Total Force Measurements

Speed versus time data were obtained from the EPA Quality Control Development Section for the six EPA certification dynamometers. The dynamometers were adjusted to simulate a vehicle weighing 4000 pounds using the automatic road load control mode of the dynamometers.

The measurements were made by placing a vehicle on the dynamometer rolls, warming the dynamometer up, and then driving the dynamometer up to some speed in excess of 60 mph. The vehicle was then moved from the dynamometer front roll and the speed of the front roll recorded on a strip chart recorder as this roll freely decelerated. The front roll periferal speeds, at five second intervals, were then read from the strip chart.

The total dynamometer force was then calculated by numerically differentiating the speed data and multiplying by the simulated vehicle mass. That is:

$$\begin{aligned} F &= ma = m\frac{dv}{dt} \\ &\simeq m\frac{\Delta v}{\Delta t} \end{aligned} \qquad (1)$$

Since the dynamometer was adjusted to simulate a vehicle weighing 4000 pounds, the mass of such a vehicle was used in the calculations. The computed force was designated as the force operating at the midpoint speed of the Δv interval. The speeds and computed forces for each of the six dynamometers are given in tables 1 through 6 of Appendix A.

The force data were regressed against speed for each dynamometer individually, and then a single equation was developed by pooling the data for all dynamometers.

The model for all the regression lines was chosen to be a second order polynomial of the form

$$F = f_0 + f_1 v + f_2 v^2 \qquad (2)$$

This model was chosen because it was believed that the torque of the power absorber would be very nearly proportional to v^2, while the residual friction should be nearly constant, increasing slightly with speed. After performing the regressions the regression coefficients were examined. Each of the coefficients were significantly different from zero. Examination of the residuals for the combined data and individually for each dynamometer seemed to support the underlying assumptions of the model.

Extensive analysis of the data supported these theoretical expectations. Direct regression of the power absorber torques indicated this torque is proportional to velocity squared and there is little statistical confidence in any other polynomial terms. Regressions of the friction forces appeared to be linear with no statistical confidence in higher order terms. The friction data is, however, somewhat "noisey" since it results from numerical differentiation and subtraction of nearly equal quantities. It is possible that a small v^2 term could appear in the residual friction, caused by aerodynamic drag on the flywheels. This component might not be detected because of the random data error, or noise in the residual friction calculations.

In addition, exponential models of the form

$$F = av^x \qquad (3)$$

were also regressed. This model was chosen because of common historical usage. The data analysis did not indicate any superiority of the exponential model over the polynomial model. The polynomial model was subsequently chosen for all remaining effort because of its stronger theoretical foundation.

The results of the polynomial regression of the pooled data were:

f_0 = 5.34 pounds
f_1 = 0.188 pounds/(mi/hr)
f_2 = 0.0283 pounds/$(\text{mi/hr})^2$

The curve represented by these coefficients is plotted in figure 1, as are the similar individual curves for each of the dynamometers. Figure 1 indicates that differences appear to exist between the different dynamometers.

Using the data for speed and torque, the differences between the dynamometers were examined by performing a two-way analysis of variance. The two factors were dynamometer number and speed, and the measuring variable was torque. This was based on the assumption that the differences in speed were so minor that they would not affect the results of the analysis of variance. The results were that the dynamometers were statistically different from each other at the 90 percent confidence level.

Because there were slight differences in speed, in order to remove the effect speed might have on torque, an analysis of covariance on torque with speed as the covariate was conducted. The covariate must fill two requirements: it must be independent of the dynamometers and it must be correlated with torque. Speed obviously fills both requirements since it is independent of the dynamometer, however, the torque of each

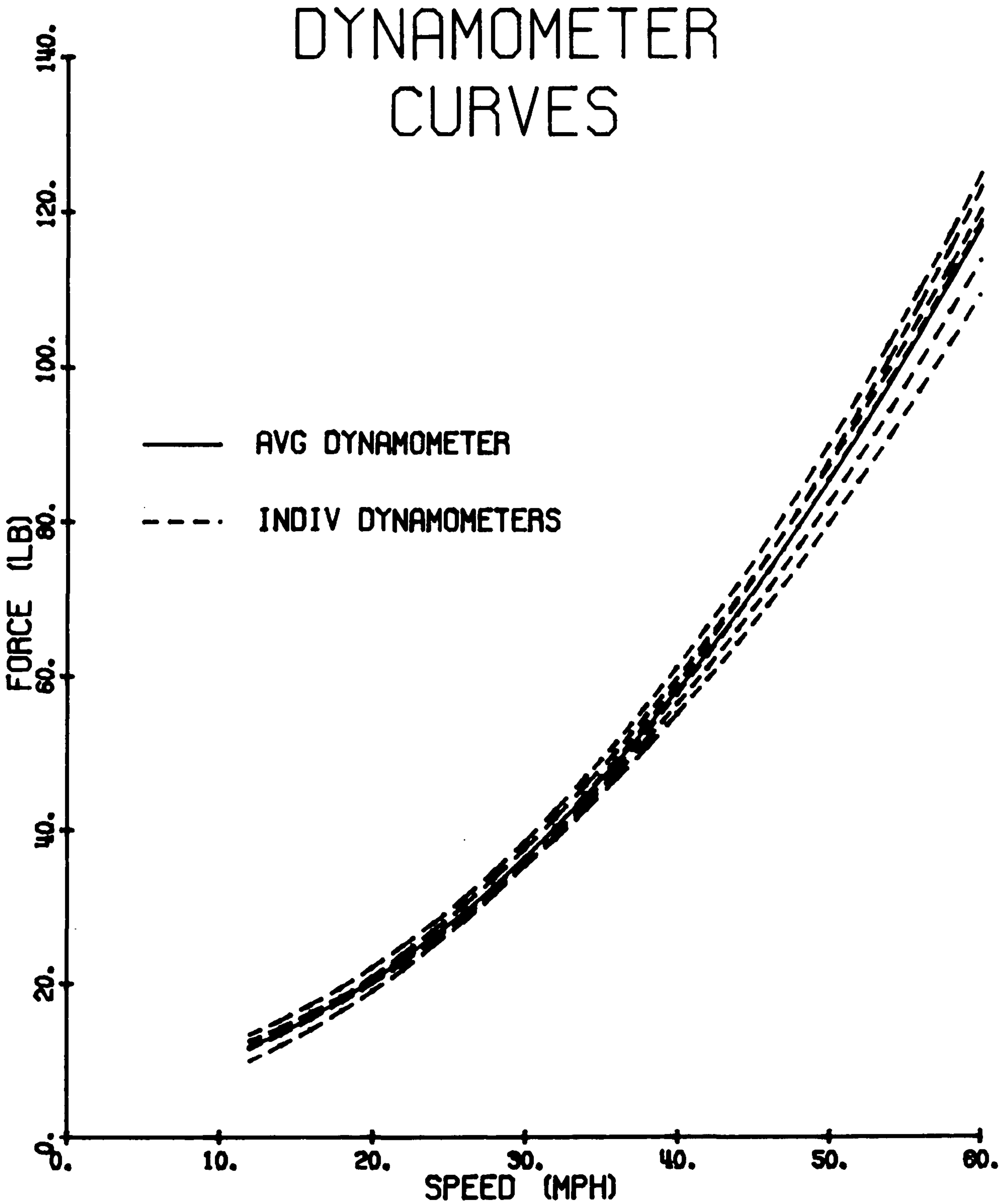

DYNAMOMETER
CURVES
AVG DYNAMOMETER
INDIV DYNAMOMETERS
FORCE (LB)
SPEED (MPH)
0.
20.
40.
60.
80.
100.
120.
140.
10.
30.
50.

FIGURE 1

dynamometer is dependent on the dynamometer speed. The results of the analysis of covariance supported the previous indication that the coefficients for the individual dynamometers differed significantly. Consequently, it was concluded that there are differences in the dynamometers even after removing the effect of speed.

In order to assure all the above tests were meaningful, the underlying assumptions of normality and equality of variances of the residuals were checked. A histogram of the residuals indicated that they were normally distributed, and Bartletts' test for equality of the variances supported the constant variance assumption.

Since the dynamometers were significantly different the action of pooling the data to compute an "average dynamometer" characteristic curve was questioned. However, each dynamometer was well represented by the model equation, and the variances of the residuals for each dynamometer were approximately equal. Therefore, the regression equation resulting from the pooled data may be used with confidence.

B. The Road Load Measurements

The vehicle road load, as a function of speed, was determined for sixty-three light-duty vehicles. These vehicles were chosen to be approximately representative of the sales distribution of light-duty vehicles and are identified in Table 1 of Appendix B.

The coast down technique was used for all road load measurements. The concept of this method is to determine the rate of deceleration of a freely coasting vehicle, then, knowing the mass of the vehicle, the road load force may be calculated by Newton's second law:

$$F = MA \tag{4}$$

The mass, M, of equation 4 represents the sum of the gravitional mass of the vehicle as tested and the "effective equivalent mass" of rotating components of the vehicle. The acceleration A was modeled as a polynomial function of velocity of the form:

$$A = a_0 + a_1 v + a_2 v^2 \tag{5}$$

where:

v = the vehicle velocity
a_0, a_1 and a_2 are constants determined for each vehicle.

The acceleration can, of course, be written as the derivative of the vehicle velocity. Equation 5 can then be integrated by separation of variables, and an analytical expression derived for the vehicle velocity as a function of time. This function was fitted to the vehicle coast down velocity versus time records to obtain the coefficients a_0, a_1 and a_2. A detailed discussion of the test procedures and the data analysis is given in the EPA technical support report "Light-Duty Vehicle Road Load Determination" (1). It should be noted that two vehicle tests included in the previous report have been deleted from this analysis. Plotting the force versus speed curves for these tests showed unrealistic behavior at low speeds. The original data sheets for these vehicles disclosed that one test had been considered void by the test personnel and that the vehicle had been retested. The retest value is presented in this report. In the case of the second deletion, there was a notation on the data sheet that the track direction had been incorrectly coded for one low speed coast down. Because of the slight track grade this could have a very significant effect in the low speed regime, while having a minimal effect on the force at 50 mph. In the case of the retested vehicle there was good agreement between both test values at 50 mph. Consequently, including these test results in the early analysis had an insignificant effect on the results which only considered the force at 50 mph.

Analogous to the acceleration coefficients a_0, a_1, a_2 a set of force coefficients, f_0, f_1 and f_2 may be obtained by multiplying each 'a' coefficient by the total vehicle effective mass, M, as indicated by equation 4. The force on the vehicle in terms of the 'f' coefficients and as a function of velocity is:

$$F = f_0 + f_1 v + f_2 v^2 \qquad (6)$$

where:

$f_0 = Ma_0$, etc.

The force of equation 6 is the total road load force acting on the vehicle, including drive train and drive tire losses. When the vehicle is placed on a dynamometer the vehicle must overcome these losses before power is transmitted to the dynamometer, therefore the drive train and drive tire losses must be subtracted to obtain an appropriate dynamometer power absorption. The tire and drive train losses were measured on a large roll electric dynamometer. From these measurements, estimates of the tire and drive train losses for a Clayton dynamometer were calculated. These calculations required the common assumption that, in the case of radial ply tires, the two vehicle drive tires dissipate as much power on the dynamometer as all four tires dissipate on a flat surface. With this assumption, the coefficients for the appropriate dynamometer power absorption to simulate the road experience of a vehicle with radial ply tires can be calculated. The radial ply tire case was chosen since radial ply tires represent over 75% of original equipment tires. These coefficients are presented for the test fleet of vehicles in Table 2 of Appendix B. A detailed discussion of the assumptions and calculations are given in the EPA technical support report "Prediction of Dynamometer Power Absorption to Simulate Light-Duty Vehicle Road Load" (2).

C. Comparison of the Dynamometer Curve and the Vehicle Curves

In order to compare the appropriate dynamometer force versus speed curves for the various vehicles, all curves were plotted in Figure 2. This figure demonstrates the wide diversity of the appropriate dynamometer force versus speed curves for a diverse class of vehicles.

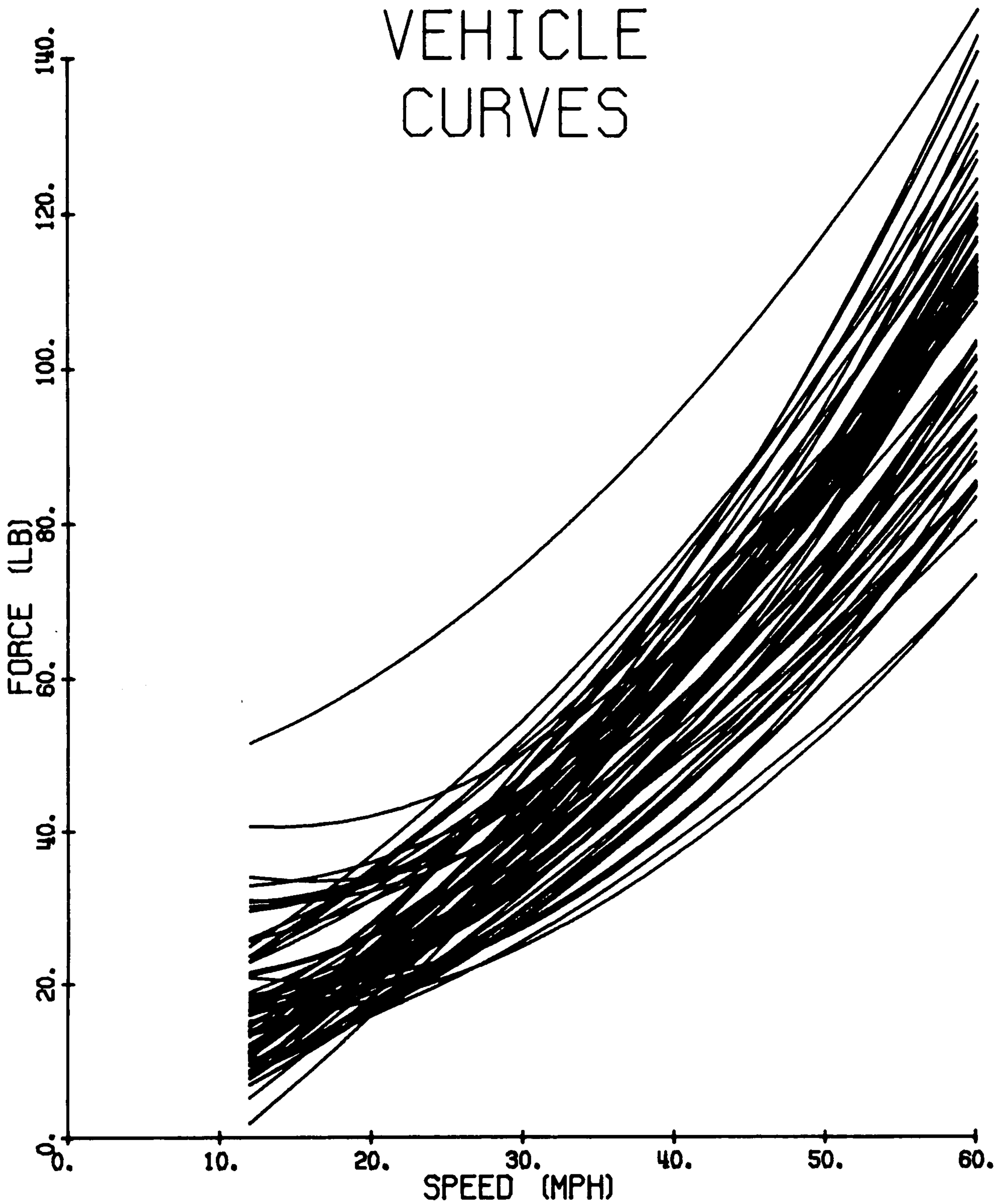
Since the dynamometer curves in Figure 1 are for a single absorber setting, they do not consider the variation in the dynamometer curve shape for different power absorber settings. To make this comparison a dynamometer curve, forced to match the vehicle curve at 50 mph, was computed for each vehicle. The previous analysis identified the v^2 term as the term dependent on the dynamometer power absorber setting. Therefore, the dynamometer curve was matched to the vehicle curve at 50 mph by adjusting the coefficient of this term.

It should be noted that this match would occur in practice only if the system used by EPA to predict the dynamometer power absorber setting was extremely accurate for the particular vehicle, or if an alternate technique was used to determine the power absorber setting. In many instances there would be an additional error introduced by inappropriate adjustment at the 50 mph point.

The dynamometer force versus speed curve, matched to the calculated appropriate dynamometer adjustment curve at 50 mph, was plotted for each vehicle. These plots are given in Appendix C. Persual of these graphs show that in the majority of cases the dynamometer curve appears to either approximately match the vehicle curve or to be lower than the vehicle curve at low speeds. In few instances is the dynamometer curve higher than the vehicle curve. Therefore, there appears to be a systematic tendency for the dynamometer curve to fall below the vehicle curve at low speeds.

In order to test if the dynamometer curves were systematically lower than the vehicle curves, the mean of each set, at 20 mph, was computed. A "t test" of the difference between the means indicated that the dynamometer curves were systematically lower than the vehicle curves with greater than 99 percent confidence. The difference between the means of the dynamometer curves and the vehicle curves, at 20 mph, was approximately 5 pounds force. This difference is approximately 20 percent of the mean vehicle force at that speed. This difference is also 20 percent of the power at this speed however, it is only 0.3 horsepower at 20 mph.

The mean speed of the EPA urban cycle is approximately 20 mph, therefore, this difference could have a significant effect on the vehicle fuel economy and exhaust emissions on this cycle. Consequently, possible sources for this difference were investigated. The vehicle



VEHICLE CURVES
FORCE (LB)
0.
20.
40.
60.
80.
100.
120.
140.
0.
10.
20.
30.
40.
50.
60.
SPEED (MPH)

FIGURE 2

curves of this report were calculated from the total measured road experience of the vehicle, by subtracting estimates of the tire and drive train losses which would occur when the vehicle is operated on a twin-roll dynamometer. The drive tire losses on the twin-roll dynamometer were estimated to be the sum of the dissipative losses of both the driving tire and non-driving tires as measured on a large single-roll dynamometer after correction to flat surface conditions. This is the common "two on the rolls equals four on the road" assumption. To the extent that the above assumption and the measurements are correct, the vehicle curve represents the aerodynamic drag of the vehicle plus the non-driving wheel bearing and brake drag forces.

The observed differences between the vehicle and dynamometer curves could occur erroneously if: the road measurements of the vehicle yielded inappropriately large values, especially in the low speed regions; or if the measured tire losses were inappropriately low, such that insufficient force was subtracted from the vehicle road measurements.

1. The Road Measurements

It was hypothesized that ambient condition effects might cause inappropriately large forces to be computed from the road measurements. For example, the presence of wind will give rise to higher observed low speed forces if not adequately treated by the data analysis. To test if the data analysis did adequately treat ambient conditions, the presence of possible relationships between the difference of the vehicle-dynamometer curves and the ambient conditions were tested. "Chi square" tests showed the difference between the curves to be strongly independent of both ambient wind conditions and ambient temperature. No correlation between the difference variable and either ambient condition was observed. It was therefore concluded that no evidence existed to support an ambient condition effect.

2. Tire Dissipation Losses

The observed vehicle-dynamometer curve differences could occur if the tire dissipation forces were systematically low. There are several reasons this could occur. The tire measurements were obtained by motoring the vehicle on the dynamometer. The wheels were motored both with the full vehicle weight on the dynamometer and with the tires "just contacting" the dynamometer roll. The difference was taken to be the tire dissipation. Even in the "just contacting" configuration some force must be acting across the tire-dynamometer interface since the dynamometer is able to turn the vehicle wheel. This force must give rise to some dissipation in the vehicle tire. This would be subtracted from the dissipation measured with the full vehicle weight on the dynamometer rolls. Therefore, there exists a systematic tendency to underestimate the tire losses.

The differences among the vehicle curves, as compared to the dynamometer curve, could be caused by difference in the non-driving wheel bearing and brake drag among the vehicles. In this case variations in the values of the vehicle residual friction would be correctly observed.

3. Non-Driving Wheel Bearing and Brake Drag

The relationship between the vehicle-dynamometer curve differences and measurements of the non-driving wheel bearing and brake drag were investigated. The scatter plot of these parameters, Figure 3, indicates some general trends between the variables. A linear regression line, also shown on the figure, has the expected positive slope characteristic. However, as expected from the scatter plots, the multiple correlation coefficients were low. Thus, the regression should only be considered as supporting evidence of a weak relationship between the variables.

The weakness of the observed relation between the differences of the vehicle and dynamometer curves possibly occurred because of the vehicle use between these measurements. The track measurements were conducted at the Transportation Research Center of Ohio and the vehicles were then driven about 150 miles to the EPA Laboratory where the dynamometer measurements were conducted. The vehicle brake drag is probably dependent on recent brake use and might change during this interval.

Even if the vehicle brake drag were dependent on recent vehicle use it would probably be related to the vehicle weight. This indirect relationship would occur because heavier vehicles would have larger brakes capable of exerting larger forces, when or if, brake drag occurred.

The relationship between the vehicle-dynamometer curve differences and the vehicle weight was statistically investigated. "Chi square" tests for the independence of the vehicle-dynamometer differences versus the vehicle weight rejects the hypothesis that these variabiles are independent at the 90 percent confidence level. A linear regression between these variables demonstrated the expected increase in vehicle-dynamometer curve differences with increasing vehicle weight. The data, and the regression line are plotted in Figure 4. As would be expected from the data scatter the correlation coefficient of the regression was quite low. Again the regression only supports the evidence of an interrelationship between these variables, and should not be expected to yield accurate predictions of the vehicle brake drag.

Stepwise forward and backward multiple regressions of the vehicle-dynamometer curve differences using both the measured drag and the vehicle weight were computed. By both methods, drag entered in the regression and weight was left out. That is, drag statistically contributes more to the equation than does weight. This is to be expected since the vehicle weight was only considered to be an indirect predictor of the brake drag.

Vehicle-Dynamometer Curve Differences

versus

Measured Non-Driving Wheel Bearing and Brake Drag

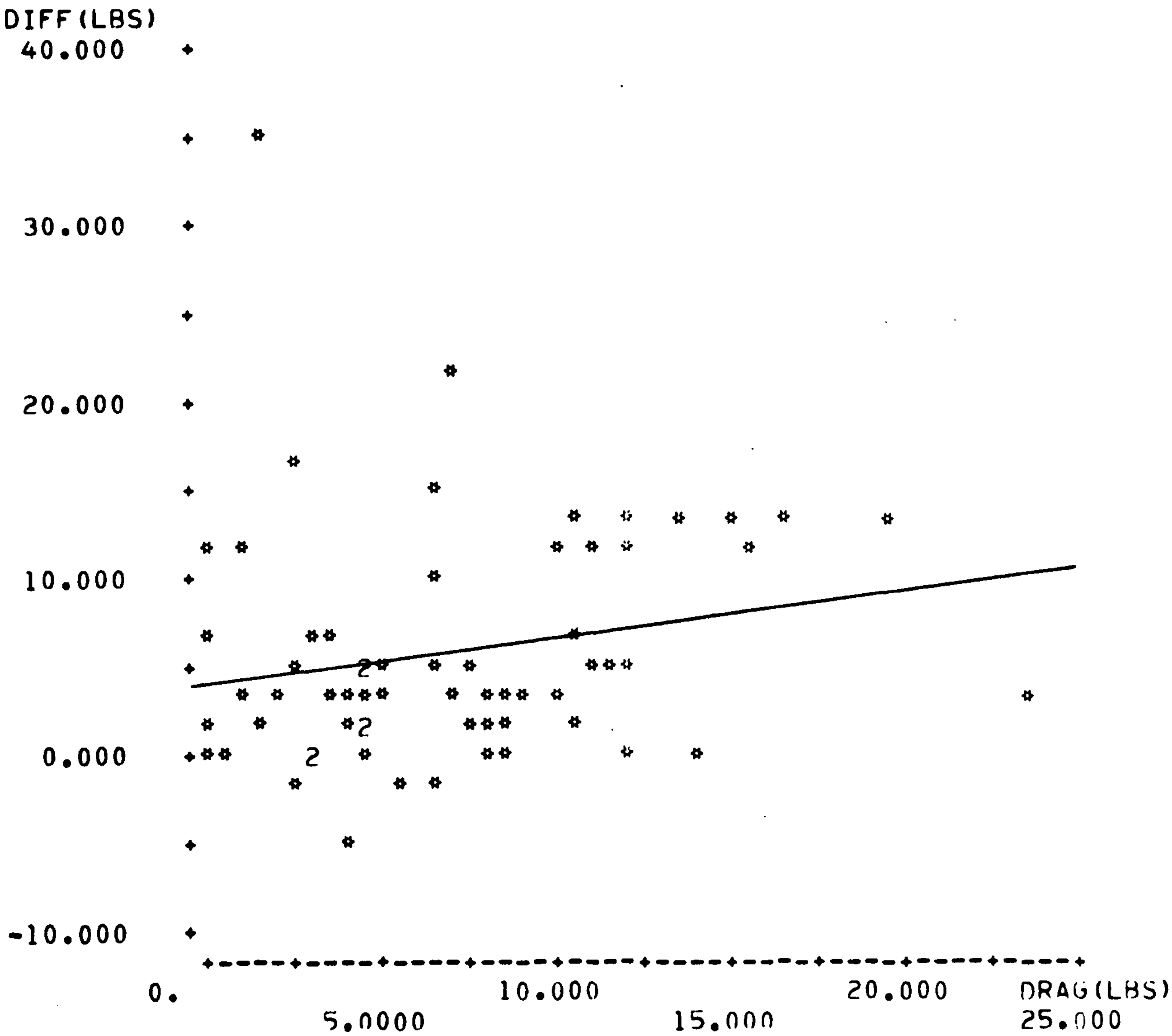


Figure 3

Vehicle-Dynamometer Curve Differences

versus

Vehicle Weight

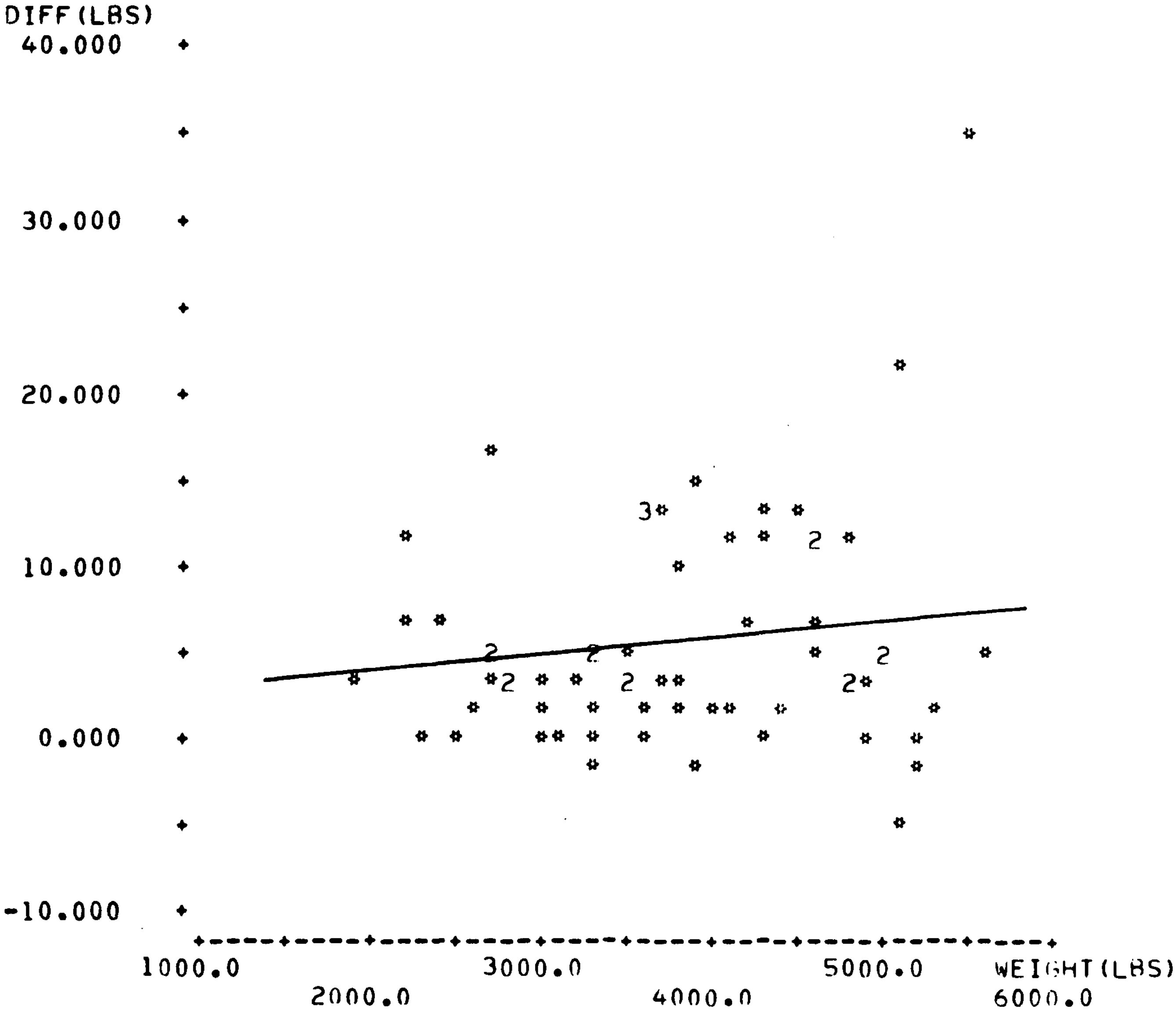


Figure 4

The dynamometer measurements were primarily intended to determine the tire rolling resistances. Consequently, the experimental errors observed when measuring the much smaller wheel bearing and brake drag forces could be considerable. In addition, if the observed brake drag is dependent on the recent brake experience, errors could occur in the dynamometer measurement of the non-driving wheel bearing and brake drag since these measurements were conducted after considerable dynamometer warm-up of the vehicle. This warm-up was conducted by motoring the vehicle with the dynamometer and did not exercise the vehicle brakes. During the track phase of the vehicle testing, however, the brakes would probably be exercised during the vehicle turn-around manuvers at the end of the straight track.

To further verify that the vehicle-vehicle and vehicle-dynamometer curve differences could be caused by brake drag, more precise measurements of vehicle non-driving wheel bearing and brake drag were conducted on several vehicles in the EPA parking lot. In these measurements the force necessary to cause front wheel rotation was measured directly. Care was taken to attempt to measure the force necessary to maintain wheel rotation and to minimize the observation of static friction or "break away" effect.

The measured forces ranges from about 1 pound to about 10 pounds for the total drag force for both wheels of vehicle non-driving axle. The lowest force measurements occurred on the vehicle with the highest mileage, while the highest force measurement occurred on the vehicle with the lowest mileage. These measurements demonstrate that significant differences can exist in vehicle road load forces at low speeds.

Many of the vehicles used in the road load project were low mileage rental vehicles or vehicles which had been used for certification testing. Therefore, brake drag measurements were repeated on several 4000 mile certification vehicles. The mean of these force measurements was 9.7 pounds. This indicates that the observed systematic tendency for the vehicle curves to be higher than the dynamometer curves in the low speed region may occur because the dynamometer load in this region is insufficient to simulate the typical brake drag of a low mileage vehicle. In addition, this supports the other evidence that the vehicle-dynamometer curve differences are at least partially related to the vehicle brake drag.

IV. Conclusions

The following aspects were concluded during this study:

1. Variations among the different EPA dynamometers exist and are statistically significant.

2. Differences exist between the appropriate dynamometer road load simulation curves for different vehicles. The observed variations

among the vehicles are greater than the dynamometer variations.

3. The current EPA dynamometers appear to supply insufficient load at low speeds to correctly simulate the average vehicle road experience. This conclusion is, however, very dependent on the tire-twin roll interaction; i.e., the assumption that two tires dissipate as much energy on the dynamometer as four tire dissipate on the road.

A. Variations Among EPA Dynamometers.

This study observed a maximum variation of ± 5 pounds force in the dynamometer loads at 50 mph. At 50 mph, this is equivalent to approximately ± 0.7 horsepower. While this may seem relatively small it is approximately ± 6%. This may have a potential fuel economy variation of ± 1% on the urban cycle and ± 2% on the highway cycle. On a 30 mpg car the "dynamometer lottery" could win 1.2 mpg on the highway test in a best to worst dynamometer variation.

B. Vehicle Variations.

The variations among the vehicles are, of course, more pronounced than the variations among the dynamometers. The variations at 50 mph can be adequately treated with the current dynamometers, however the low speed characteristics of the dynamometer are strongly influenced by the dynamometer residual friction and are not subject to adjustment.

C. Vehicle - Dynamometer Simulation Variances

The data of this report indicate that the current EPA dynamometers cannot be expected to exactly simulate the road experience of all vehicles throughout the vehicle speed range. The current dynamometers appear to demand insufficient power to simulate the average vehicle during the low speed operation. This conclusion is somewhat tentative since it is quite dependent on any assumptions about tire power dissipation on the twin-roll dynamometer.

The conclusion that the dynamometer tends to under load vehicles at low speeds is supported by analysis of data submitted by GM (3). The submitted data were coast down measurements conducted on both the road and on the dynamometer for nine vehicles. The purpose of the submission was to show that the current Federal Register table was approximately correct for typical light-duty vehicles, but that wide variations could occur for atypical vehicles. Seven of the nine vehicles were typical conventional sedans in which the road and dynamometer data at 50 mph were in good agreement. For these vehicles the dynamometer and road forces were normalized to the force at 50 mph. For all seven conventional sedans the normalized dynamometer force in the low speed regime was less than the normalized road force.

The recent change to the automatic mode of the dynamometer power adjustment may have caused a slight reduction of the dynamometer load at low speed. This effect would be quite marginal since the real question is the low speed tire characteristics and the residual friction of the dynamometer. These parameters are not affected by the mode of dynamometer adjustment. The recently announced intention of the Clayton Manufacturing Company to substitute bearings with lower friction in new and replacement installations may have a greater effect, since this does influence the dynamometer residual friction.

The fuel economy effect of low speed dynamometer loading errors would, of course, be predominantly observed on the urban driving cycle where the average speed is approximately 20 mph.

A current EPA contract with Southwest Research Institute is investigating the fuel economy effects associated with changes in the low speed dynamometer characteristics. Preliminary results from this contract indicate that a 10% change in dynamometer load at 35 mph will result in a 2% change in the vehicle fuel economy measured on the EPA urban cycle (4). The observed systematic dynamometer underloading is approximately 12% at 35 mph; therfore, a two to three percent effect in the vehicle fuel economy on the urban cycle may be assocaited with this vehicle-dynamometer difference.

V. Recommendations

It is recommended that the following areas receive continued or further investigation:

1. The tire-dynamometer rolls interaction;

2. Dynamometer calibration and adjustment;

3. The fuel economy effects of variations in low speed dynamometer characteristics.

These areas are recommended for attention since they appear to be the greatest sources of current or potential error. It is further recommended that initial investigations in these areas be theoretical in nature, since it is believed that sufficient data currently exists to allow relatively easy computation of the approximate magnitude of these effects.

References

1. G.D. Thompson, EPA Technical Support Report for Regulatory Action, "Light-Duty Vehicle Road Load Determination", December 1976.

2. G.D. Thompson, EPA Technical Support Report for Regulatory Action, "Prediction of Dynamometer Power Absorption to Simulate Light-Duty Vehicle Road Load", April 1977.

3. J.P. DeKany, EPA memorandum, "Electric Chassis Dynamometers for Exhaust Emission (FTP) Testing", May 19, 1977.

4. J.D. Murrel, EPA discussions.

APPENDIX A

Dynamometer Data

TABLE 1 - DYNAMOMETER 1
DYNAMOMETER COAST DOWN DATA

AVG SPEED (MPH)	TOT FORCE (LB)	IND FORCE (LB)	FRIC FORCE (LB)
59.65	123.90	100.81	23.09
56.40	106.48	91.34	15.15
53.45	102.88	82.52	20.36
50.70	92.37	74.77	17.60
48.15	88.79	68.07	20.72
45.85	74.81	62.27	12.54
43.75	74.73	57.04	17.69
41.75	67.69	52.41	15.29
39.95	60.66	48.12	12.53
38.25	60.60	43.97	16.63
36.70	50.06	40.67	9.39
35.30	50.02	37.59	12.43
33.90	49.98	34.72	15.26
32.55	46.44	32.28	14.16
31.35	39.39	29.75	9.64
30.30	35.85	27.54	8.31
29.25	39.34	25.70	13.64
28.25	32.28	24.12	8.16
27.30	35.78	22.30	13.49
26.35	32.24	21.14	11.11
25.50	28.70	20.11	8.60
24.70	28.69	18.79	9.89
23.90	28.67	17.49	11.18
23.15	25.13	16.33	8.80
22.45	25.12	15.26	9.86
21.75	25.10	14.30	10.80
21.10	21.56	13.62	7.94
20.45	25.08	12.87	12.21
19.90	14.43	12.25	2.18
19.40	21.53	11.47	10.06
18.75	25.04	10.73	14.31
18.15	17.97	10.19	7.78
17.65	17.96	9.83	8.14
17.15	17.96	9.47	8.49
16.65	17.95	8.99	8.96
16.20	14.40	8.54	5.86
15.75	17.93	8.16	9.78
15.25	17.93	7.68	10.24
14.85	10.82	7.13	3.69
14.45	17.91	6.73	11.18
14.00	14.37	6.51	7.86
13.55	17.89	6.13	11.76
13.10	14.36	5.80	8.56
12.80	7.23	5.48	1.75
12.45	17.86	5.06	12.80
12.05	10.80	4.75	6.05
11.75	10.79	4.39	6.41
11.40	14.32	4.25	10.08
11.05	10.79	4.26	6.52
10.65	17.80	4.11	13.69
10.15	17.78	3.87	13.91

TABLE 2 - DYNAMOMETER 2
DYNAMOMETER COAST DOWN DATA

AVG SPEED (MPH)	TOT FORCE (LB)	IND FORCE (LB)	FRIC FORCE (LB)
59.80	113.57	92.85	20.72
56.90	92.62	84.26	8.37
54.25	96.00	76.00	20.00
51.70	85.47	69.41	16.06
49.40	78.42	63.72	14.70
47.30	71.37	58.37	13.00
45.35	67.81	53.55	14.26
43.50	64.26	49.33	14.93
41.80	57.21	45.28	11.93
40.20	57.16	41.58	15.58
38.70	50.11	38.82	11.29
37.35	46.56	36.37	10.20
36.00	50.04	33.94	16.10
34.70	42.98	31.76	11.22
33.55	39.44	29.78	9.65
32.40	42.93	27.72	15.21
31.30	35.87	26.01	9.86
30.35	32.32	24.50	7.82
29.40	35.83	23.15	12.68
28.45	32.28	21.99	10.29
27.55	32.27	20.80	11.47
26.70	28.72	19.76	8.96
25.90	28.71	18.80	9.90
25.15	25.16	17.77	7.39
24.45	25.15	16.58	8.57
23.75	25.14	15.74	9.40
23.10	21.58	15.06	6.53
22.45	25.12	14.31	10.81
21.75	25.10	13.71	11.39
21.15	18.01	13.06	4.95
20.60	21.55	12.31	9.24
20.05	18.00	11.74	6.25
19.50	21.53	11.12	10.41
18.95	17.98	10.67	7.31
18.40	21.51	10.16	11.35
17.60	35.43	9.35	26.08
16.95	10.84	8.93	1.91
16.30	35.35	8.06	27.30
15.55	17.93	7.45	10.49
15.15	10.82	7.25	3.57
14.85	10.82	7.01	3.81
14.45	17.91	6.73	11.18
14.05	10.82	6.53	4.28
13.65	17.89	6.37	11.53
13.25	10.81	6.06	4.75
12.95	10.81	5.58	5.23
12.60	14.35	5.32	9.03
12.25	10.80	5.10	5.70
12.00	7.23	4.88	2.34
11.70	14.33	4.72	9.61
11.30	14.32	4.72	9.60
11.00	7.22	4.64	2.58
10.70	14.31	4.48	9.83
10.35	10.78	4.50	6.28
10.05	10.77	4.50	6.28
9.85	3.63	4.42	-0.79

TABLE 3 - DYNAMOMETER 3
DYNAMOMETER COAST DOWN DATA

AVG SPEED (MPH)	TOT FORCE (LB)	IND FORCE (LB)	FRIC FORCE (LB)
60.20	127.37	103.36	24.02
56.95	103.05	92.27	10.78
54.10	99.46	83.19	16.26
51.35	95.86	74.86	21.00
48.90	78.40	67.93	10.47
46.65	81.79	61.48	20.31
44.45	74.76	55.53	19.22
42.55	60.73	51.01	9.72
40.80	64.17	46.68	17.50
39.10	57.13	42.98	14.15
37.55	53.59	39.35	14.24
36.10	50.04	35.72	14.33
34.75	46.50	32.67	13.83
33.45	46.47	30.29	16.18
32.25	39.41	28.00	11.41
31.20	35.86	25.66	10.21
30.20	35.85	23.98	11.86
29.15	39.34	22.29	17.05
28.15	32.28	20.57	11.71
27.25	32.26	19.14	13.12
26.35	32.24	17.60	14.64
25.50	28.70	16.09	12.61
24.75	25.15	15.04	10.11
24.10	21.59	14.24	7.36
23.05	52.94	12.48	40.46
22.05	18.02	11.16	6.85
21.40	28.62	10.26	18.36
20.65	25.08	9.68	15.40
20.15	10.85	9.30	1.55
19.65	25.06	8.62	16.44
19.10	14.42	8.08	6.34
18.60	21.52	7.57	13.95
18.10	14.42	7.24	7.17
17.65	17.96	6.99	10.98
17.20	14.41	6.65	7.76
16.70	21.48	6.02	15.46
16.20	14.40	5.46	8.94
15.85	10.83	5.12	5.71
15.45	17.93	4.73	13.20
15.00	14.38	4.39	10.00
14.60	14.38	4.15	10.23
14.20	14.37	3.79	10.58
13.80	14.37	3.32	11.05
13.40	14.36	2.96	11.40
13.05	10.81	2.73	8.08
12.75	10.80	2.61	8.19
12.45	10.80	2.38	8.43
12.15	10.80	2.02	8.78
11.85	10.80	1.90	8.90
11.50	14.33	1.77	12.55
11.15	10.79	1.54	9.24
10.90	7.22	1.31	5.91
10.60	14.31	1.06	13.24
10.25	10.77	0.95	9.83
10.05	3.63	0.84	2.79
9.85	10.77	0.71	10.06

TABLE 4 - DYNAMOMETER 4
DYNAMOMETER COAST DOWN DATA

AVG SPEED (MPH)	TOT FORCE (LB)	IND FORCE (LB)	FRIC FORCE (LB)
59.85	110.11	100.58	9.53
56.80	106.50	89.25	17.26
54.00	92.51	81.22	11.30
51.40	92.40	73.17	19.23
49.00	78.41	66.29	12.12
46.90	71.36	61.18	10.18
44.90	71.29	56.19	15.10
43.00	64.24	51.32	12.92
41.25	60.70	47.32	13.37
39.65	53.64	44.33	9.31
38.15	53.60	40.78	12.82
36.75	46.55	37.30	9.24
35.45	46.52	34.91	11.60
34.25	39.45	32.75	6.70
33.05	46.46	30.63	15.83
31.90	35.88	28.98	6.90
30.85	39.38	27.37	12.01
29.85	32.31	26.27	6.04
28.95	32.29	24.14	8.15
28.10	28.74	22.49	6.25
27.25	32.26	21.62	10.64
26.35	32.24	20.43	11.81
25.50	28.70	19.51	9.19
24.75	25.15	18.71	6.44
24.10	21.59	17.68	3.92
23.35	32.18	16.38	15.79
22.55	25.12	15.38	9.74
22.00	14.44	14.52	-0.08
21.45	25.10	13.82	11.27
20.75	25.08	13.23	11.85
20.20	14.43	12.60	1.83
19.70	21.54	11.95	9.59
19.15	17.98	11.50	6.49
18.60	21.52	11.11	10.41
18.10	14.42	10.45	3.96
17.60	21.50	9.80	11.70
17.05	17.96	9.59	8.37
16.60	14.40	9.26	5.15
16.20	14.40	8.90	5.50
15.70	21.45	8.37	13.08
15.30	7.24	7.99	-0.75
15.00	14.38	7.70	6.68
14.60	14.38	7.46	6.92
14.25	10.82	7.25	3.57
13.90	14.37	6.98	7.38
13.50	14.36	6.75	7.62
13.10	14.36	6.62	7.73
12.80	7.23	6.55	0.68
12.50	14.35	6.03	8.31
12.10	14.34	5.55	8.79
11.75	10.79	5.34	5.46
11.40	14.32	5.19	9.13
11.05	10.79	5.09	5.69
10.75	10.78	4.86	5.92
10.40	14.30	4.71	9.59
10.10	7.22	4.64	2.58
9.90	7.21	4.40	2.82
9.70	7.21	4.28	2.94

TABLE 5 - DYNAMOMETER 5
DYNAMOMETER COAST DOWN DATA

AVG SPEED (MPH)	TOT FORCE (LB)	IND FORCE (LB)	FRIC FORCE (LB)
59.40	120.45	105.57	14.87
56.15	109.93	93.74	16.19
53.30	92.49	84.47	8.01
50.75	88.91	76.16	12.75
48.20	92.25	67.90	24.35
45.90	71.32	61.75	9.57
43.80	78.20	55.82	22.38
41.80	64.21	51.05	13.16
40.10	57.16	47.12	10.04
38.55	53.62	43.26	10.36
37.10	50.07	39.62	10.45
35.65	53.53	36.25	17.28
34.30	42.97	33.18	9.79
33.10	42.95	30.44	12.50
31.95	39.40	28.46	10.95
30.85	39.38	26.56	12.82
29.85	32.31	24.50	7.81
28.95	32.29	22.59	9.70
28.05	32.28	21.16	11.12
27.15	32.26	19.74	12.52
26.30	28.71	18.22	10.49
25.50	28.70	17.03	11.67
24.75	25.15	15.99	9.16
24.05	25.14	14.92	10.22
23.35	25.13	14.08	11.05
22.70	21.58	13.16	8.42
22.10	21.57	12.20	9.37
21.40	28.62	11.32	17.29
20.70	21.55	10.65	10.90
20.20	14.43	10.11	4.32
19.70	21.54	9.46	12.07
19.15	17.98	9.01	8.97
18.60	21.52	8.39	13.12
18.05	17.97	7.82	10.15
17.60	14.41	7.48	6.93
17.15	17.96	6.99	10.97
16.65	17.95	6.51	11.44
16.20	14.40	6.17	8.23
15.75	17.93	5.79	12.14
15.30	14.39	5.45	8.93
14.95	10.82	5.11	5.71
14.60	14.38	4.74	9.64
14.15	17.90	4.37	13.54
13.75	10.81	4.28	6.54
13.40	14.36	4.14	10.22
13.00	14.35	3.90	10.45
12.65	10.80	3.56	7.24
12.30	14.34	3.19	11.15
11.95	10.80	3.08	7.71
11.60	14.33	2.95	11.38
11.25	10.79	2.84	7.94
10.95	10.78	2.84	7.94
10.65	10.78	2.72	8.06
10.30	14.30	2.48	11.82
10.05	3.63	2.27	1.36
9.85	10.77	2.13	8.64

TABLE 6 - DYNAMOMETER 6
DYNAMOMETER COAST DOWN DATA

AVG SPEED (MPH)	TOT FORCE (LB)	IND FORCE (LB)	FRIC FORCE (LB)
59.40	113.55	103.12	10.42
56.30	106.48	93.11	13.37
53.45	95.96	83.94	12.02
50.90	85.44	76.56	8.88
48.40	92.26	68.97	23.30
46.10	71.33	62.92	8.41
44.15	67.78	57.30	10.47
42.30	64.22	52.35	11.87
40.60	57.18	48.43	8.74
38.95	60.62	44.10	16.52
37.45	46.56	40.51	6.06
36.05	53.54	37.19	16.35
34.70	42.98	34.72	8.27
33.45	46.47	32.52	13.95
32.25	39.41	30.48	8.94
31.20	35.86	28.14	7.72
30.25	32.31	26.16	6.16
29.30	35.83	24.22	11.61
28.35	32.28	22.35	9.93
27.45	32.27	21.03	11.23
26.60	28.72	19.88	8.84
25.80	28.71	18.57	10.14
25.10	21.60	17.45	4.16
24.45	25.15	16.22	8.92
23.75	25.14	15.15	9.99
23.10	21.58	14.23	7.35
22.50	21.58	13.28	8.30
21.95	18.01	12.59	5.43
21.30	28.61	11.79	16.82
20.60	21.55	11.01	10.54
20.15	10.85	10.49	0.36
19.75	17.99	9.96	8.03
19.25	17.99	9.48	8.50
18.70	21.52	8.98	12.53
18.20	14.42	8.67	5.75
17.80	14.41	8.20	6.22
17.35	17.96	7.58	10.38
16.95	10.84	7.26	3.58
16.55	17.95	6.86	11.09
16.10	14.40	6.52	7.87
15.75	10.83	6.19	4.64
15.40	14.39	5.69	8.70
15.05	10.82	5.35	5.47
14.75	10.82	4.99	5.83
14.35	17.91	4.60	13.30
13.95	10.82	4.40	6.42
13.65	10.81	4.28	6.54
13.30	14.36	4.14	10.22
13.00	7.23	3.93	3.30
12.75	10.80	3.68	7.12
12.45	10.80	3.44	7.36
12.15	10.80	3.32	7.48
11.90	7.23	3.22	4.01
11.65	10.79	2.96	7.83
11.30	14.32	2.72	11.61
11.00	7.22	2.50	4.72
10.70	14.31	2.24	12.07
10.35	10.78	2.01	8.76
10.10	7.22	1.90	5.31
9.95	3.63	1.91	1.71

APPENDIX B

Vehicle Data

TABLE 1
TEST FLEET

VEHICLE IDENTIFICATION NUMBER	MODEL YEAR	MANUFACTURER	MODEL NAME	BODY STYLE	TEST WEIGHT (LBS)
101	1974	Chevrolet	Impala	Sedan	4560
201	1975	Chevrolet	Chevelle	Sedan	4100
301	1975	Pontiac	Firebird	Sedan	3640
401	1975	Pontiac	Ventura	Sedan	3520
502	1975	Ford	Pinto	Sedan	2800
601	1975	Oldsmobile	Cutlass	Sedan	4250
804	1974	American Motors	Gremlin	Sedan	2970
901	1975	Chevrolet	Impala	Stationwagon	5250
1001	1975	Chevrolet	Vega	Sedan	2680
1102	1975	Ford	Granada	Sedan	3510
1201	1975	Buick	Century	Sedan	4140
1301	1975	Buick	Special	Sedan	4020
1401	1975	Buick	Skylark	Sedan	3720
1501	1975	Buick	Apollo	Sedan	3910
1601	1975	Chevrolet	Monza	Sedan	3490
1702	1975	Ford	Mustang Mach 1	Sedan	3000
1802	1975	Ford	Mustang	Sedan	3020
1901	1975	Buick	Skyhawk	Sedan	3200
2102	1975	Mercury	Capri II	Sedan	2570
2203	1975	Plymouth	Valiant	Sedan	3600
2301	1975	Buick	LeSabre	Sedan	4870
2401	1975	Buick	Estate	Stationwagon	5590
2502	1975	Lincoln	Continental	Sedan	5450
2602	1973	Mercury	Capri	Sedan	2350
2706	1975	Toyota	Corolla	Sedan	2470
2802	1975	Mercury	Comet	Sedan	3320
2906	1975	Toyota	Celica	Sedan	2760
3011	1975	Saab	99	Sedan	2710
3102	1975	Ford	Mustang Mach 1	Sedan	3320
3212	1975	Triumph	TR6	Convertible	2650
3304	1975	American Motors	Pacer	Sedan	3330
3402	1975	Ford	Maverick	Sedan	3320
3505	1975	Volkswagen	Rabbit	Sedan	2170
3613	1975	Honda	CVCC	Sedan	1900
3908	1975	Mazda	RX-3	Stationwagon	2680
4014	1975	Fiat	128	Sedan	2180
4102	1975	Mercury	Montego	Sedan	4560
4202	1975	Ford	Gran Torino	Sedan	4570
4402	1975	Ford	LTD	Sedan	4860
4507	1975	Datsun	280Z	Sedan	3110
4607	1975	Datsun	B210	Sedan	2310
4701	1975	Pontiac	Lemans	Sedan	4230
4801	1975	Oldsmobile	Cutlass Supreme	Sedan	4330
4903	1975	Dodge	Dart	Sedan	3610
5103	1975	Plymouth	Valient Custon	Sedan	4260
5203	1975	Plymouth	Gran Fury	Sedan	4840
5303	1975	Plymouth	Scamp	Sedan	3680
5403	1975	Plymouth	Valiant	Sedan	3620
5503	1975	Chrysler	New Yorker	Sedan	5120
5603	1975	Chrysler	Newport	Sedan	4840
5601	1975	Pontiac	Lemans	Sedan	4320
5701	1975	Oldsmobile	Delta 88	Sedan	4770
5802	1975	Ford	Granada	Sedan	3760
6002	1975	Mercury	Montego	Sedan	4500
6102	1975	Ford	LTD	Sedan	5020
6202	1975	Ford	Torino	Sedan	4420
6302	1975	Ford	Granada(1)	Sedan	3800
6402	1975	Ford	LTD	Sedan	5060
6502	1975	Ford	Torino	Stationwagon	5210
6702	1975	Ford	Gran Torino	Stationwagon	5000
6802	1975	Ford	Gran Torino	Sedan	4600
6909	1976	Volvo	264DL	Sedan	3290
8101	1975	Chevrolet	Corvette	Sedan	3850
8401	1975	Oldsmobile	Toronado	Sedan	5170
9101	1975	Chevrolet	Corvette(2)	Sedan	3820

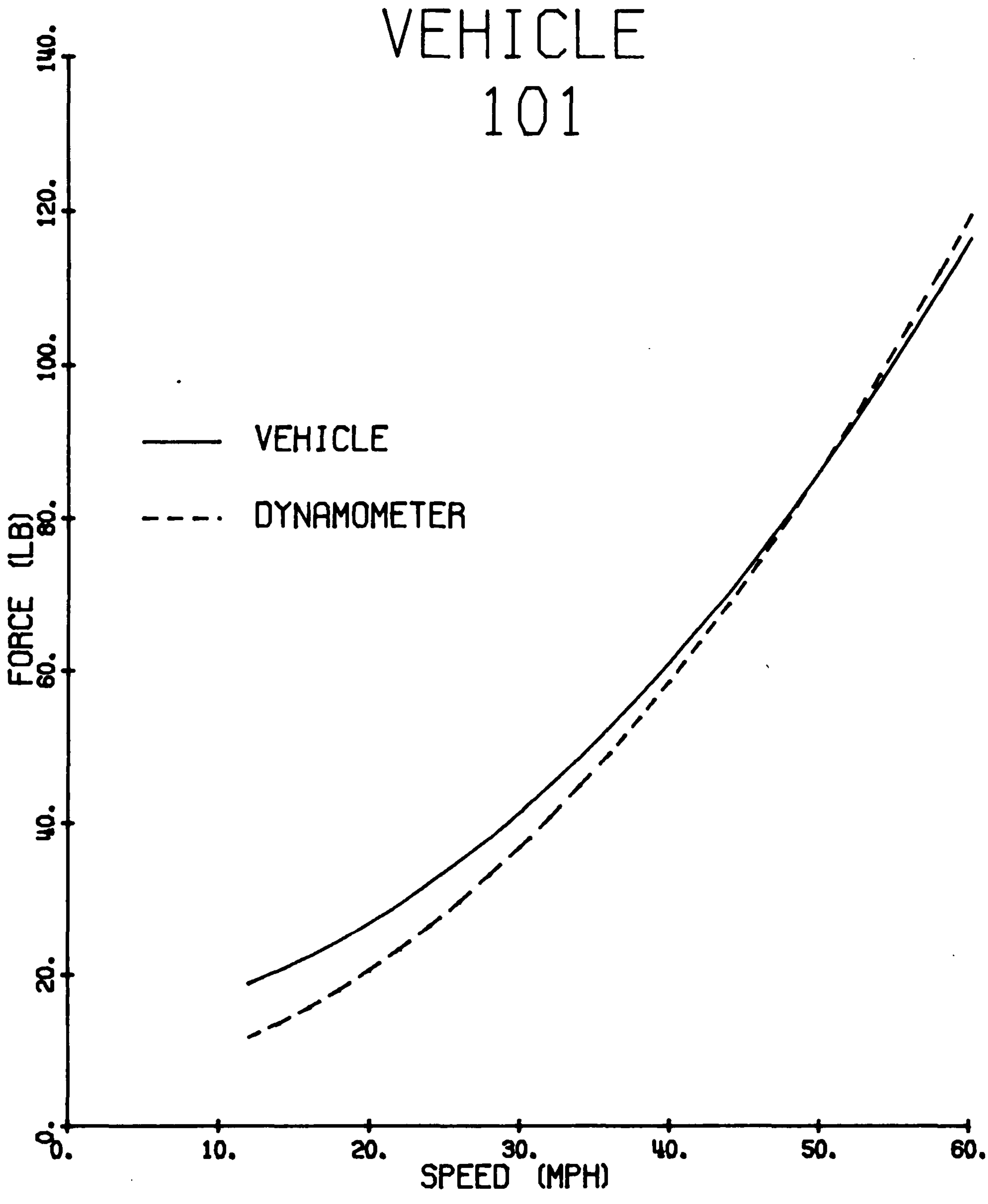
(1) Same vehicle as 5802.
(2) Same vehicle as 8101, however head lamps up.

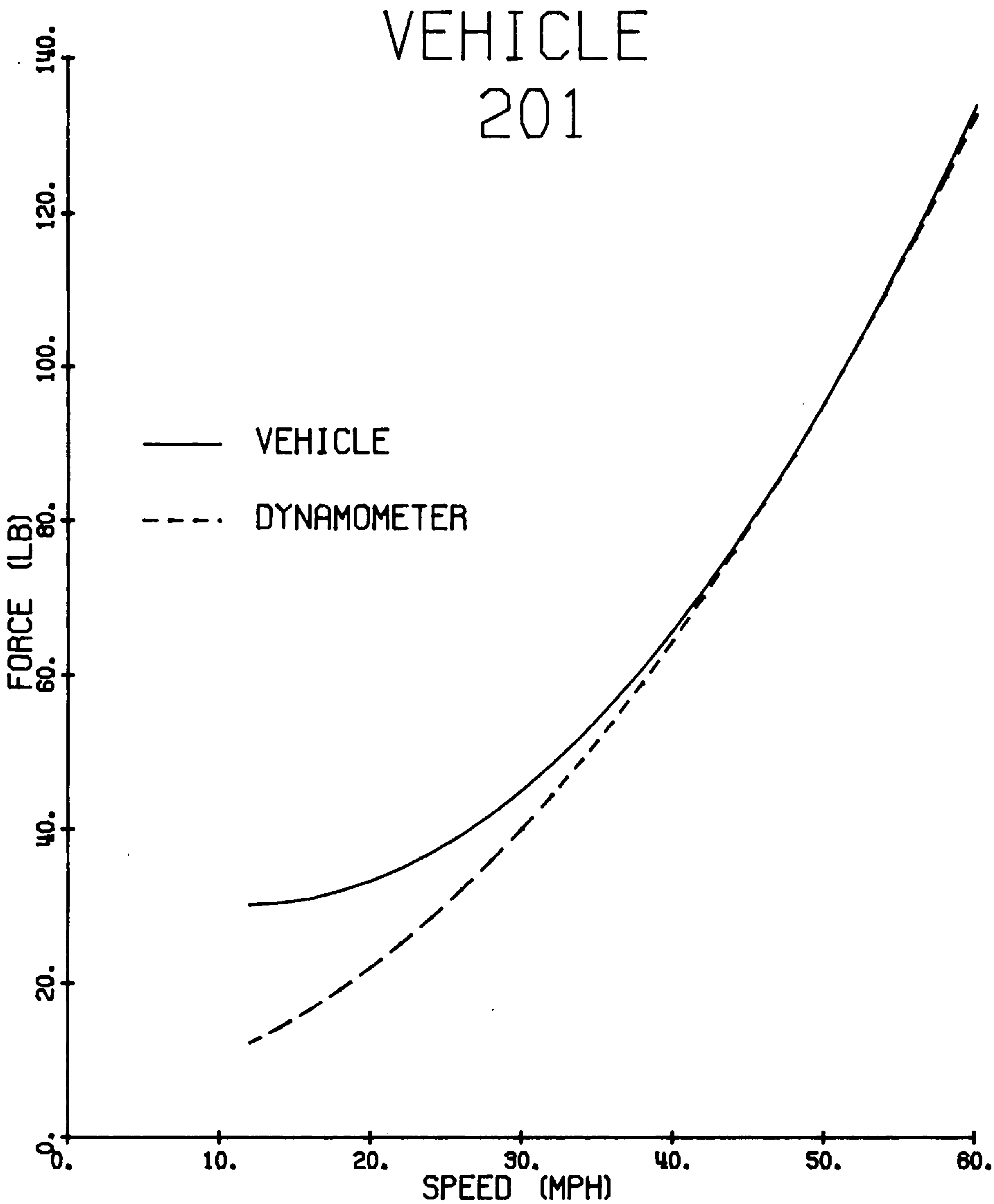
TABLE 2
TWIN SMALL ROLL DYNAMOMETER POWER ABSORPTION ESTIMATES
FOR VEHICLES WITH RADIAL TIRES

ID	F0 (NT)	F1 (KG/SEC)	F2 (KG/M)	F@50 (NT)	HP@50 (HP)
101	0.5961E+02	0.1414E+01	0.5860E+00	0.3839E+03	11.507
201	0.1614E+03	-0.1040E+02	0.9936E+00	0.4253E+03	12.746
301	-0.2327E+02	0.8876E+01	0.2000E+00	0.2750E+03	8.243
401	0.8863E+02	-0.4969E+01	0.6926E+00	0.3235E+03	9.697
502	0.8553E+02	-0.5252E+01	0.7195E+00	0.3276E+03	9.817
601	0.1756E+03	-0.1207E+02	0.9457E+00	0.3783E+03	11.340
804	-0.4747E+02	0.1464E+02	0.1032E+00	0.3314E+03	9.933
901	0.1724E+02	0.4515E+01	0.6562E+00	0.4459E+03	13.365
1001	0.4774E+02	0.2625E+01	0.4068E+00	0.3096E+03	9.280
1102	0.3281E+02	0.5216E+01	0.4610E+00	0.3797E+03	11.379
1201	-0.4175E+02	0.1318E+02	0.3270E+00	0.4162E+03	12.475
1301	-0.1257E+02	0.8975E+01	0.3936E+00	0.3846E+03	11.528
1401	-0.1984E+02	0.1184E+02	0.2255E+00	0.3574E+03	10.711
1501	-0.1846E+02	0.7160E+01	0.3596E+00	0.3212E+03	9.627
1601	0.7333E+02	-0.3808E+01	0.4953E+00	0.2356E+03	7.062
1702	0.1301E+02	0.3076E+01	0.4373E+00	0.3002E+03	8.998
1802	0.3457E+02	0.3445E+01	0.4544E+00	0.3385E+03	10.147
1901	0.7912E+02	-0.4224E+01	0.5647E+00	0.2668E+03	7.996
2102	0.4788E+02	-0.6730E+00	0.5188E+00	0.2920E+03	8.751
2203	0.1517E+03	-0.6778E+01	0.7477E+00	0.3737E+03	11.202
2301	-0.7248E+01	0.6477E+01	0.5202E+00	0.3974E+03	11.910
2401	0.3278E+02	0.4406E+01	0.6615E+00	0.4617E+03	13.838
2502	0.1963E+03	0.3310E+01	0.5077E+00	0.5239E+03	15.702
2602	0.5375E+02	0.3099E+01	0.3366E+00	0.2912E+03	8.726
2706	0.1340E+01	0.4767E+01	0.3499E+00	0.2827E+03	8.472
2802	0.5872E+02	0.1062E+01	0.4602E+00	0.3123E+03	9.361
2906	0.9889E+02	-0.6976E+01	0.6477E+00	0.2665E+03	7.988
3011	0.1594E+03	-0.6169E+01	0.6943E+00	0.3683E+03	11.039
3102	0.1473E+02	0.5061E+01	0.3735E+00	0.3144E+03	9.424
3212	0.1295E+03	-0.1108E+02	0.7864E+00	0.2746E+03	8.231
3304	0.6325E+01	0.3905E+01	0.3760E+00	0.2814E+03	8.435
3402	-0.5651E+02	0.1382E+02	0.1693E+00	0.3370E+03	10.100
3505	0.1055E+03	-0.1047E+01	0.5202E+00	0.3419E+03	10.249
3613	0.3142E+01	0.8338E+01	0.2122E+00	0.2955E+03	8.857
3908	0.6141E+02	-0.1287E+01	0.6015E+00	0.3331E+03	9.984
4014	0.9543E+02	-0.3597E+01	0.6859E+00	0.3577E+03	10.720
4102	0.5200E+02	0.6834E+01	0.4874E+00	0.4482E+03	13.433
4202	-0.5724E+02	0.1814E+02	0.1744E+00	0.4352E+03	13.045
4402	0.5926E+02	-0.1486E+01	0.6670E+00	0.3592E+03	10.766
4507	-0.1193E+02	0.7797E+01	0.2515E+00	0.2880E+03	8.631
4607	0.2209E+02	0.2361E+01	0.3359E+00	0.2426E+03	7.273
4701	0.8817E+02	-0.2181E+01	0.6013E+00	0.3398E+03	10.184
4801	0.5423E+02	-0.2535E+01	0.7274E+00	0.3609E+03	10.817
4903	-0.2160E+02	0.1088E+02	0.1701E+00	0.3065E+03	9.185
5103	0.4212E+02	0.1055E+02	0.2431E+00	0.3994E+03	11.972
5203	0.7191E+02	0.3683E+01	0.4845E+00	0.3962E+03	11.876
5303	0.4619E+02	0.9681E+01	0.2600E+00	0.3924E+03	11.762
5403	0.1426E+03	-0.6241E+01	0.7847E+00	0.3951E+03	11.841
5503	0.2105E+03	-0.9938E+01	0.8128E+00	0.3944E+03	11.822
5601	0.8358E+02	0.3676E+01	0.4269E+00	0.3790E+03	11.359
5603	-0.2999E+02	0.1350E+02	0.2314E+00	0.3874E+03	11.610
5701	0.2092E+02	0.5547E+01	0.4750E+00	0.3822E+03	11.454
5802	0.2062E+02	0.5750E+01	0.4446E+00	0.3712E+03	11.126
6002	0.5095E+02	0.9232E+01	0.3783E+00	0.4463E+03	13.375
6102	-0.4376E+02	0.1612E+02	0.2086E+00	0.4208E+03	12.612
6202	-0.3876E+02	0.1294E+02	0.2446E+00	0.3726E+03	11.168
6302	0.6972E+02	-0.3356E+01	0.7182E+00	0.3535E+03	10.594
6402	-0.6875E+02	0.1239E+02	0.3583E+00	0.3871E+03	11.603
6502	-0.1947E+02	0.6926E+01	0.5551E+00	0.4126E+03	12.367
6702	0.4439E+02	0.2241E+01	0.7385E+00	0.4634E+03	13.888
6802	0.1688E+03	-0.1115E+02	0.9875E+00	0.4129E+03	12.377
6909	-0.4329E+01	0.9895E+01	0.3338E+00	0.3836E+03	11.496
8101	0.1883E+03	-0.1099E+02	0.7654E+00	0.3250E+03	9.741
8401	-0.2707E+01	0.5436E+01	0.5472E+00	0.3921E+03	11.753
9101	0.7218E+02	0.3061E+01	0.4822E+00	0.3815E+03	11.433

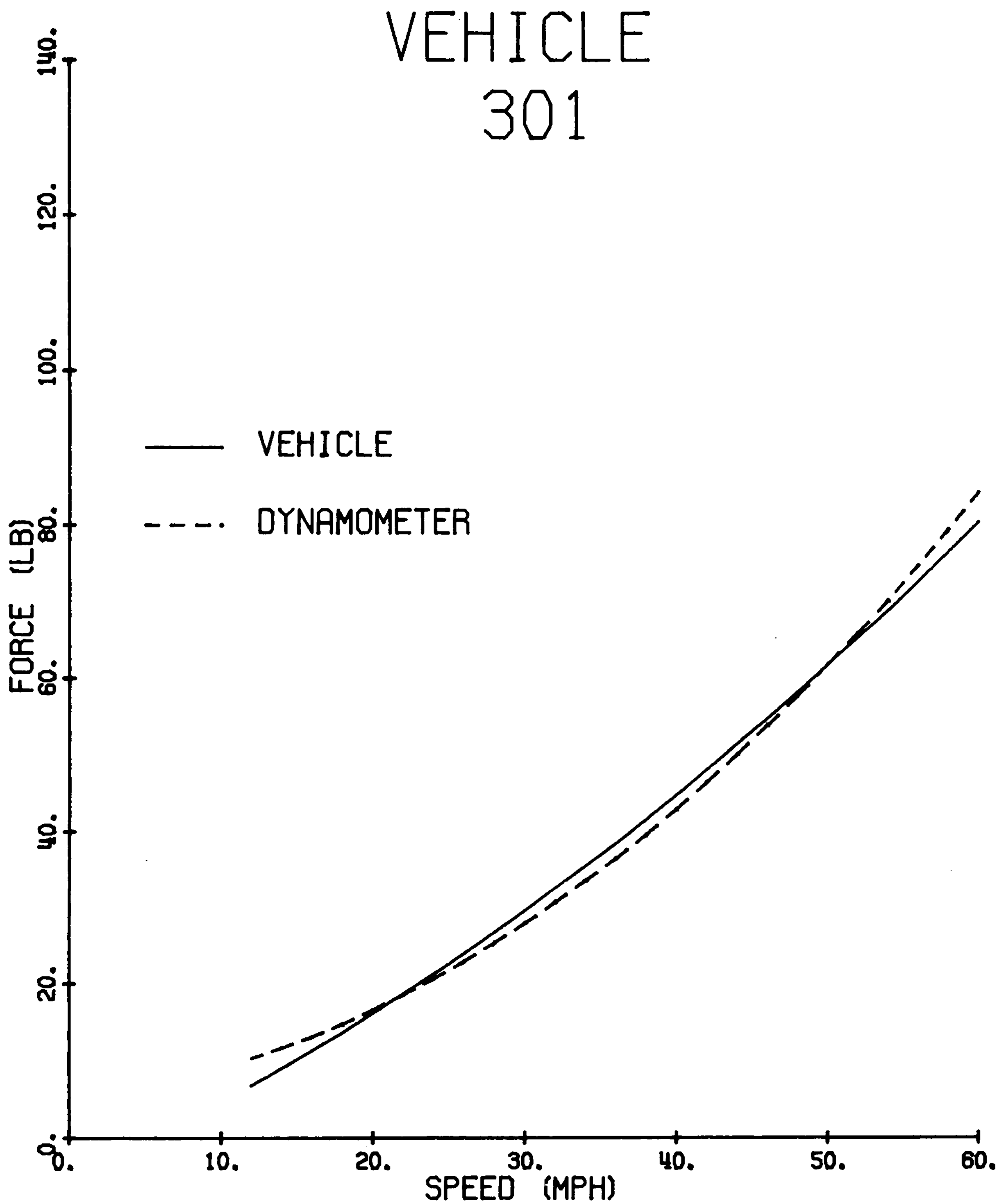
APPENDIX C

Vehicle - Dynamometer Comparison Plots

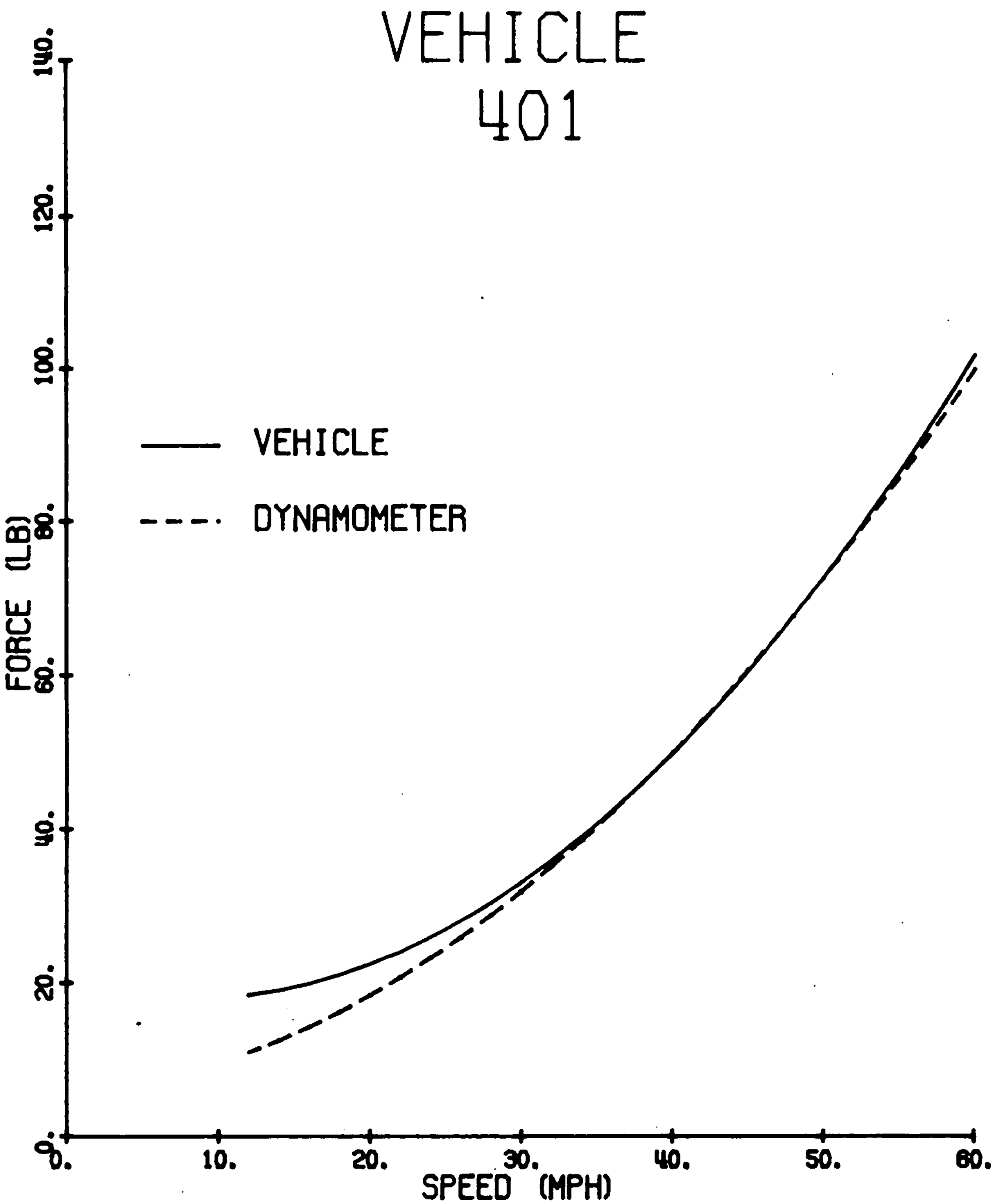

VEHICLE
101
FORCE (LB)
0.
20.
40.
60.
80.
100.
120.
140.
SPEED (MPH)
0.
10.
20.
30.
40.
50.
60.
VEHICLE
DYNAMOMETER



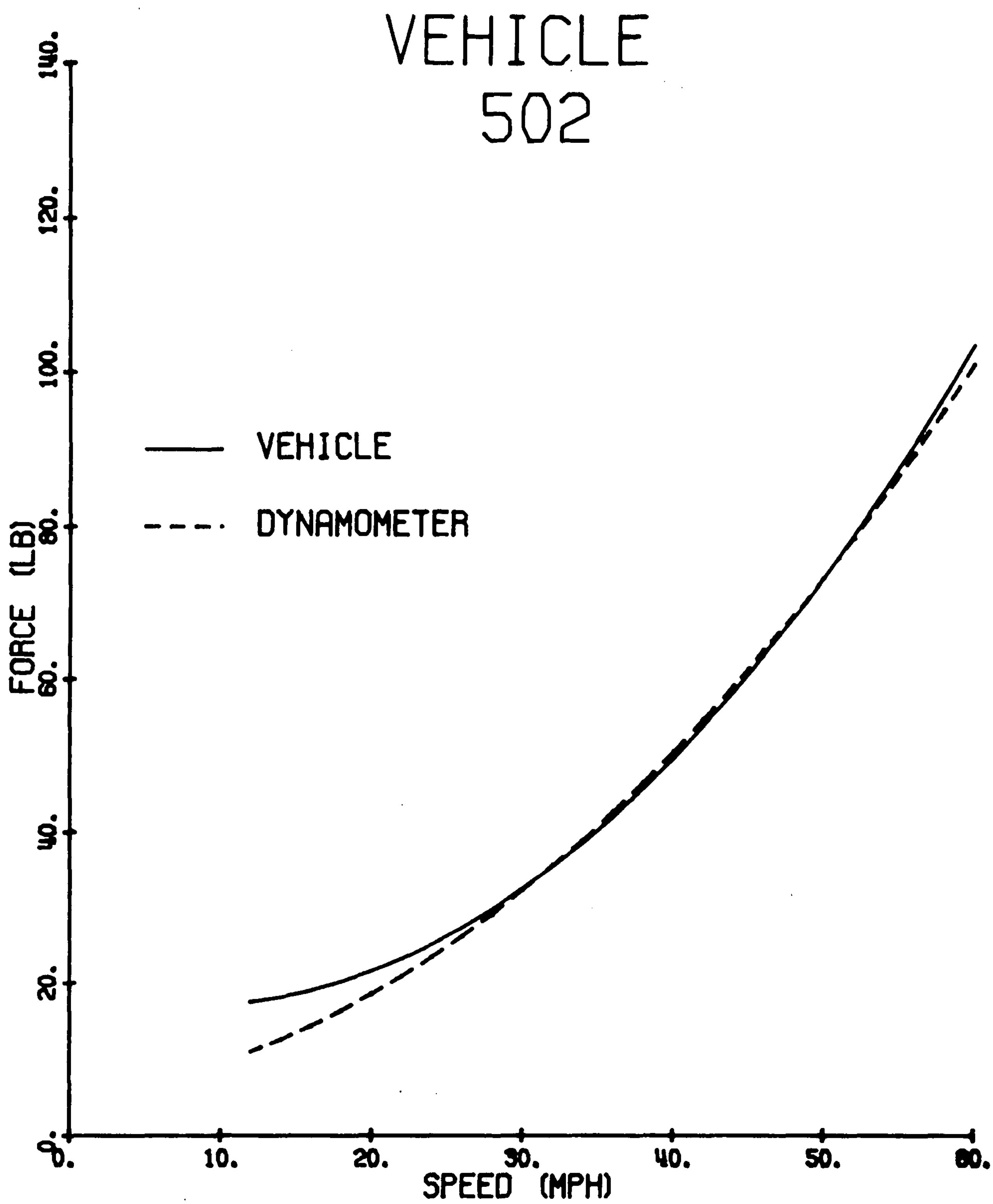
VEHICLE
201
VEHICLE
DYNAMOMETER
FORCE (LB)
0.
20.
40.
60.
80.
100.
120.
140.
0.
10.
20.
30.
40.
50.
60.
SPEED (MPH)



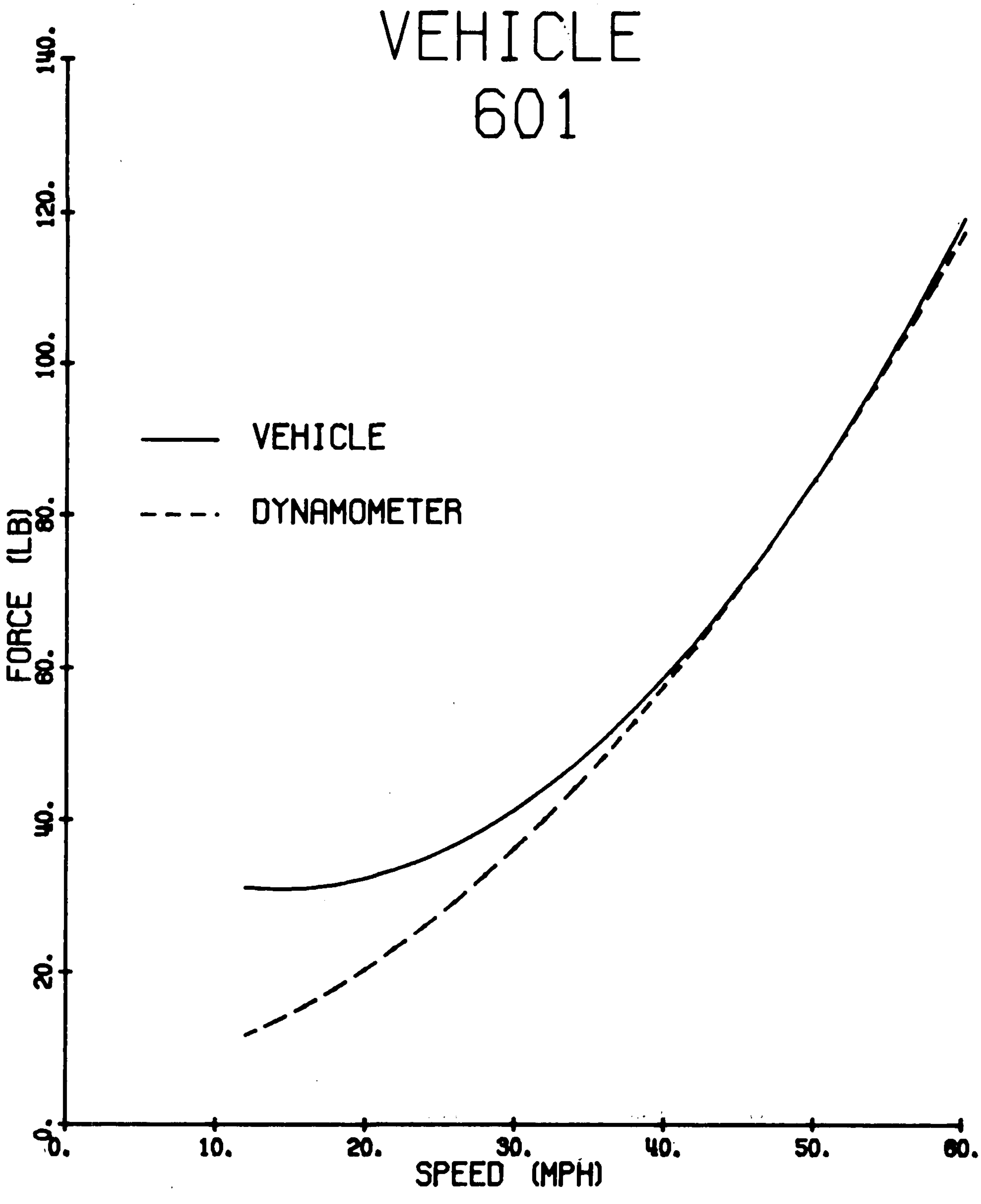
VEHICLE
301
VEHICLE
DYNAMOMETER
FORCE (LB)
0.
20.
40.
60.
80.
100.
120.
140.
0.
10.
20.
30.
40.
50.
60.
SPEED (MPH)

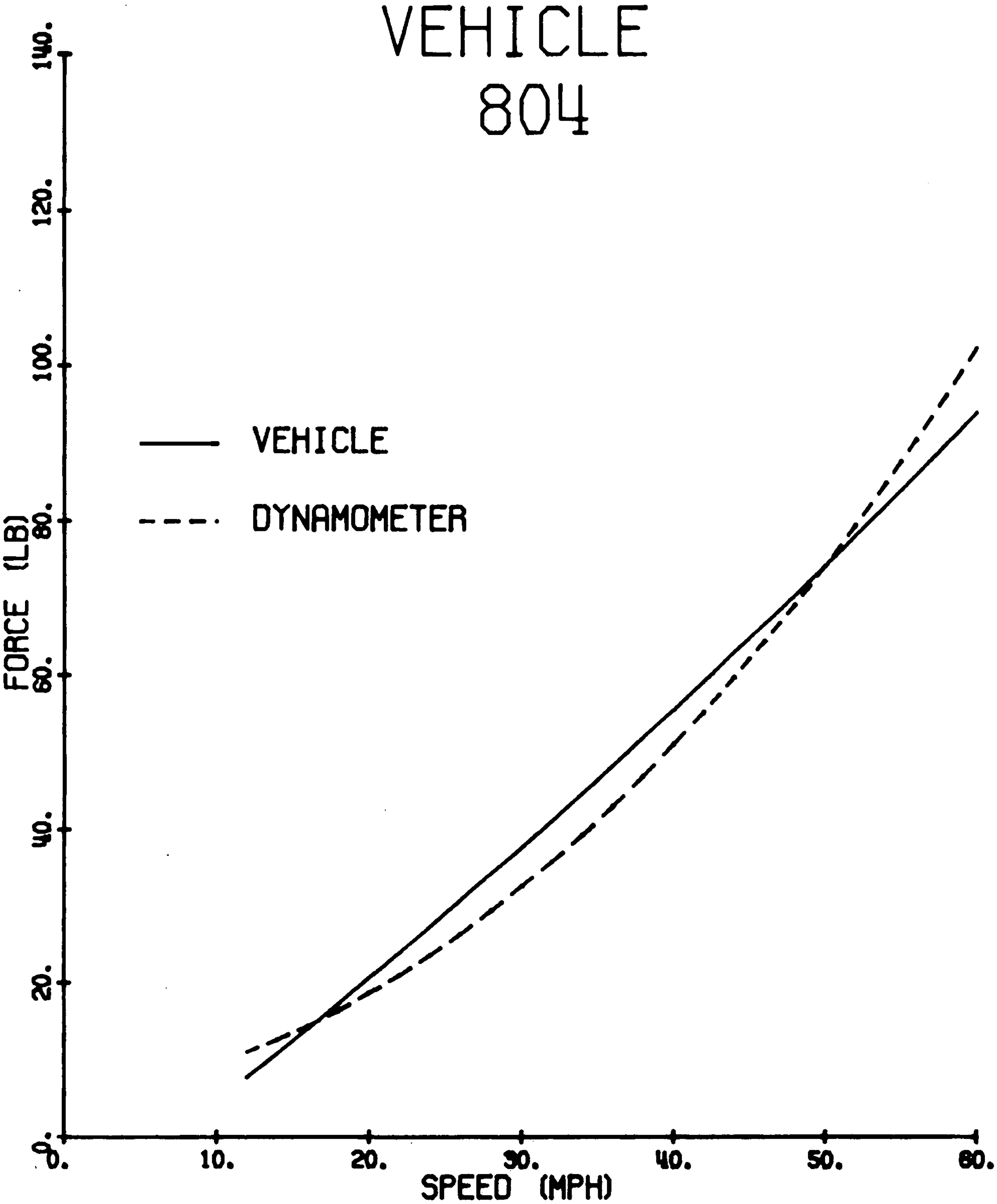


VEHICLE
401
FORCE (LB)
0.
20.
40.
60.
80.
100.
120.
140.
SPEED (MPH)
0.
10.
20.
30.
40.
50.
60.
VEHICLE
DYNAMOMETER

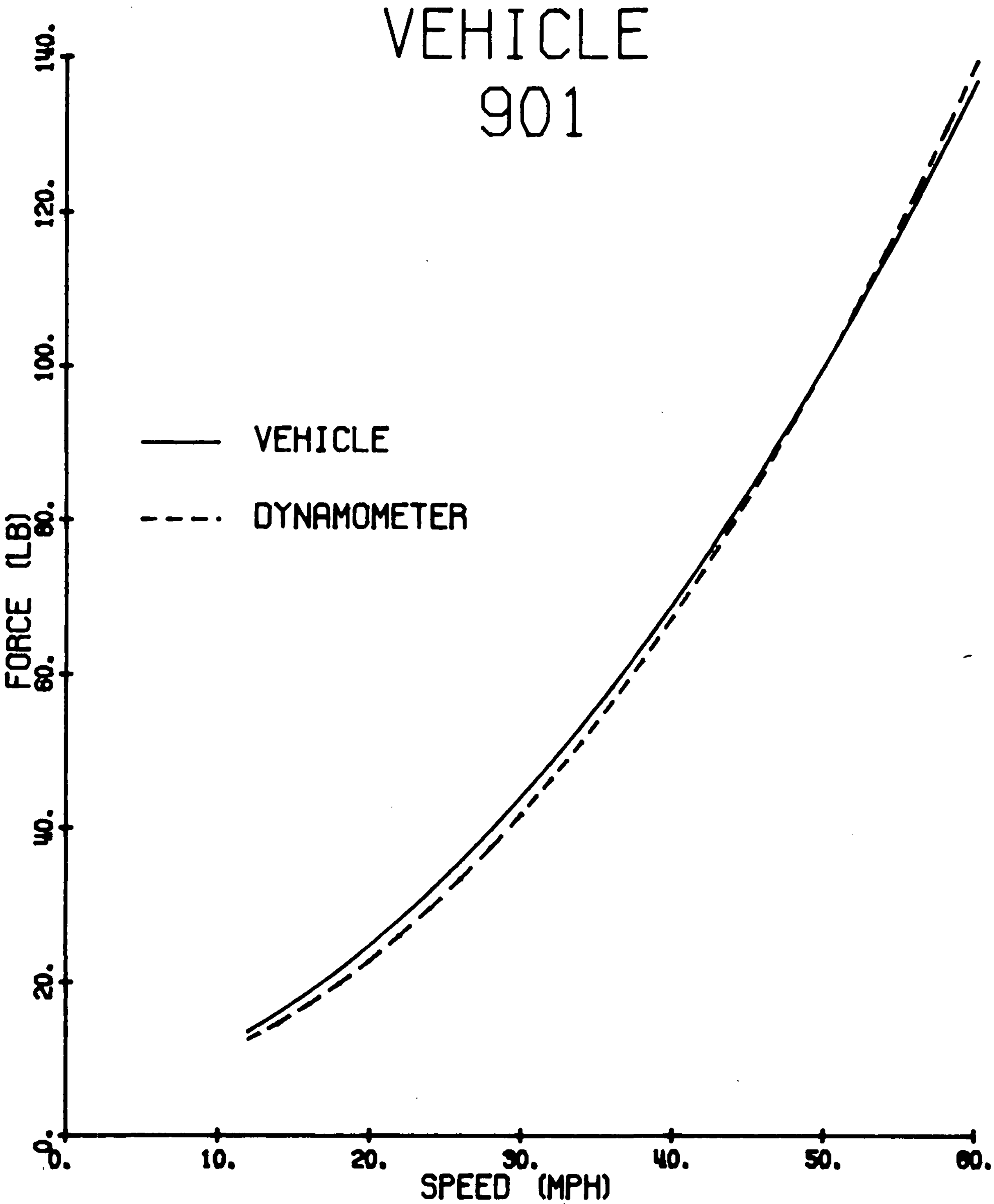


VEHICLE
502
VEHICLE
DYNAMOMETER
FORCE (LB)
SPEED (MPH)
0.
20.
40.
60.
80.
100.
120.
140.
0.
10.
20.
30.
40.
50.
60.

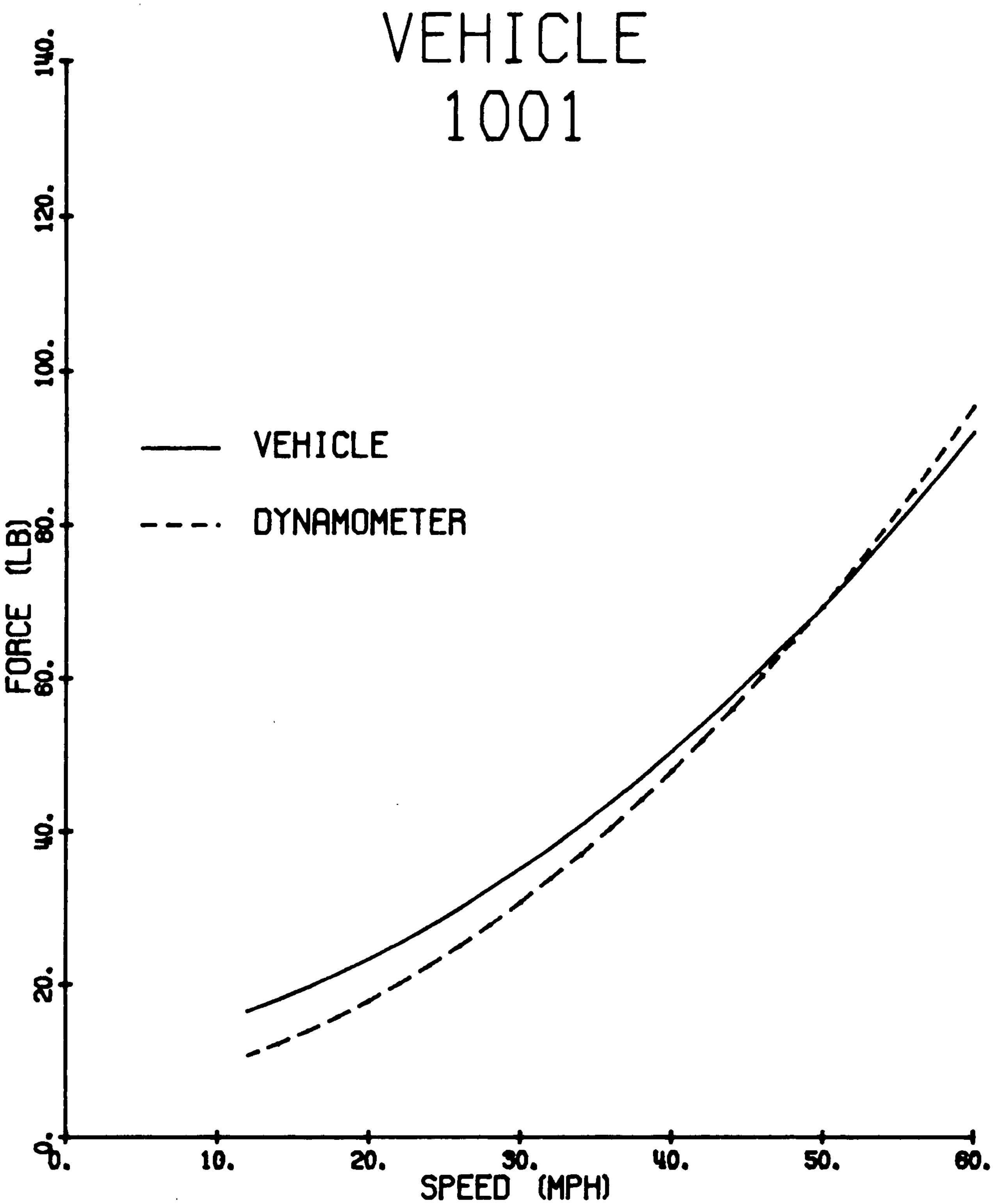

VEHICLE
601
VEHICLE
DYNAMOMETER
FORCE (LB)
0.
20.
40.
60.
80.
100.
120.
140.
0.
10.
20.
30.
40.
50.
60.
SPEED (MPH)



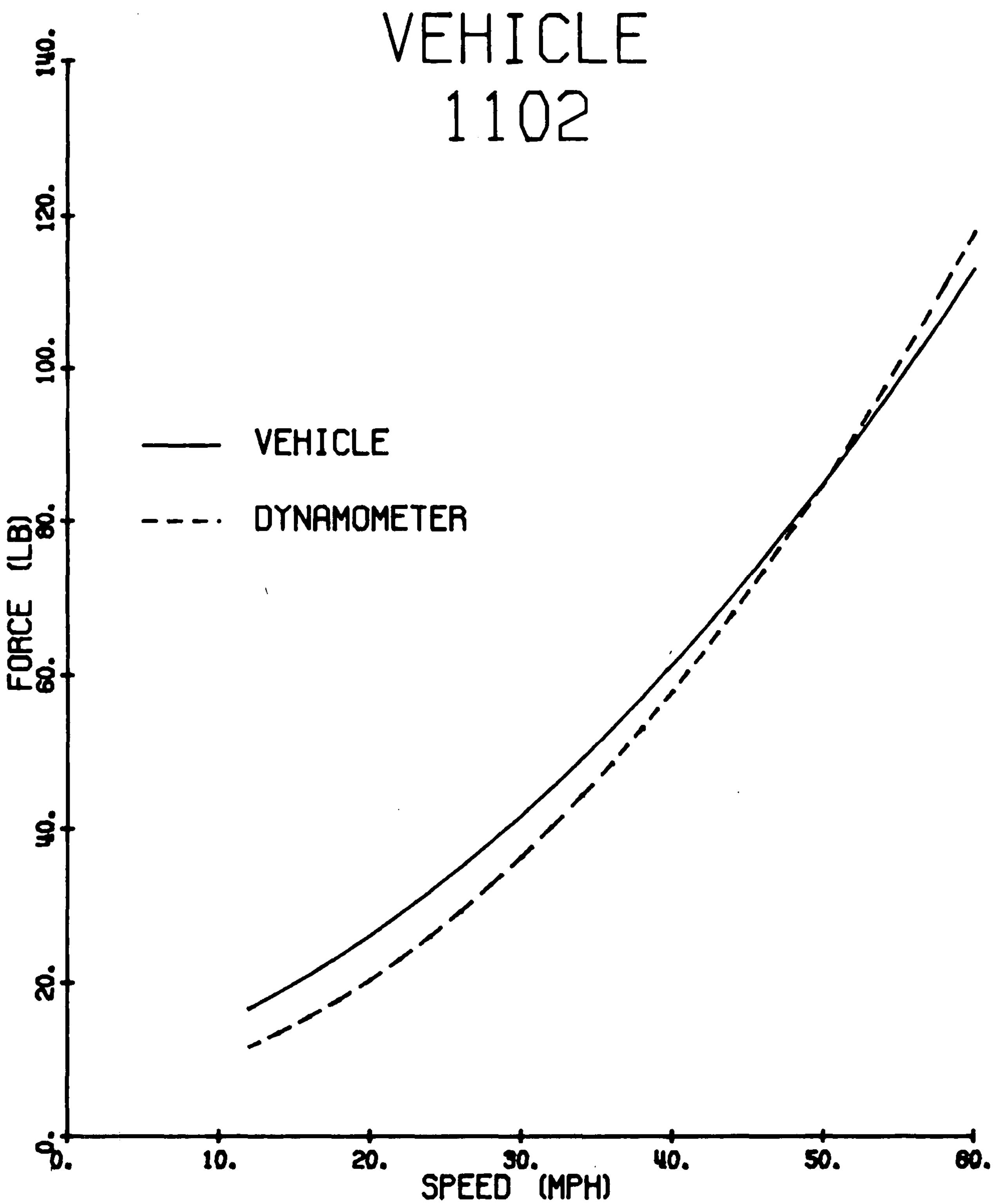
VEHICLE
804
VEHICLE
DYNAMOMETER
FORCE (LB)
0.
20.
40.
60.
80.
100.
120.
140.
0.
10.
20.
30.
40.
50.
60.
SPEED (MPH)

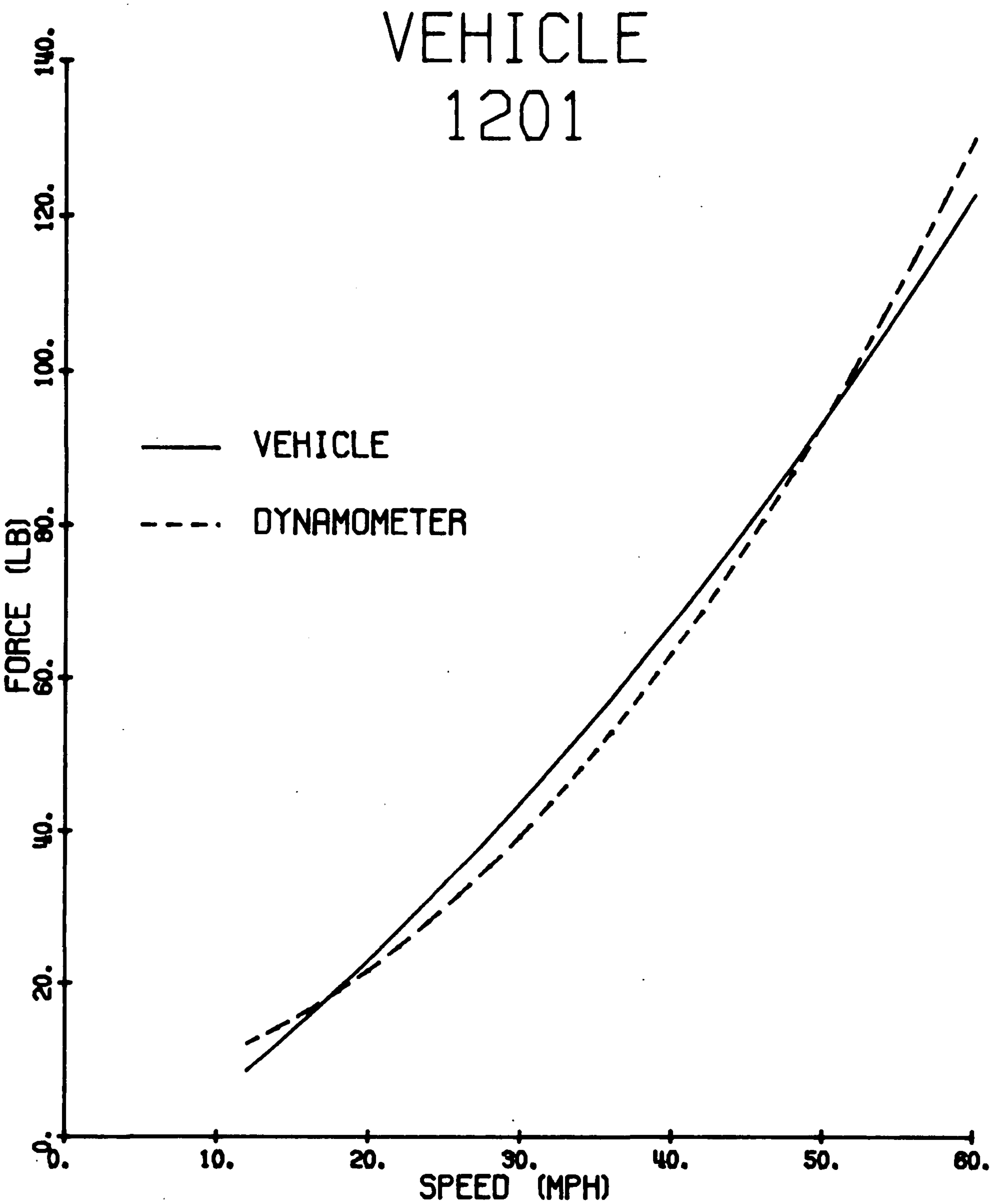


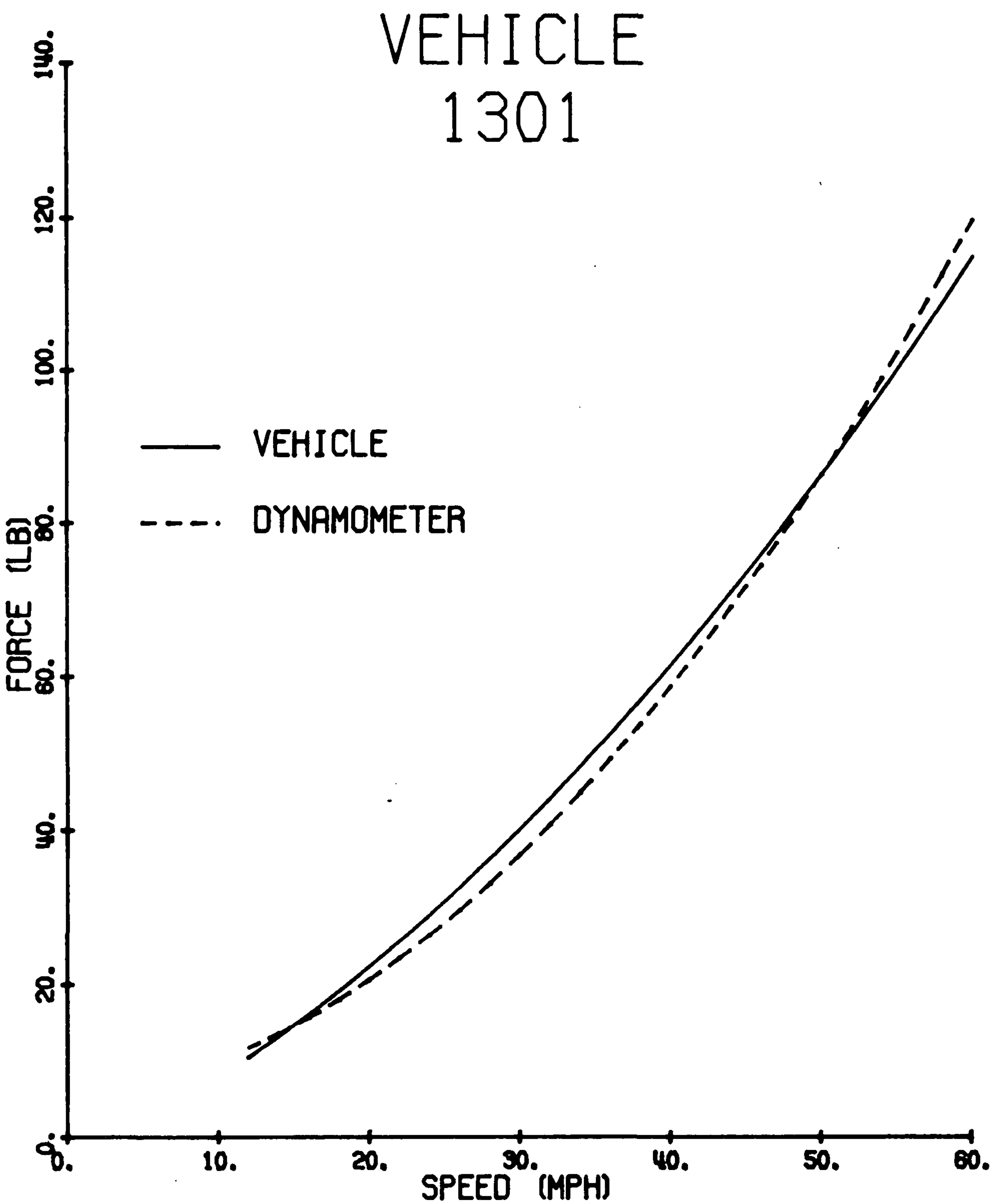
VEHICLE
901
VEHICLE
DYNAMOMETER
FORCE (LB)
SPEED (MPH)
0.
20.
40.
60.
80.
100.
120.
140.
0.
10.
20.
30.
40.
50.
60.



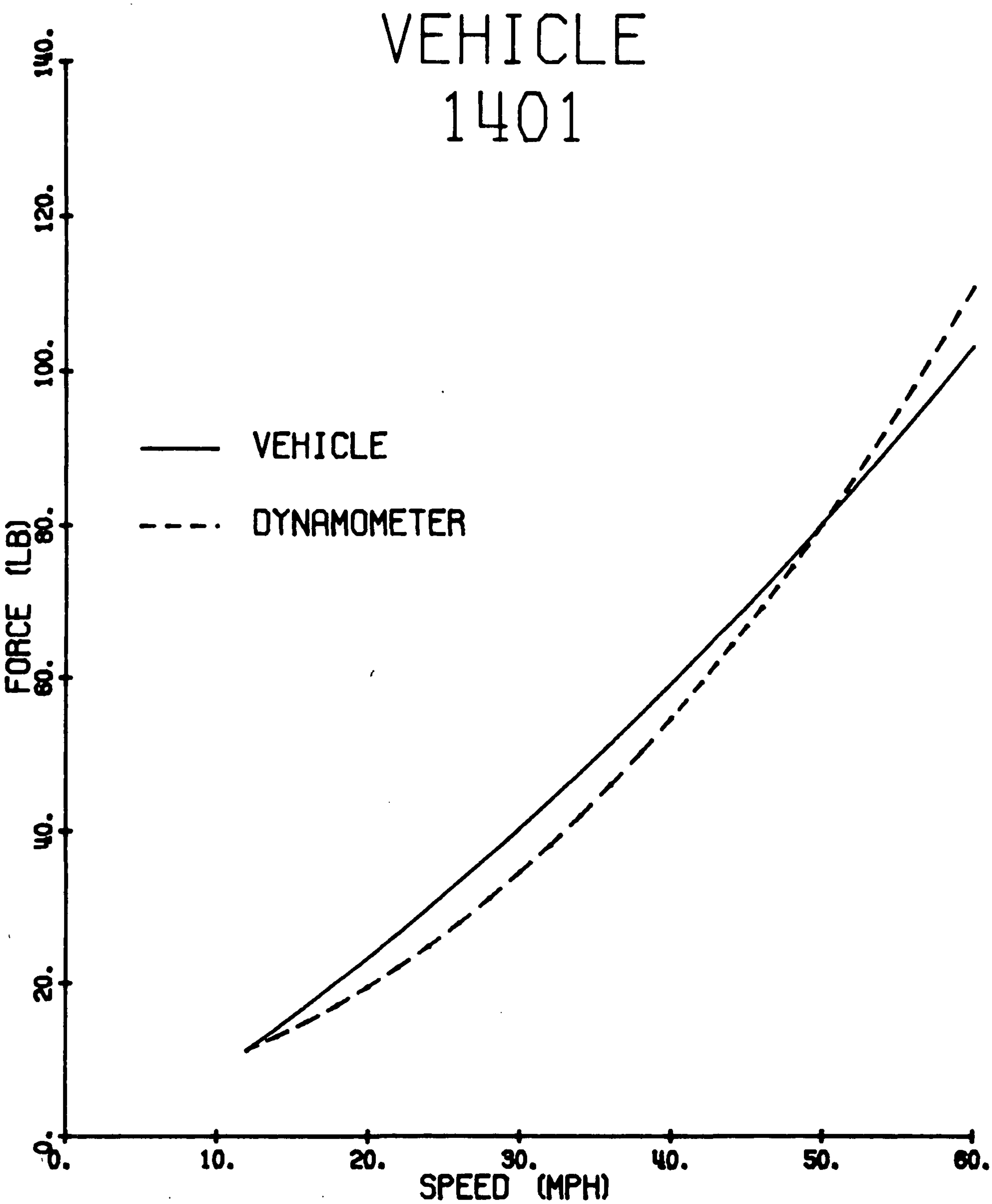
VEHICLE
1001
VEHICLE
DYNAMOMETER
FORCE (LB)
SPEED (MPH)
0.
20.
40.
60.
80.
100.
120.
140.
10.
30.
50.


VEHICLE
1102
VEHICLE
DYNAMOMETER
FORCE (LB)
SPEED (MPH)
0.
20.
40.
60.
80.
100.
120.
140.
0.
10.
20.
30.
40.
50.
60.

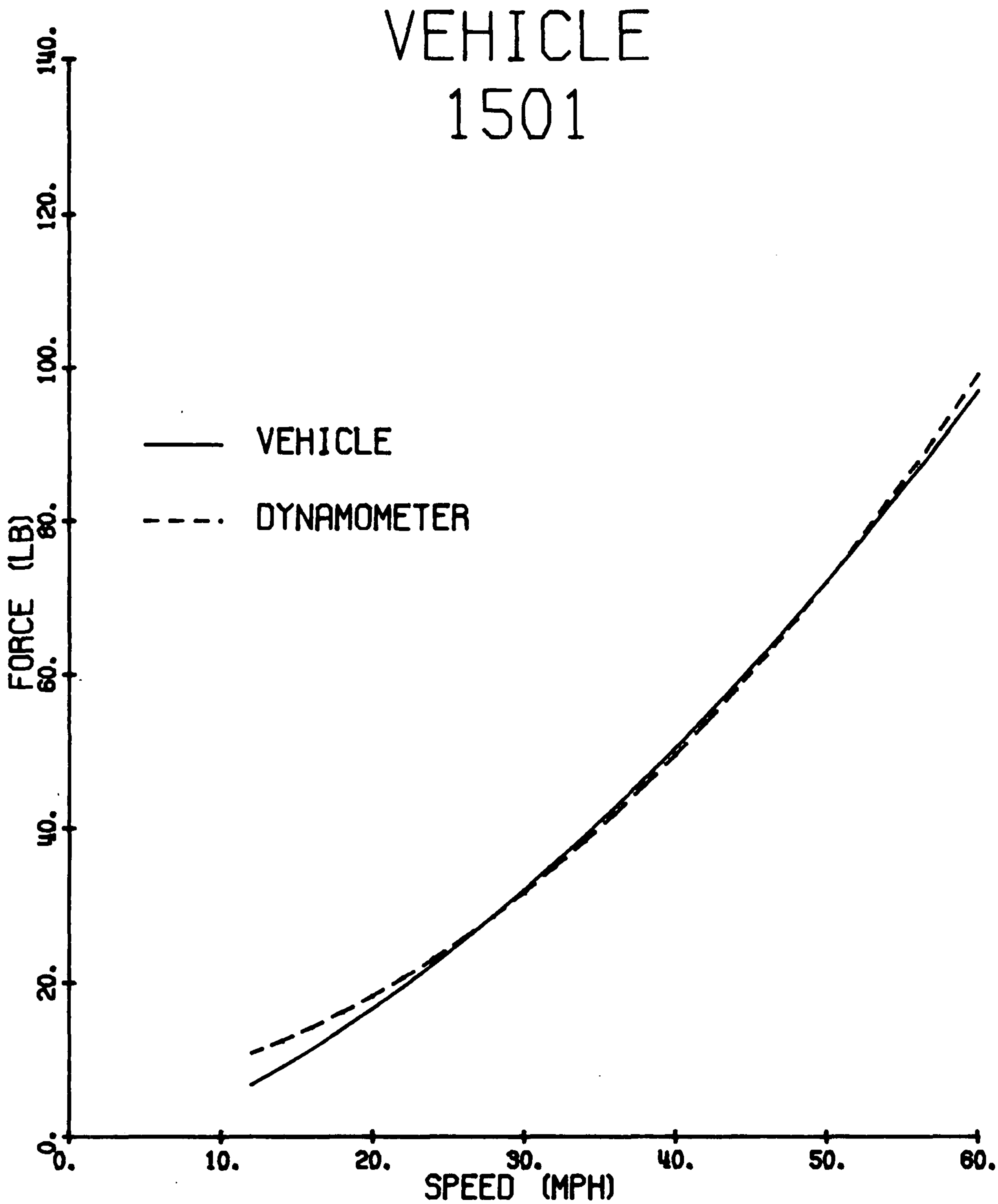

VEHICLE
1201
FORCE (LB)
SPEED (MPH)
VEHICLE
DYNAMOMETER
0.
20.
40.
60.
80.
100.
120.
140.
0.
10.
20.
30.
40.
50.
60.



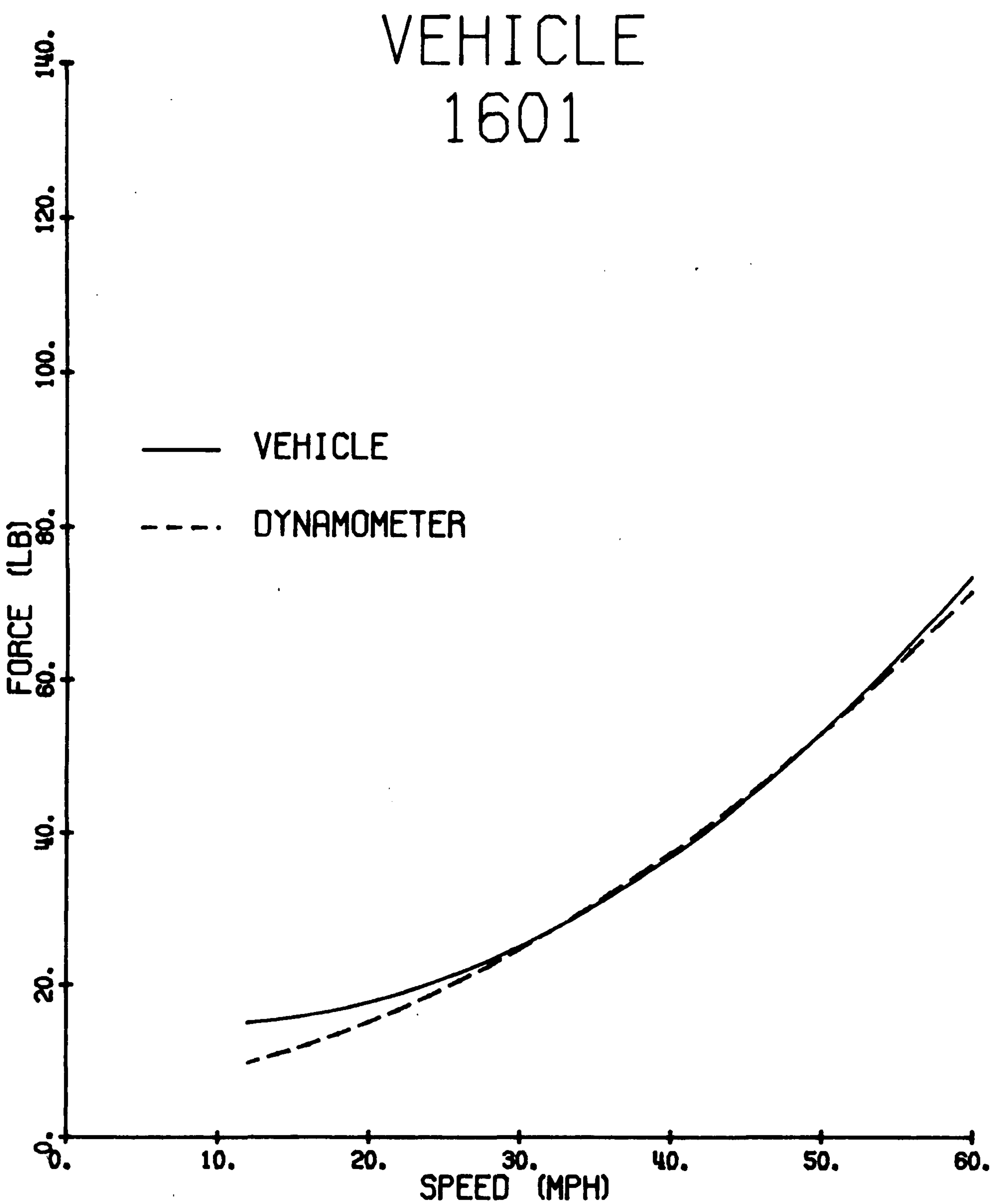
VEHICLE
1301
VEHICLE
DYNAMOMETER
FORCE (LB)
SPEED (MPH)
0.
20.
40.
60.
80.
100.
120.
140.
10.
30.
50.

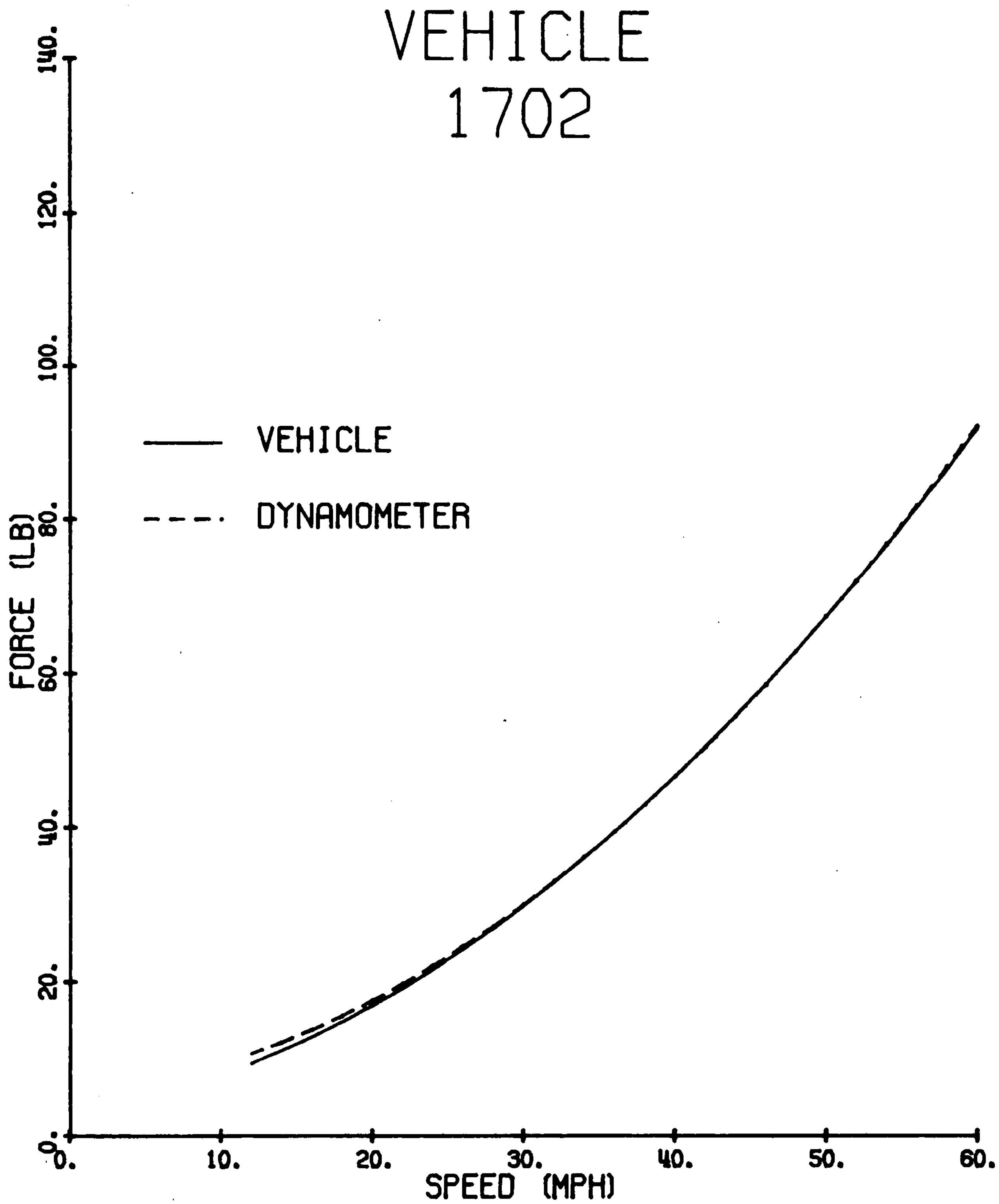


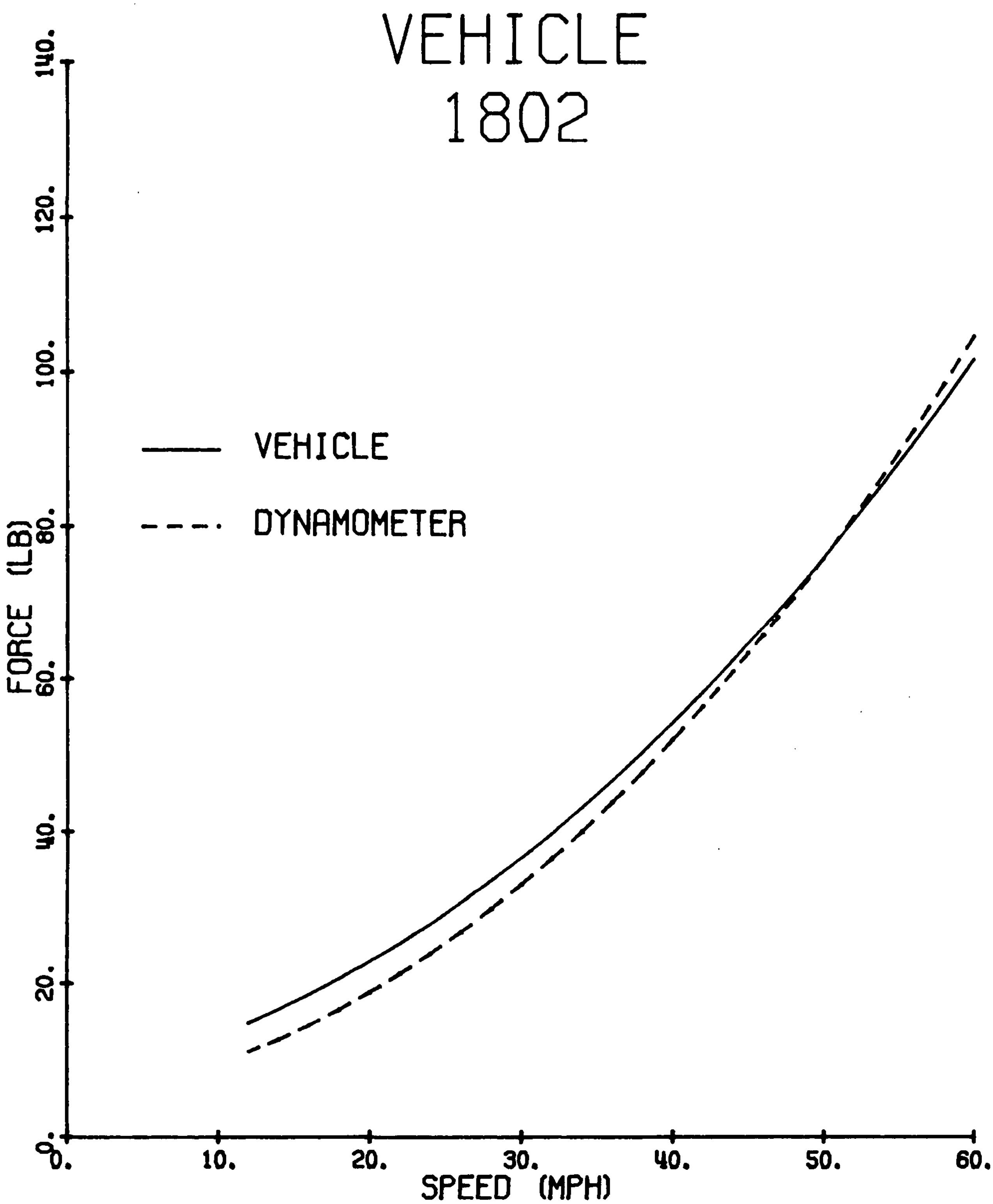
VEHICLE
1401
VEHICLE
DYNAMOMETER
FORCE (LB)
SPEED (MPH)
0.
20.
40.
60.
80.
100.
120.
140.
10.
30.
50.



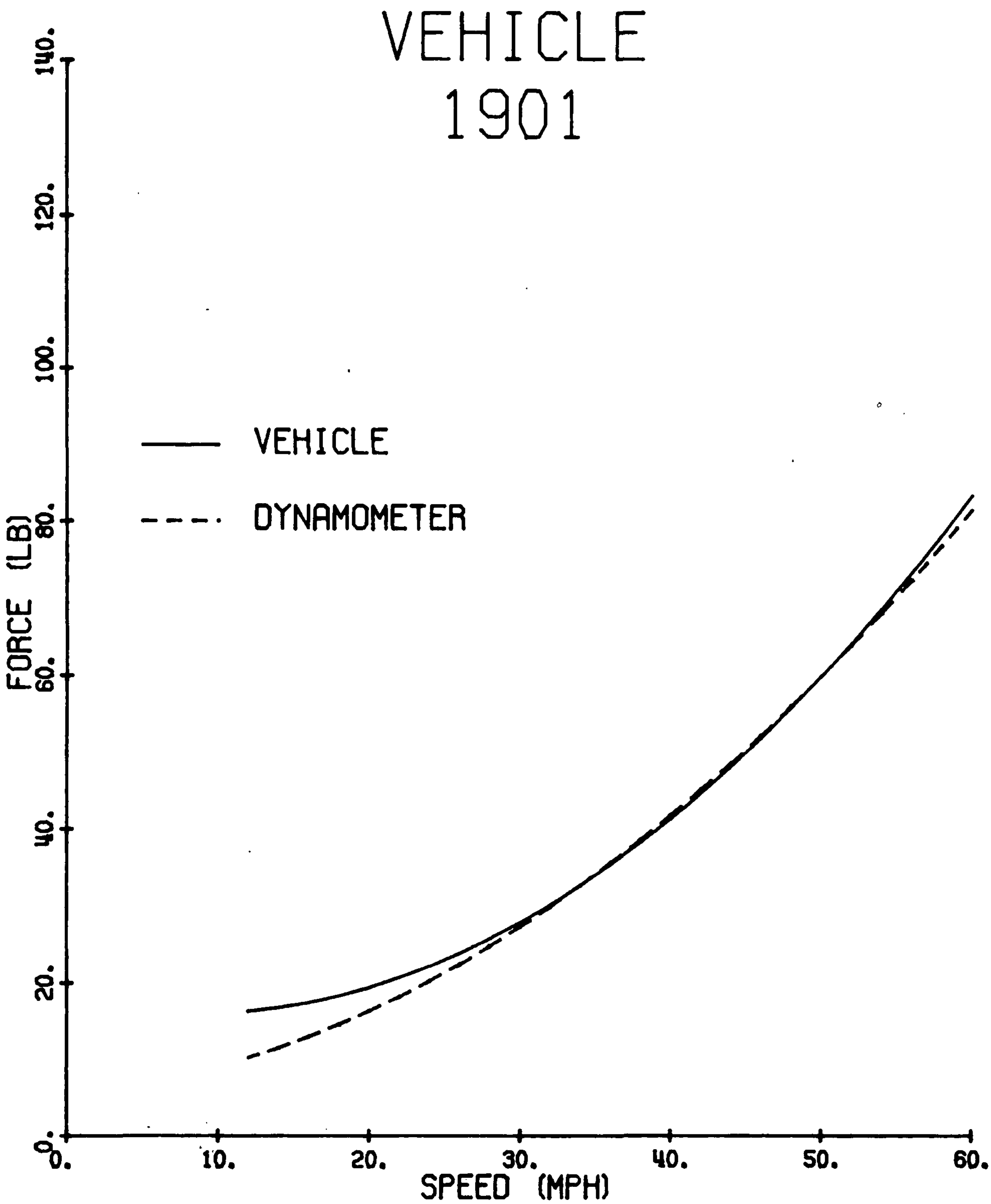
VEHICLE
1501
VEHICLE
DYNAMOMETER
FORCE (LB)
SPEED (MPH)
0.
20.
40.
60.
80.
100.
120.
140.
10.
30.
50.


VEHICLE
1601
VEHICLE
DYNAMOMETER
FORCE (LB)
SPEED (MPH)
0.
20.
40.
60.
80.
100.
120.
140.
0.
10.
20.
30.
40.
50.
60.

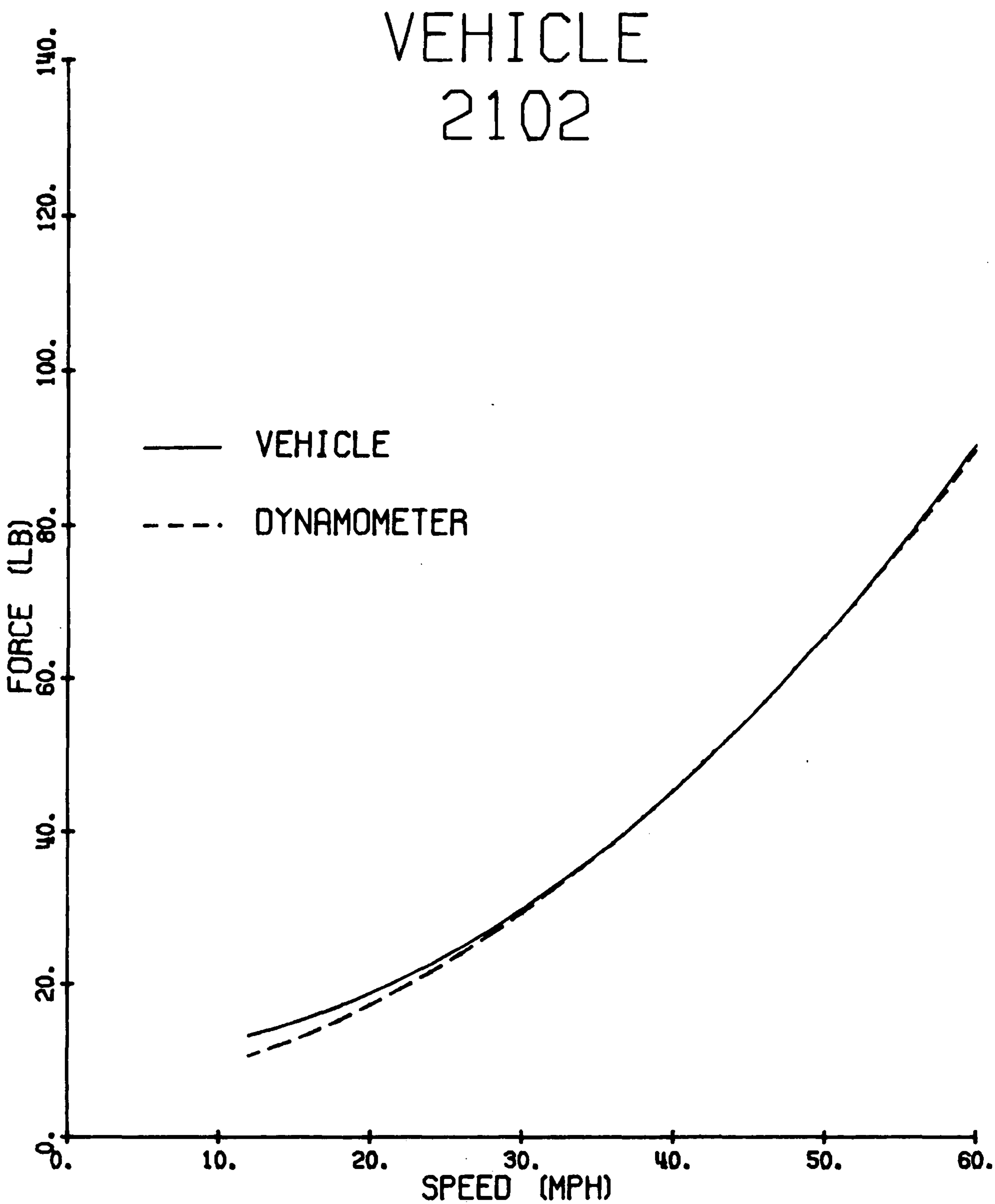

VEHICLE
1702
VEHICLE
DYNAMOMETER
FORCE (LB)
SPEED (MPH)
0.
20.
40.
60.
80.
100.
120.
140.
0.
10.
20.
30.
40.
50.
60.

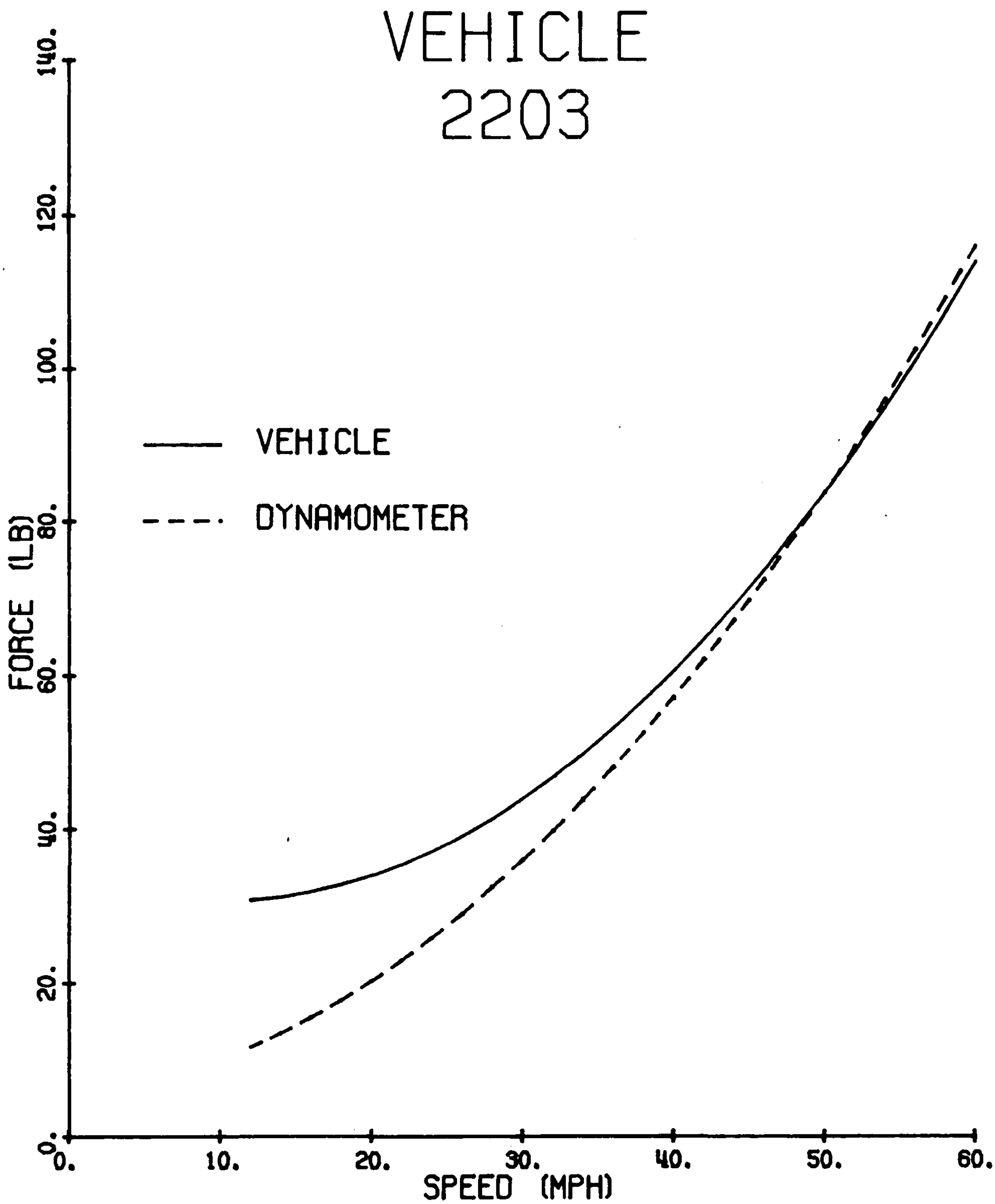


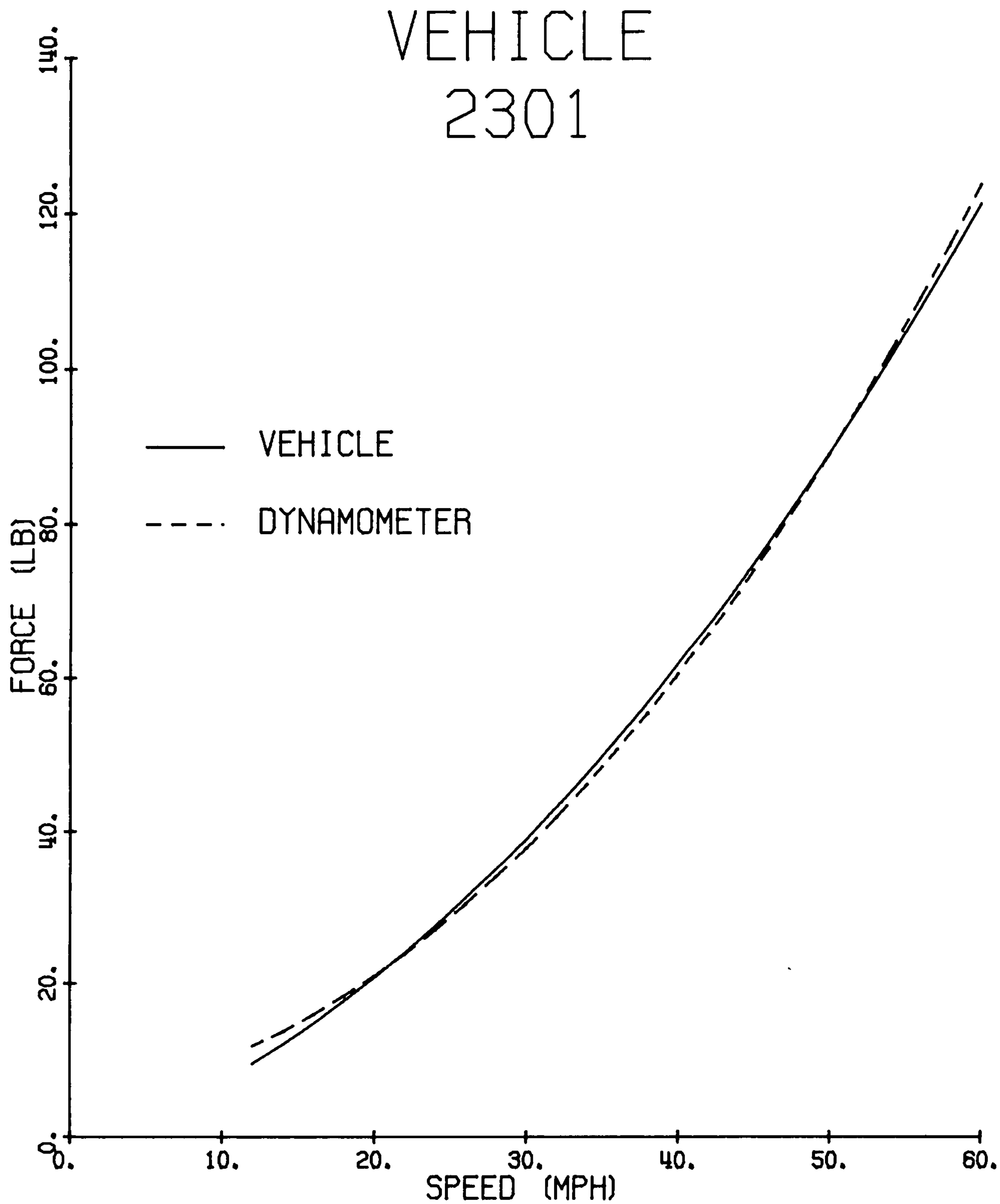
VEHICLE
1802
VEHICLE
DYNAMOMETER
FORCE (LB)
SPEED (MPH)
0.
20.
40.
60.
80.
100.
120.
140.
0.
10.
20.
30.
40.
50.
60.



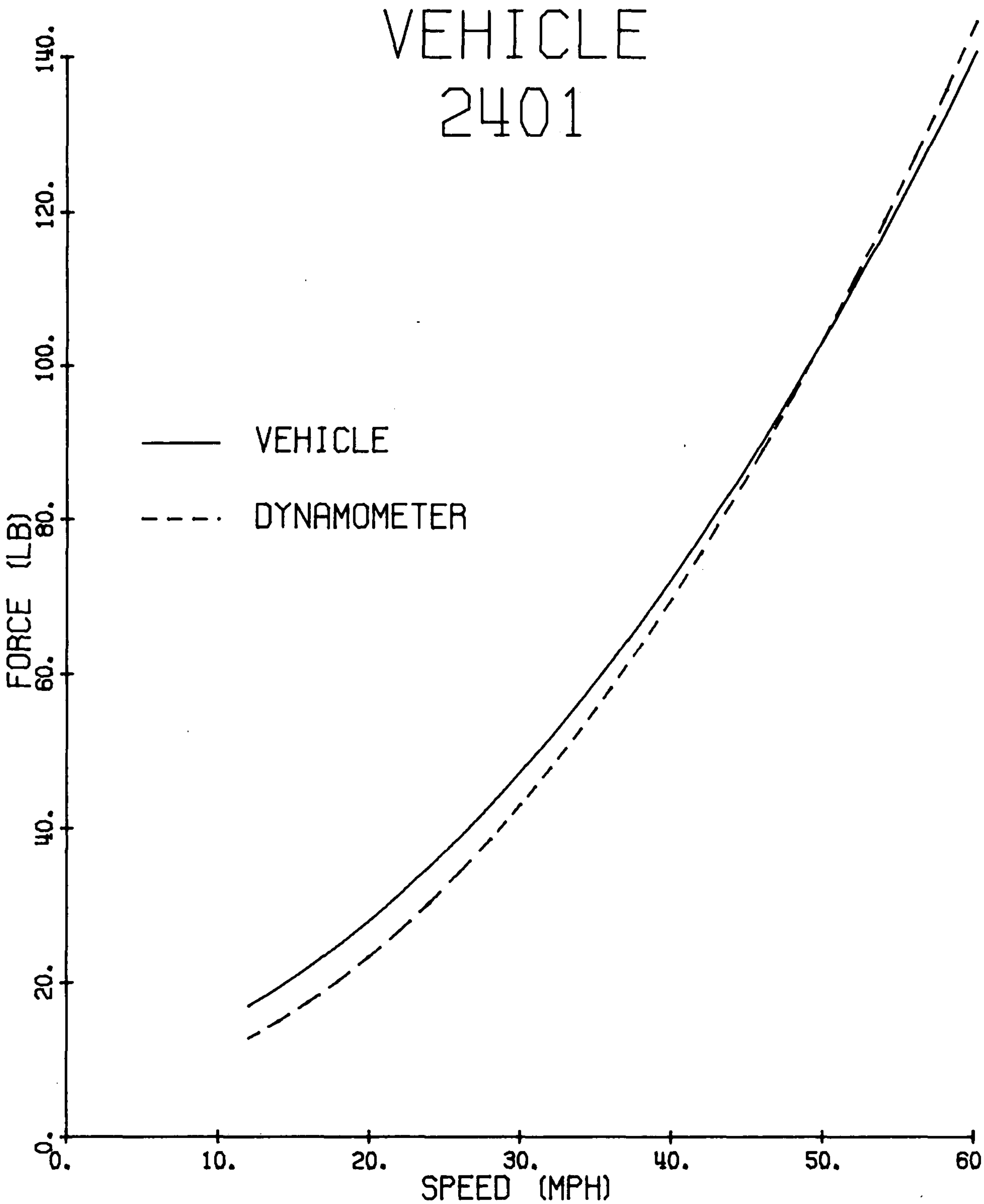
VEHICLE
1901
VEHICLE
DYNAMOMETER
FORCE (LB)
SPEED (MPH)
0.
20.
40.
60.
80.
100.
120.
140.
0.
10.
20.
30.
40.
50.
60.

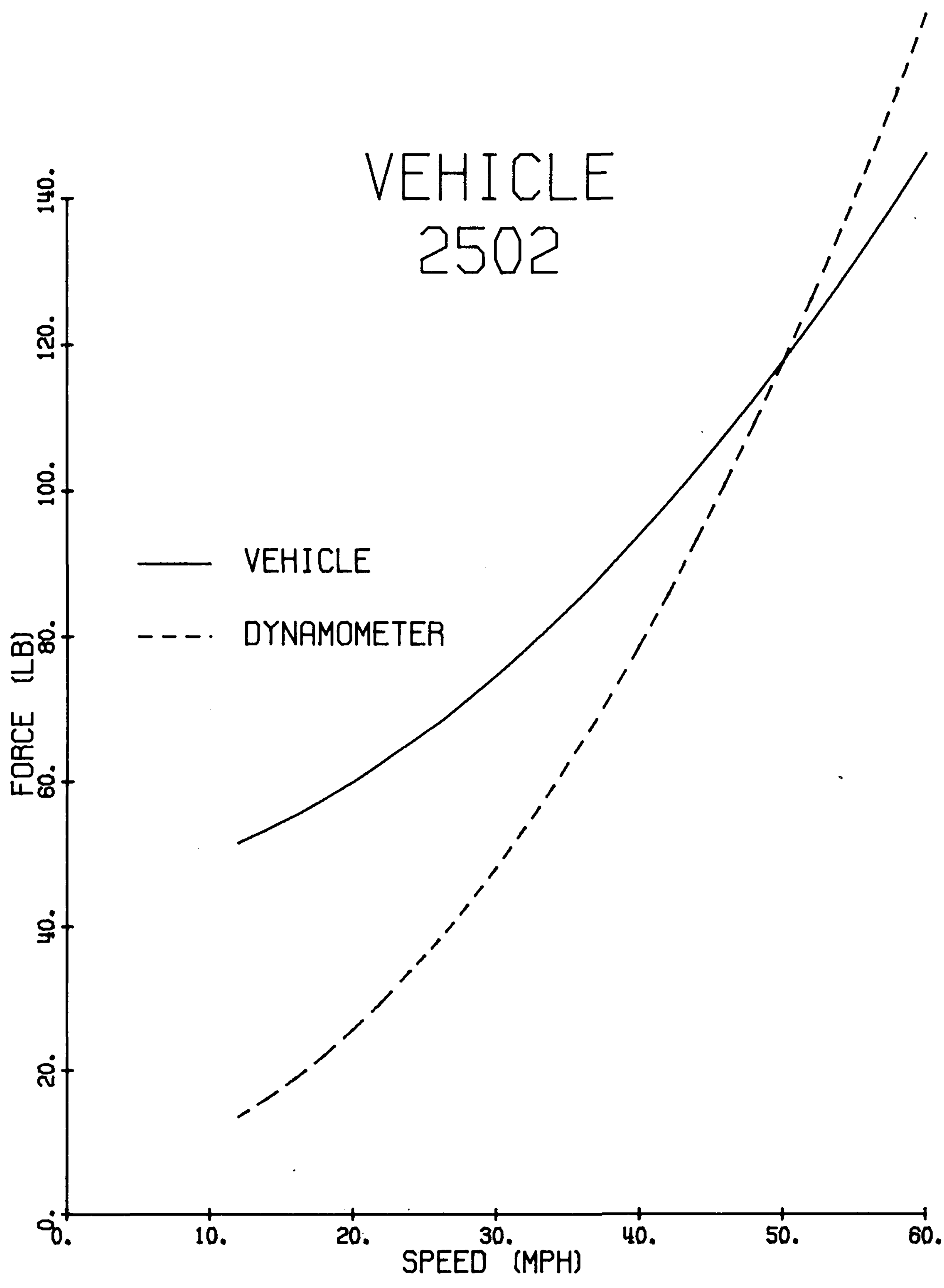

VEHICLE
2102
VEHICLE
DYNAMOMETER
FORCE (LB)
0.
20.
40.
60.
80.
100.
120.
140.
0.
10.
20.
30.
40.
50.
60.
SPEED (MPH)


VEHICLE
2203
VEHICLE
DYNAMOMETER
FORCE (LB)
SPEED (MPH)
0.
20.
40.
60.
80.
100.
120.
140.
0.
10.
20.
30.
40.
50.
60.

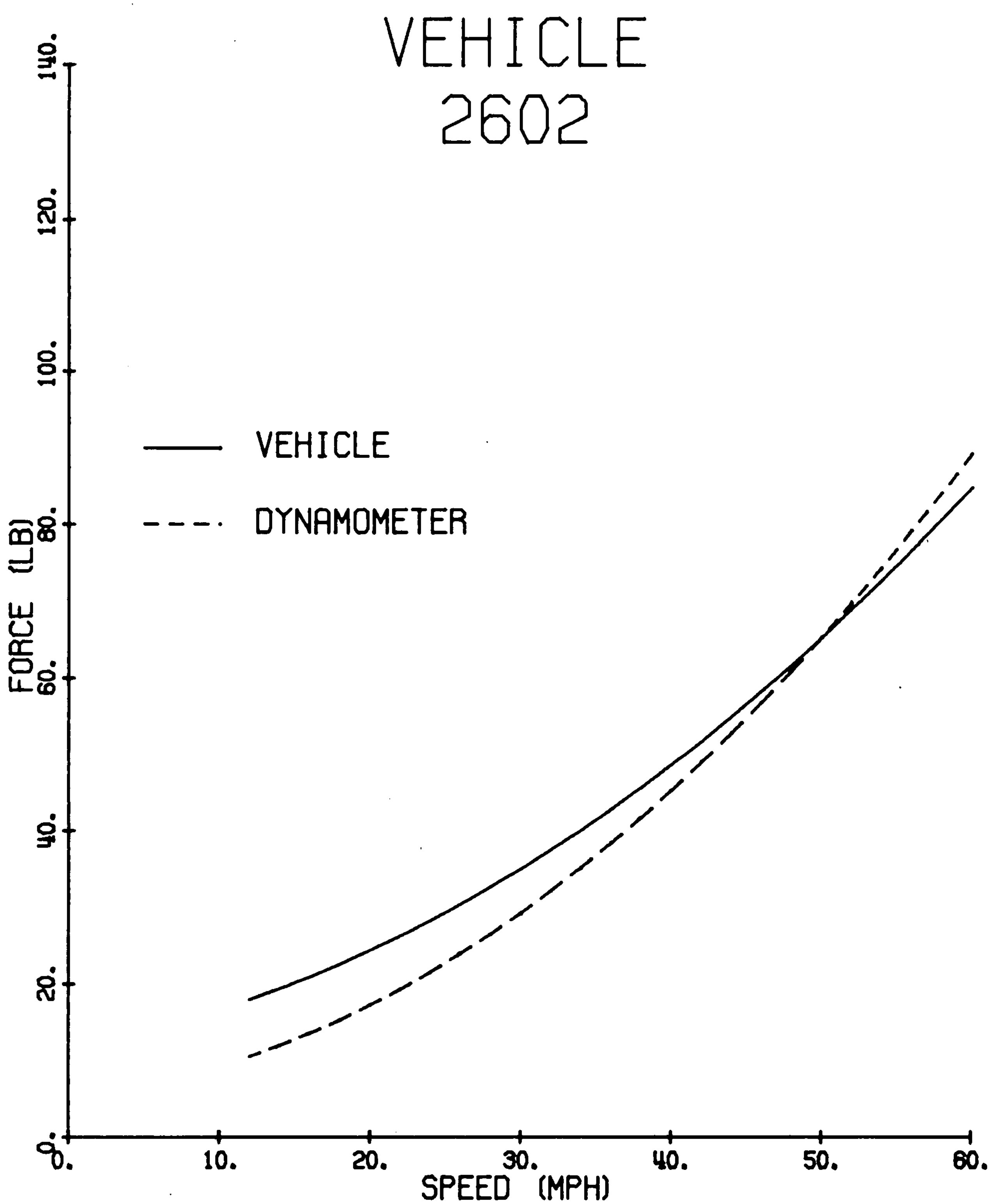


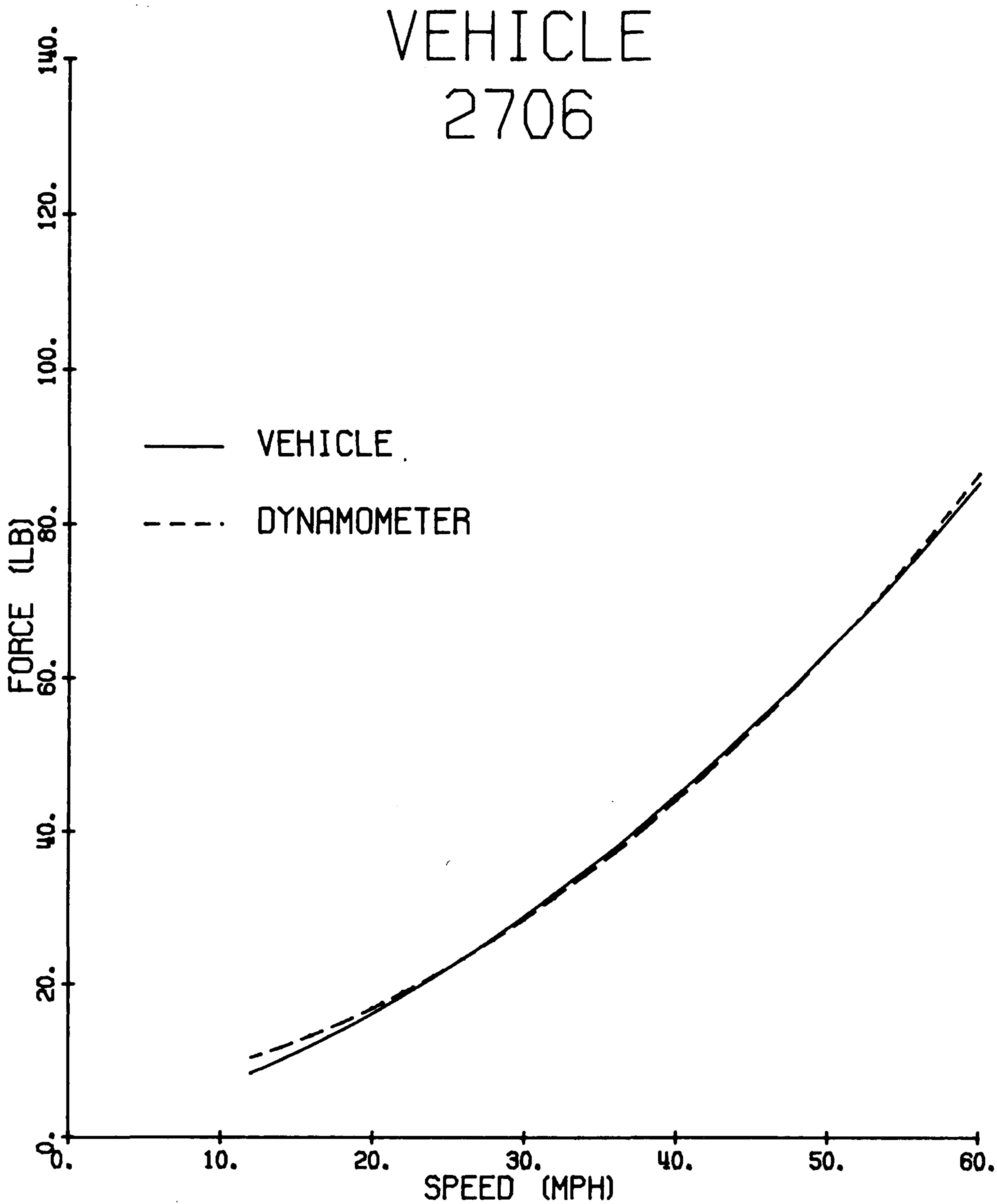
VEHICLE
2301
VEHICLE
DYNAMOMETER
FORCE (LB)
0.
20.
40.
60.
80.
100.
120.
140.
0.
10.
20.
30.
40.
50.
60.
SPEED (MPH)


VEHICLE
2401
VEHICLE
DYNAMOMETER
FORCE (LB)
0.
20.
40.
60.
80.
100.
120.
140.
0.
10.
20.
30.
40.
50.
60.
SPEED (MPH)

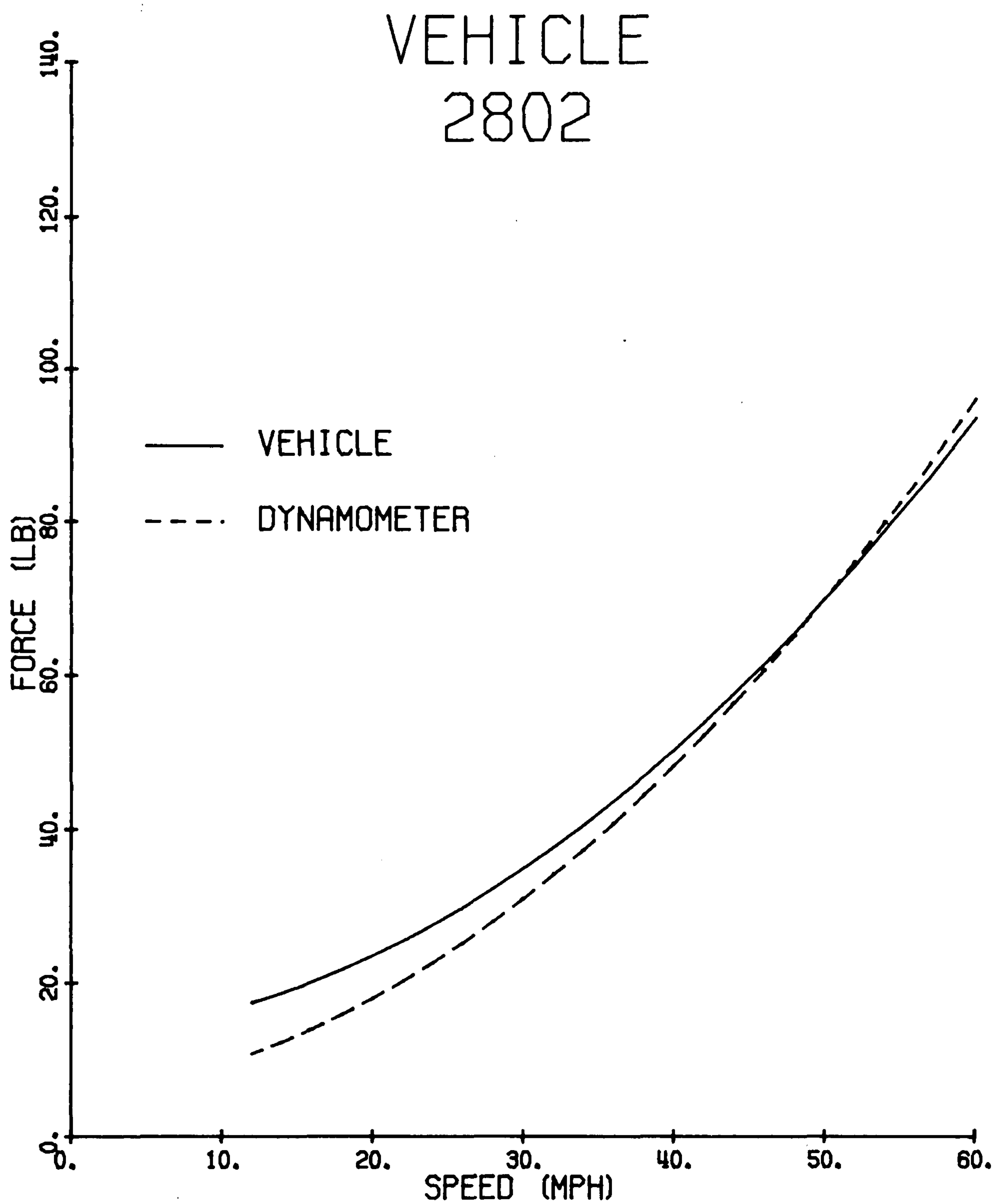


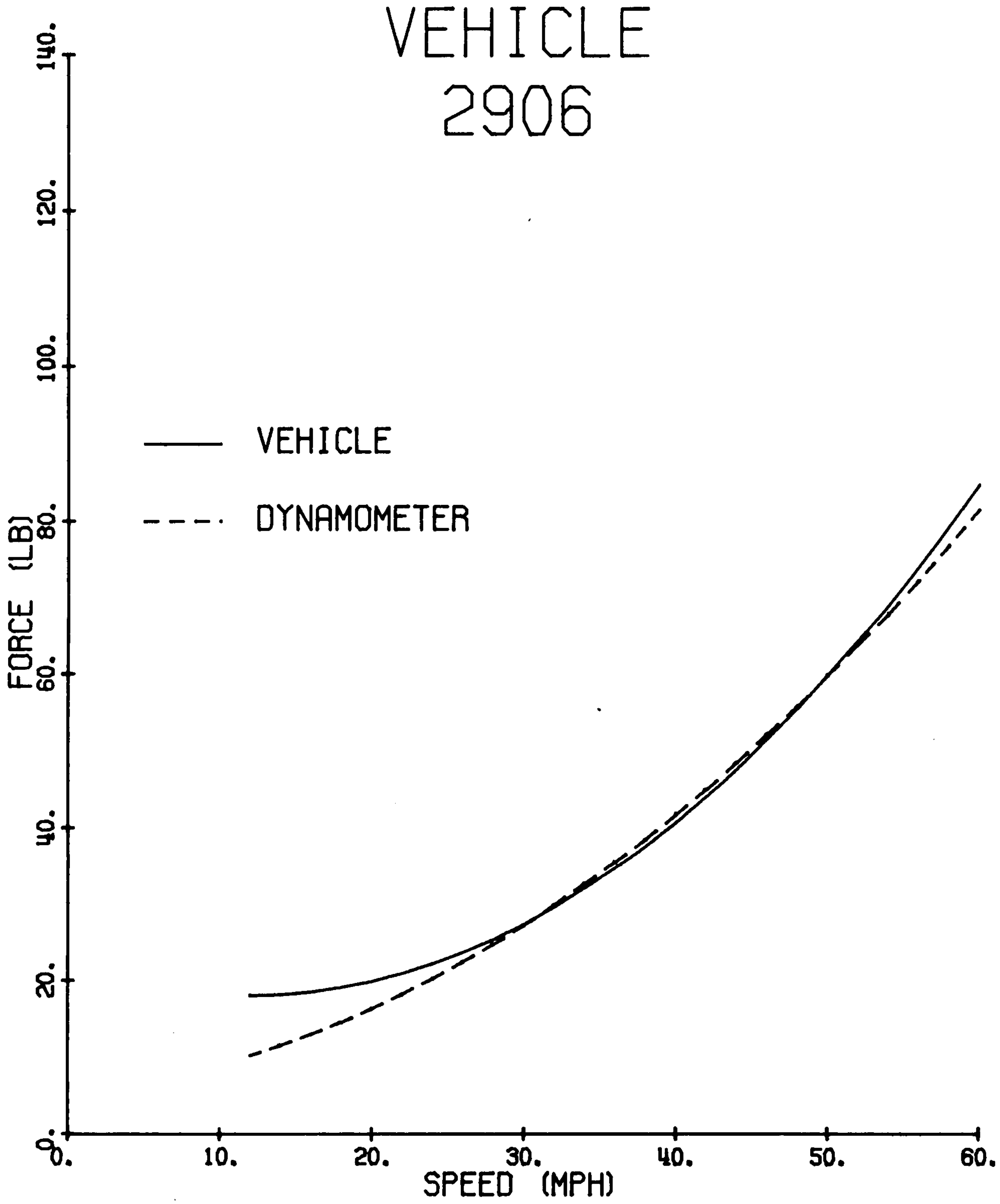
VEHICLE
2502
FORCE (LB)
0.
20.
40.
60.
80.
100.
120.
140.
SPEED (MPH)
0.
10.
20.
30.
40.
50.
60.
VEHICLE
DYNAMOMETER


VEHICLE
2602
VEHICLE
DYNAMOMETER
FORCE (LB)
140.
120.
100.
80.
60.
40.
20.
0.
0.
10.
20.
30.
40.
50.
60.
SPEED (MPH)

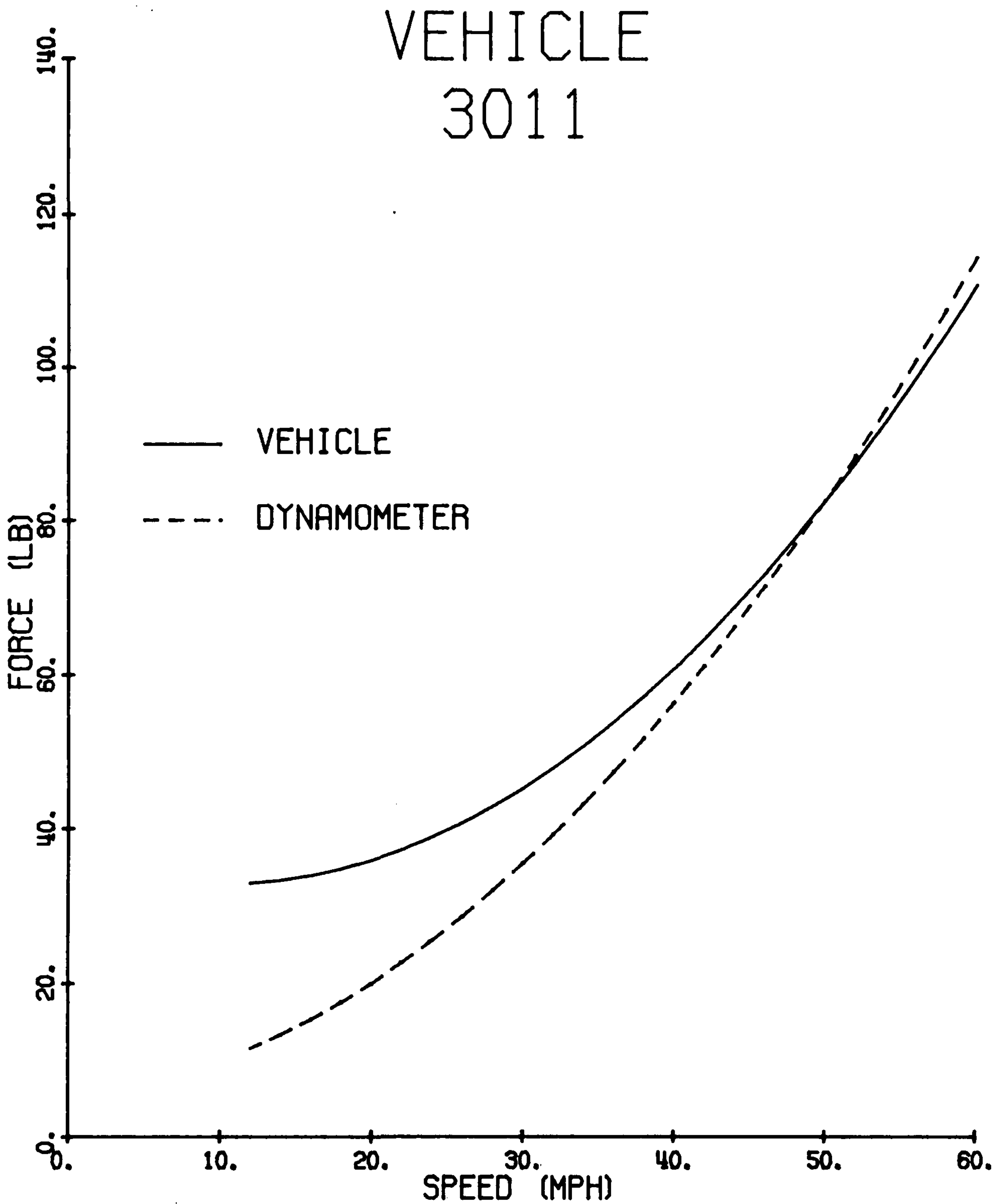


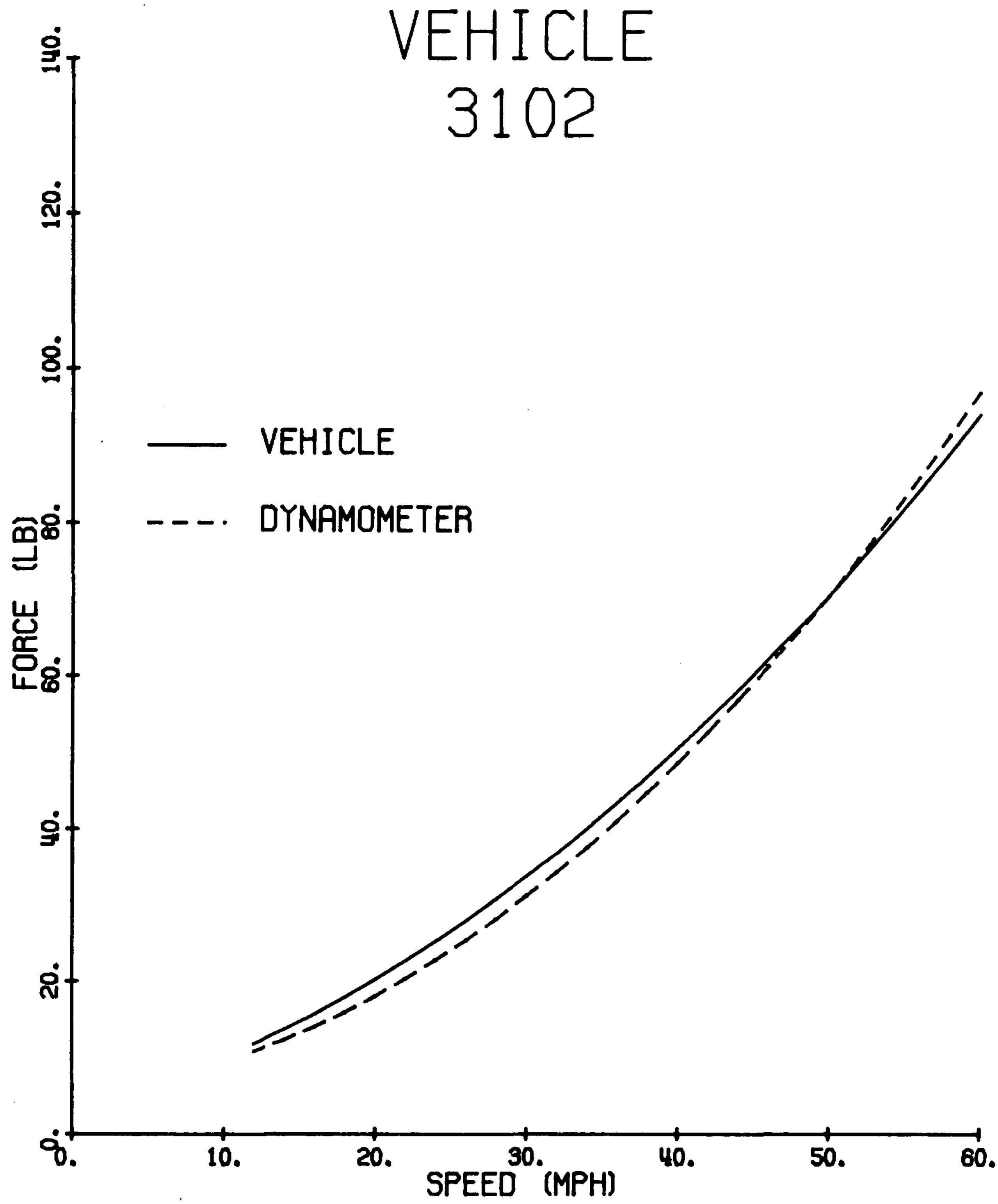
VEHICLE
2706
VEHICLE
DYNAMOMETER
FORCE (LB)
0.
20.
40.
60.
80.
100.
120.
140.
0.
10.
20.
30.
40.
50.
60.
SPEED (MPH)


VEHICLE
2802
VEHICLE
DYNAMOMETER
FORCE (LB)
0.
20.
40.
60.
80.
100.
120.
140.
0.
10.
20.
30.
40.
50.
60.
SPEED (MPH)

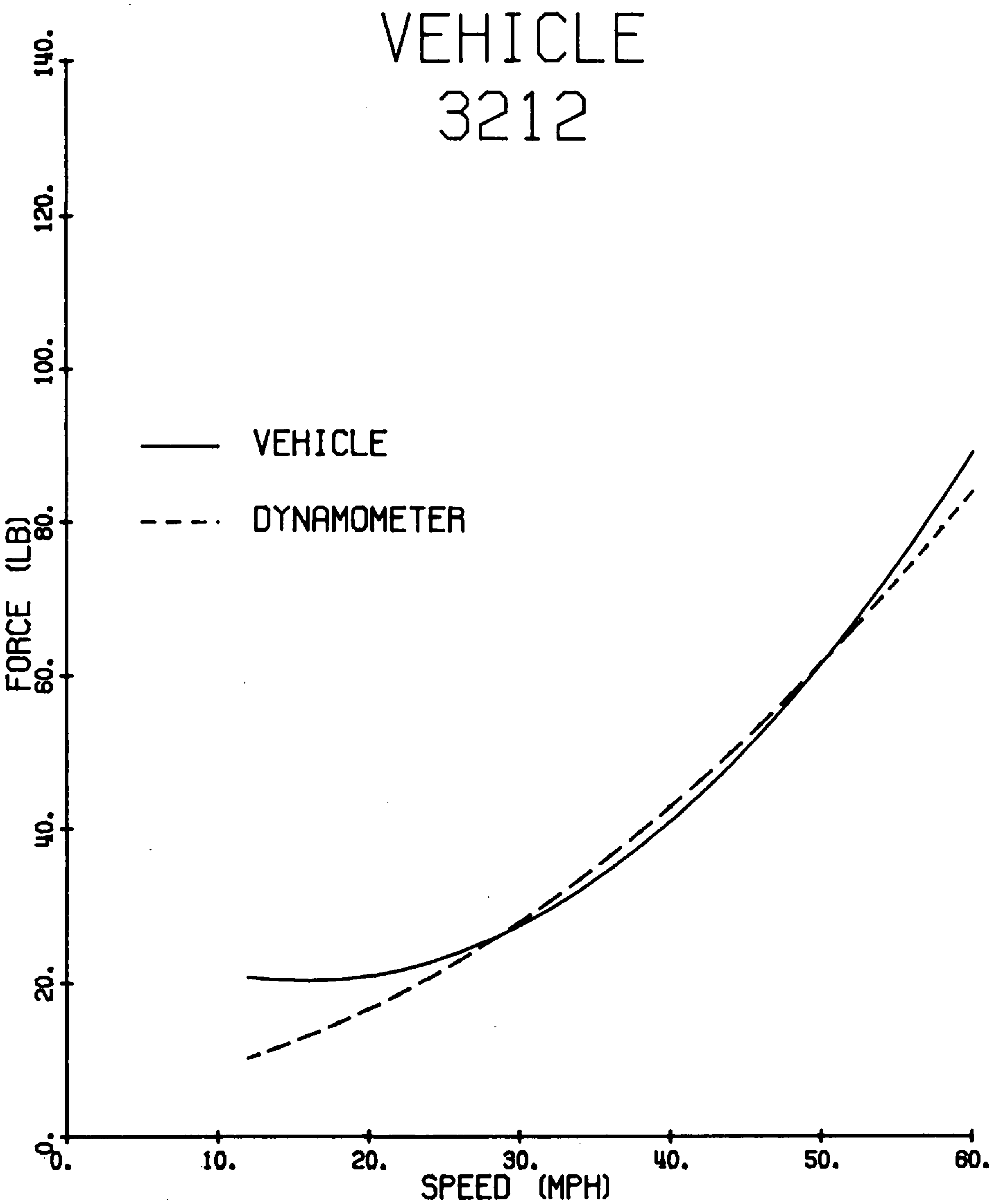


VEHICLE
2906
VEHICLE
DYNAMOMETER
FORCE (LB)
0.
20.
40.
60.
80.
100.
120.
140.
0.
10.
20.
30.
40.
50.
60.
SPEED (MPH)

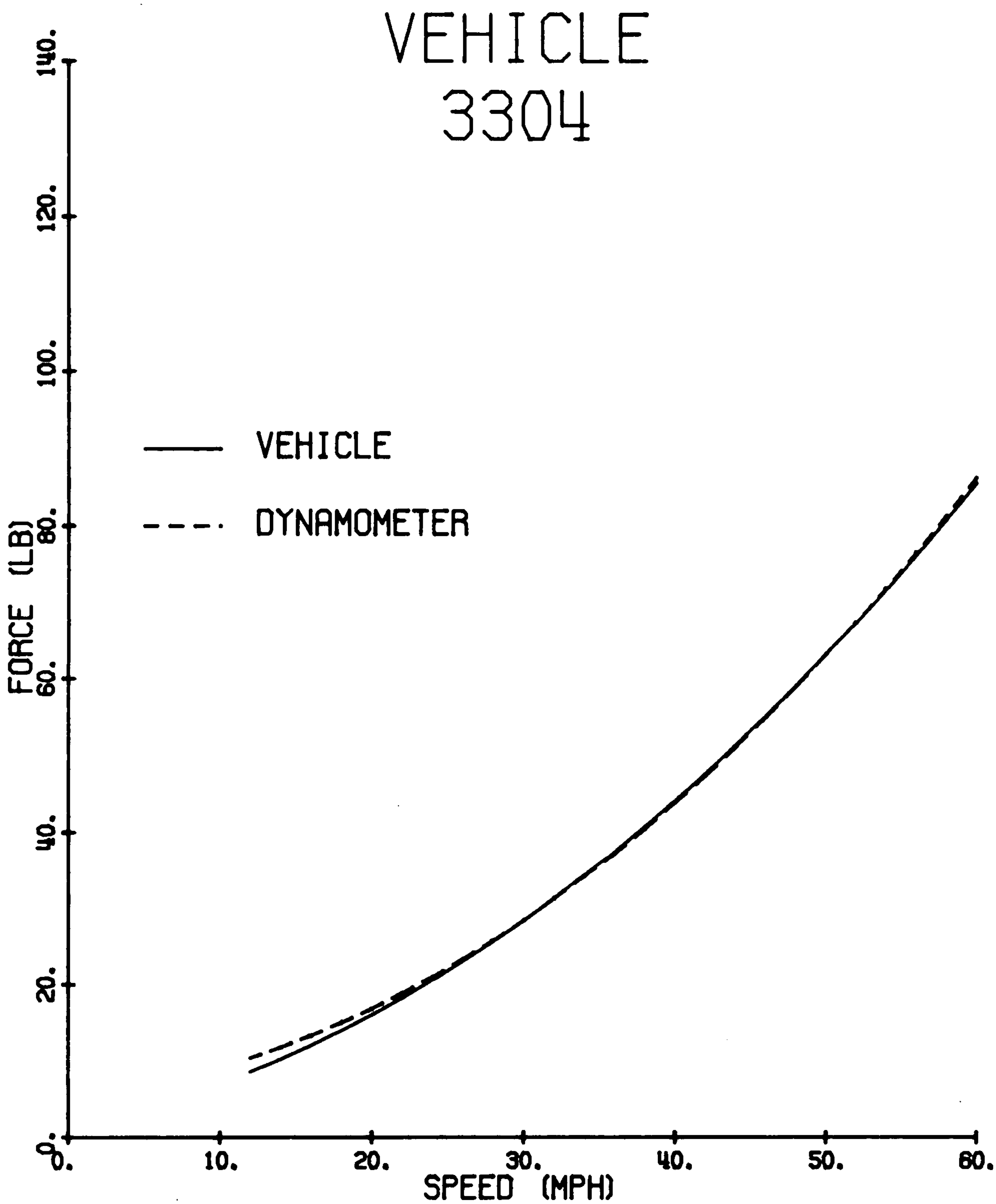

VEHICLE
3011
FORCE (LB)
0.
20.
40.
60.
80.
100.
120.
140.
0.
10.
20.
30.
40.
50.
60.
SPEED (MPH)
VEHICLE
DYNAMOMETER

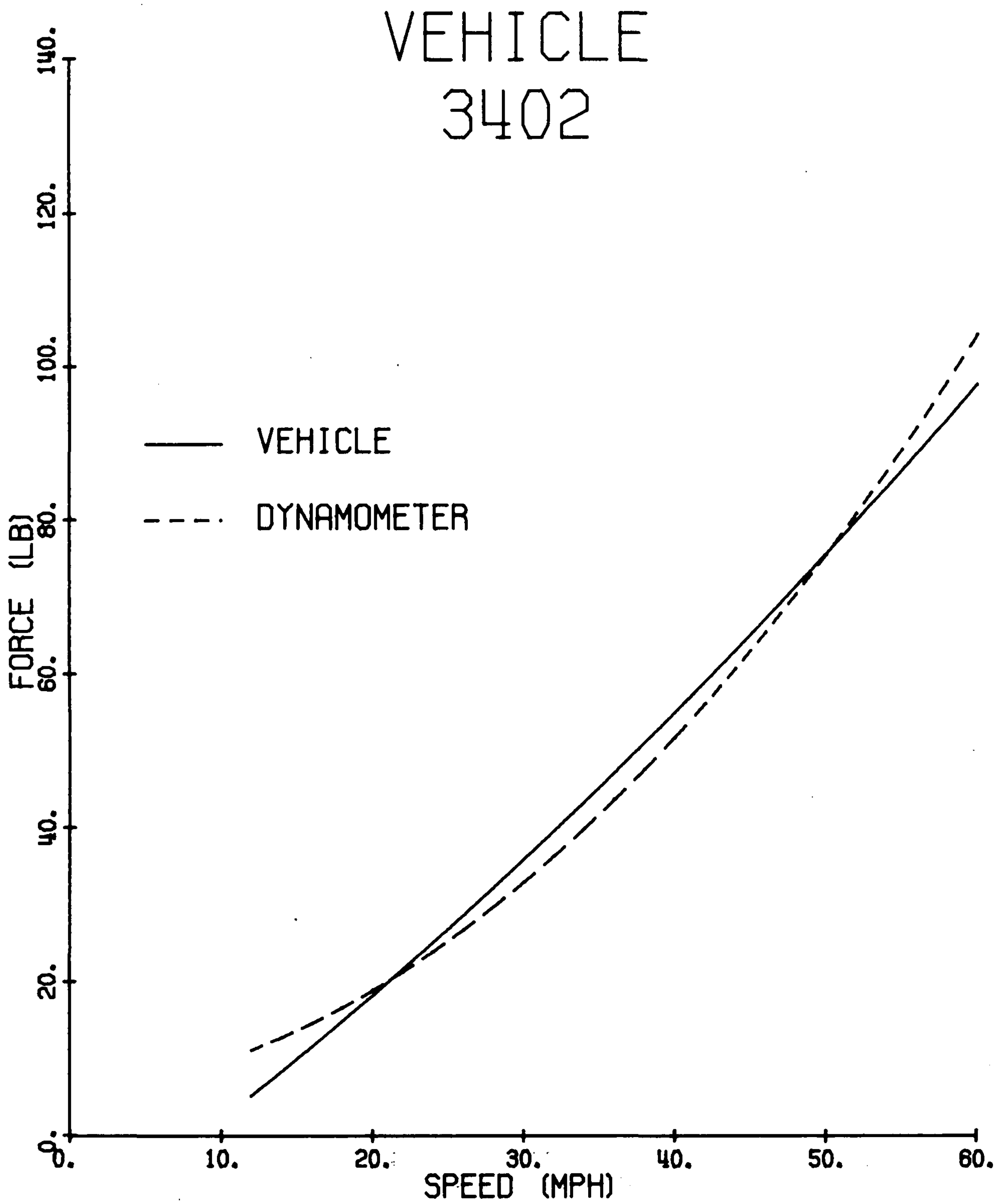


VEHICLE
3102
VEHICLE
DYNAMOMETER
FORCE (LB)
SPEED (MPH)
0.
20.
40.
60.
80.
100.
120.
140.
10.
30.
50.

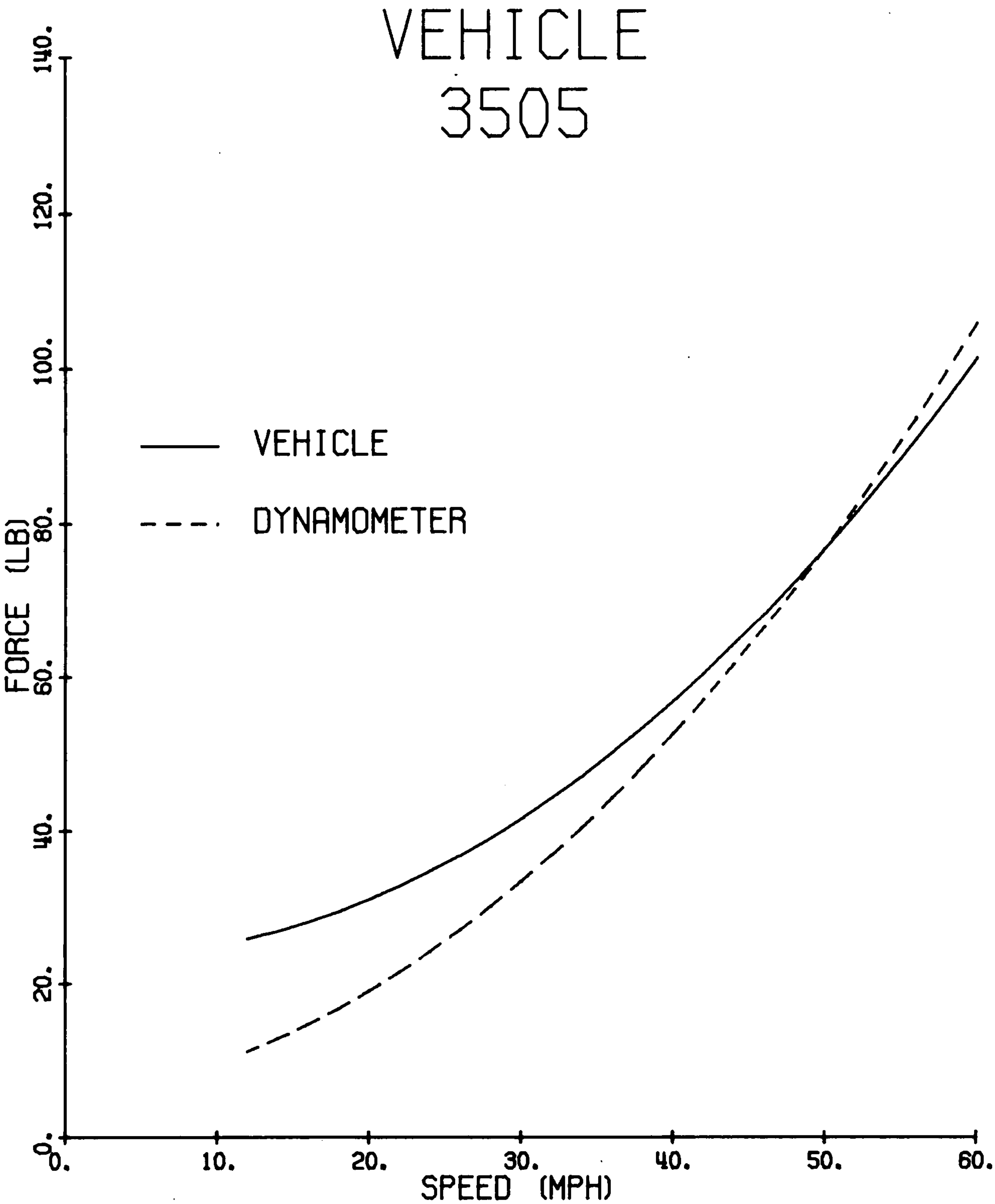


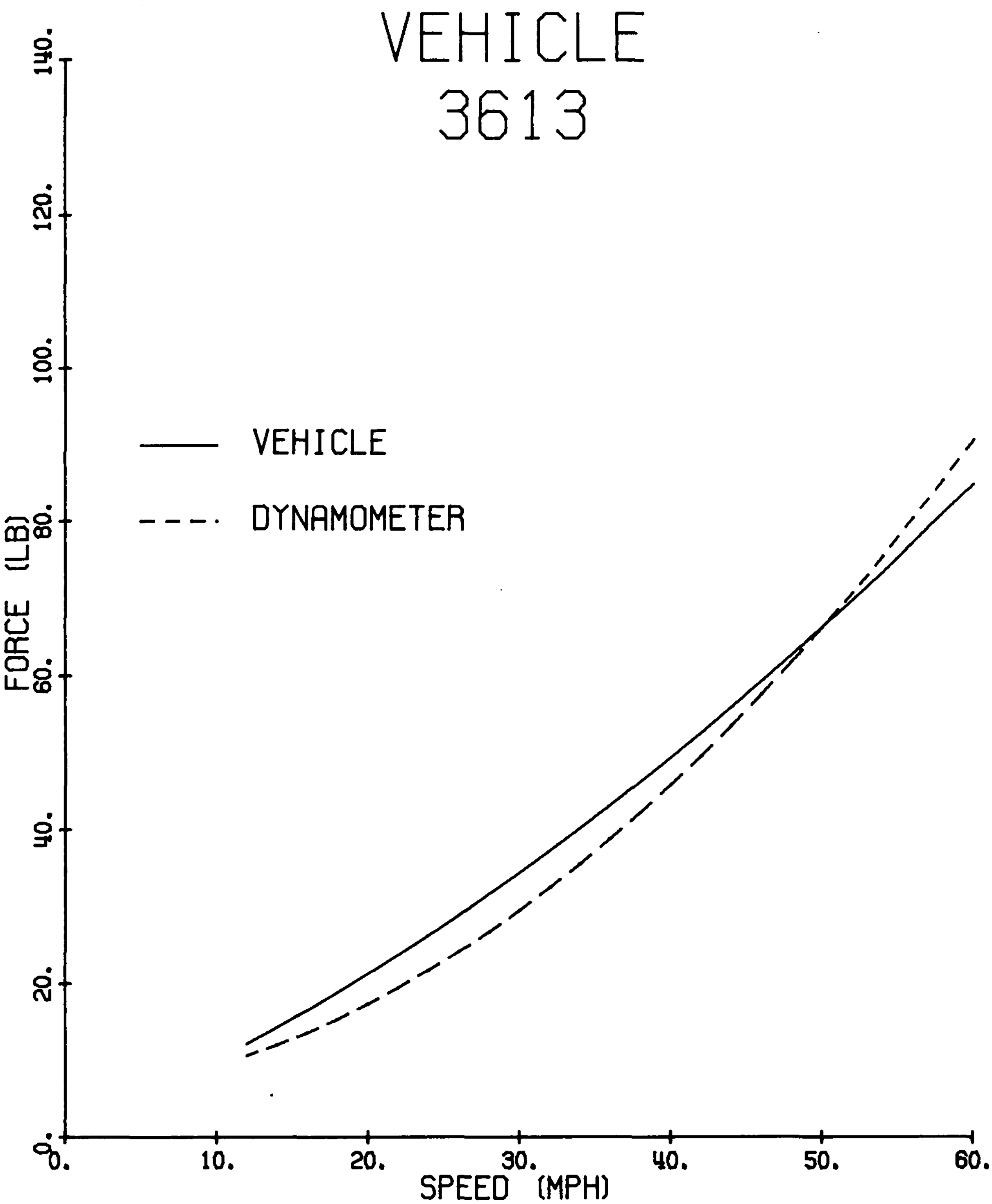
VEHICLE
3212
FORCE (LB)
0.
20.
40.
60.
80.
100.
120.
140.
0.
10.
20.
30.
40.
50.
60.
SPEED (MPH)
VEHICLE
DYNAMOMETER


VEHICLE
3304
VEHICLE
DYNAMOMETER
FORCE (LB)
0.
20.
40.
60.
80.
100.
120.
140.
0.
10.
20.
30.
40.
50.
60.
SPEED (MPH)

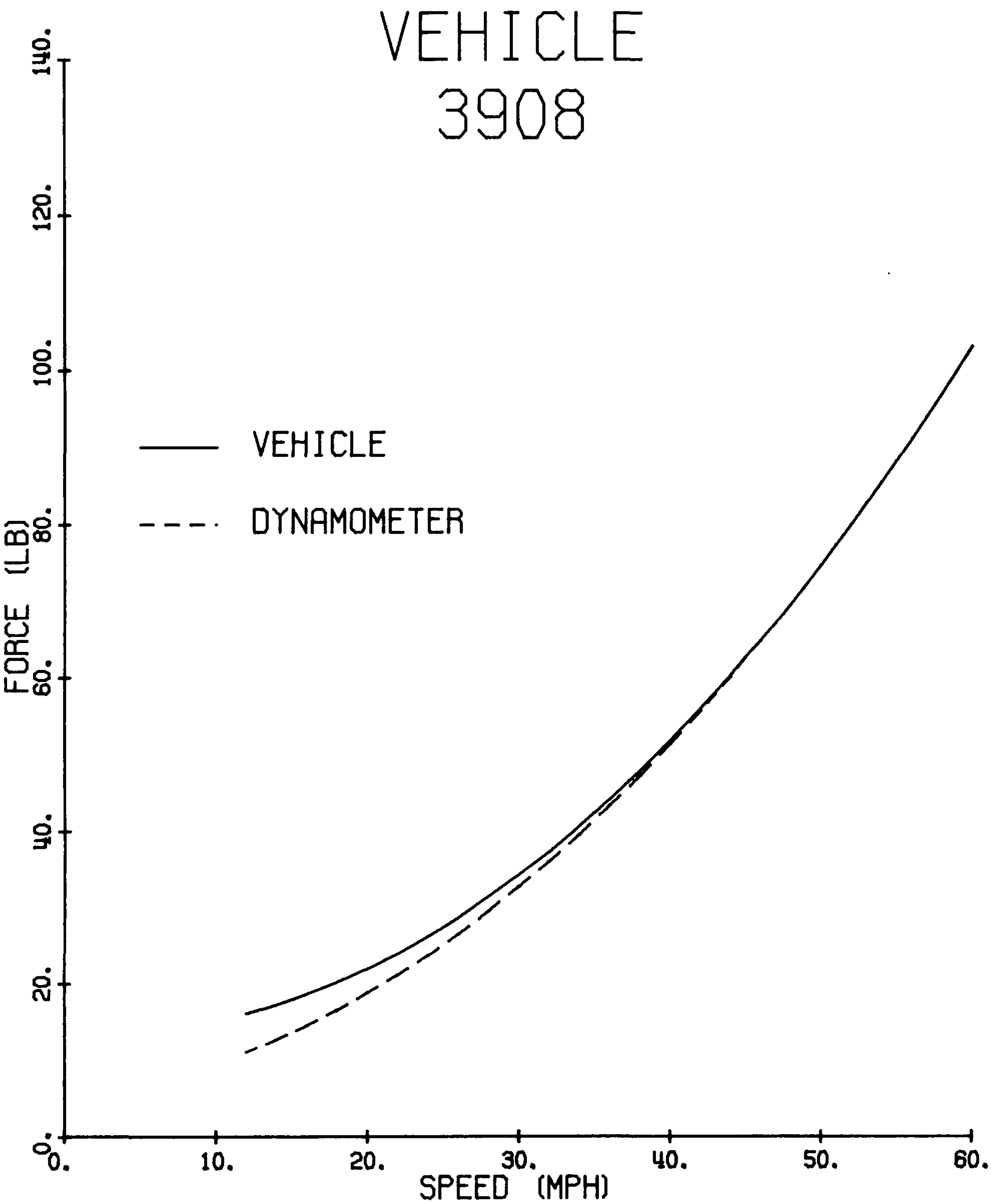


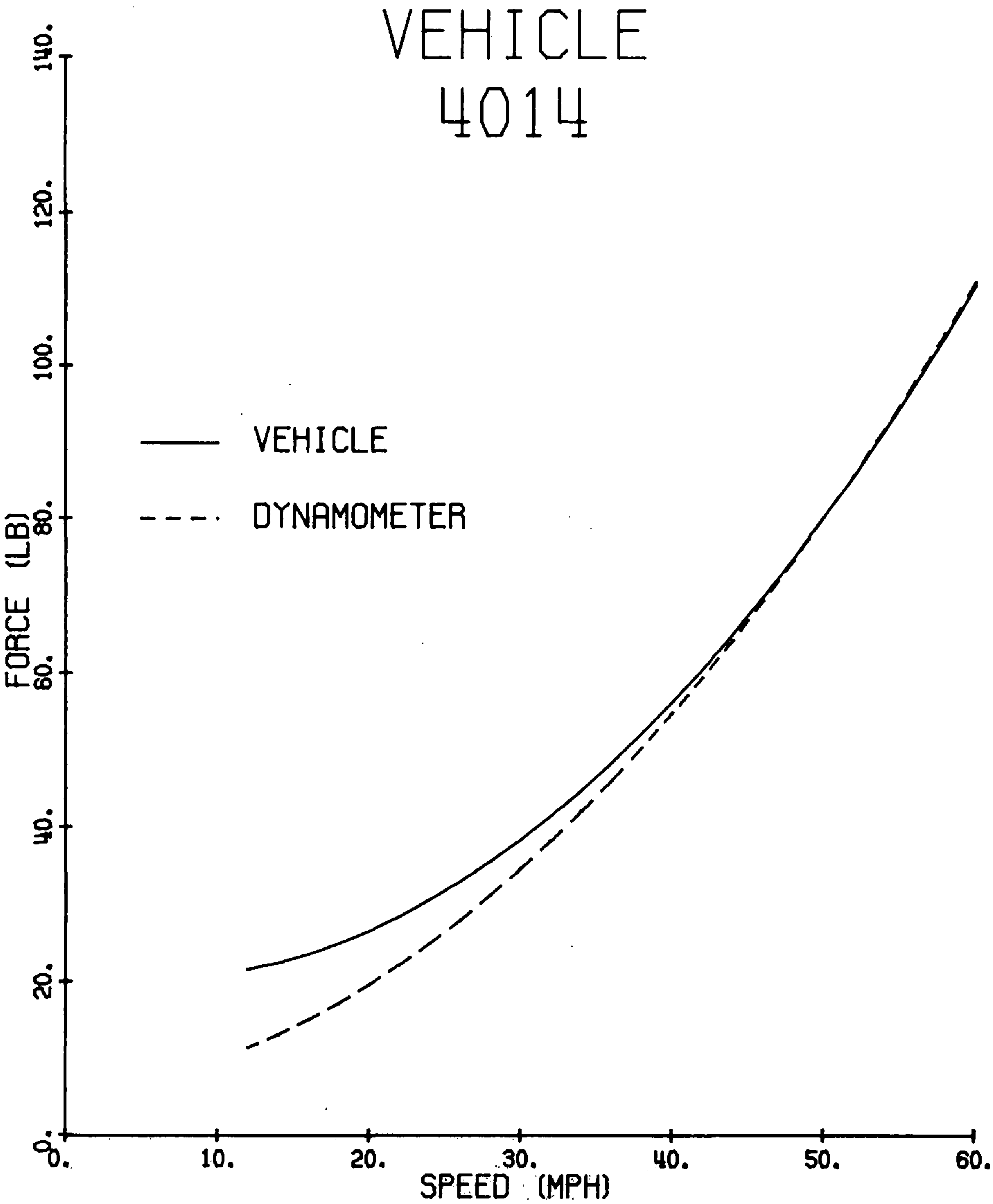
VEHICLE
3402
FORCE (LB)
0.
20.
40.
60.
80.
100.
120.
140.
0.
10.
20.
30.
40.
50.
60.
SPEED (MPH)
VEHICLE
DYNAMOMETER

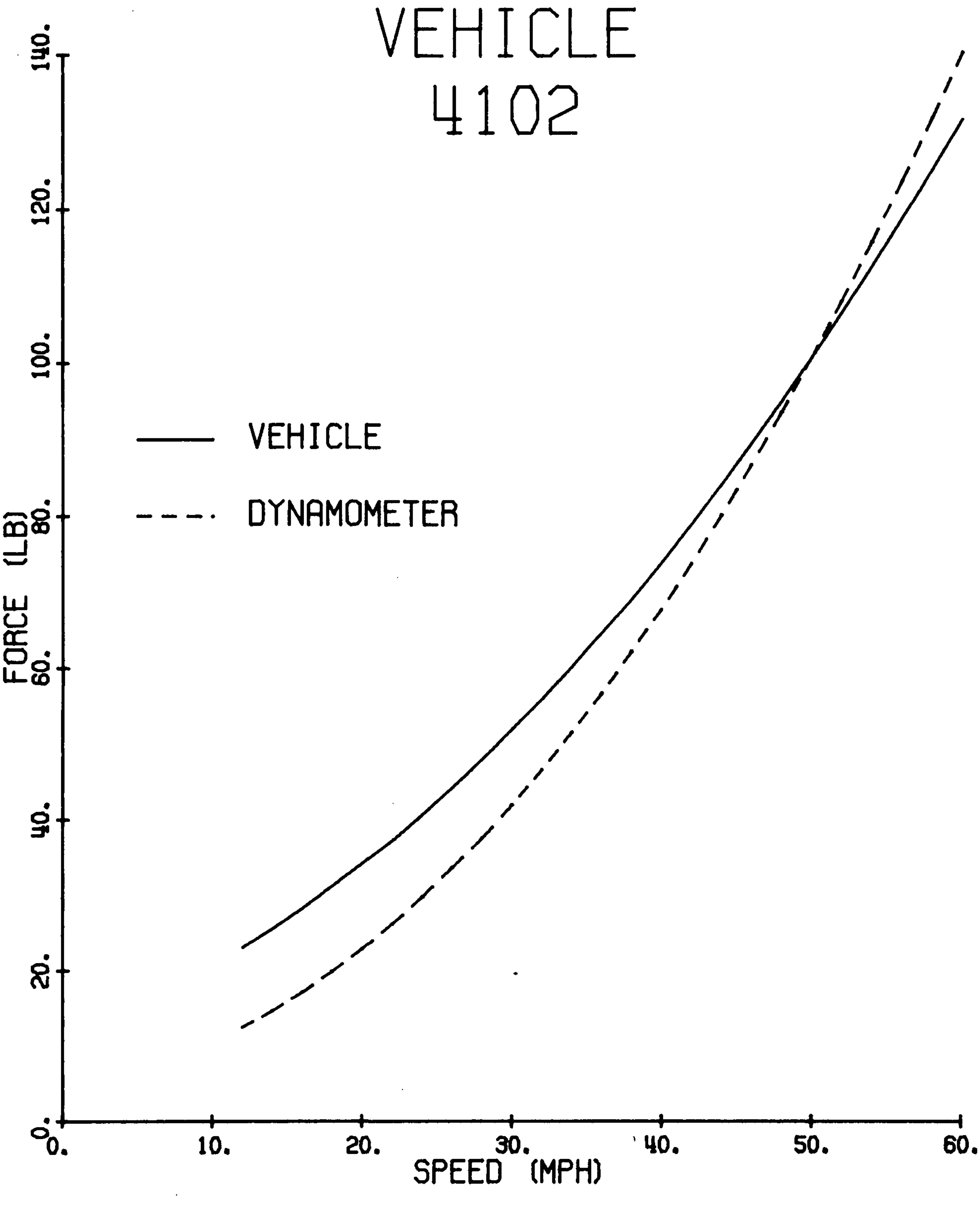

VEHICLE
3505
VEHICLE
DYNAMOMETER
FORCE (LB)
SPEED (MPH)
0.
20.
40.
60.
80.
100.
120.
140.
10.
30.
50.
60.



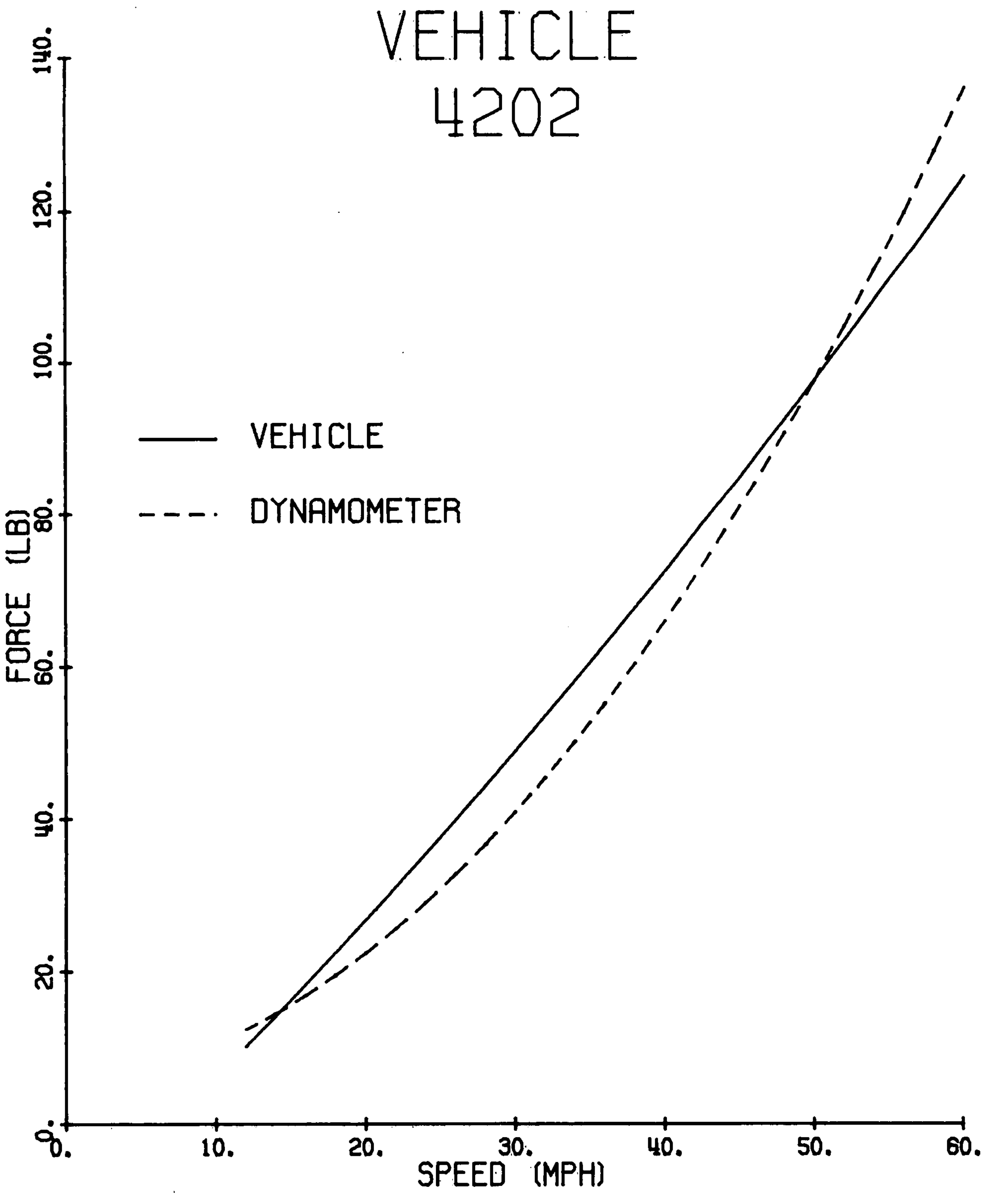
VEHICLE
3613
VEHICLE
DYNAMOMETER
FORCE (LB)
SPEED (MPH)
0.
20.
40.
60.
80.
100.
120.
140.
0.
10.
20.
30.
40.
50.
60.

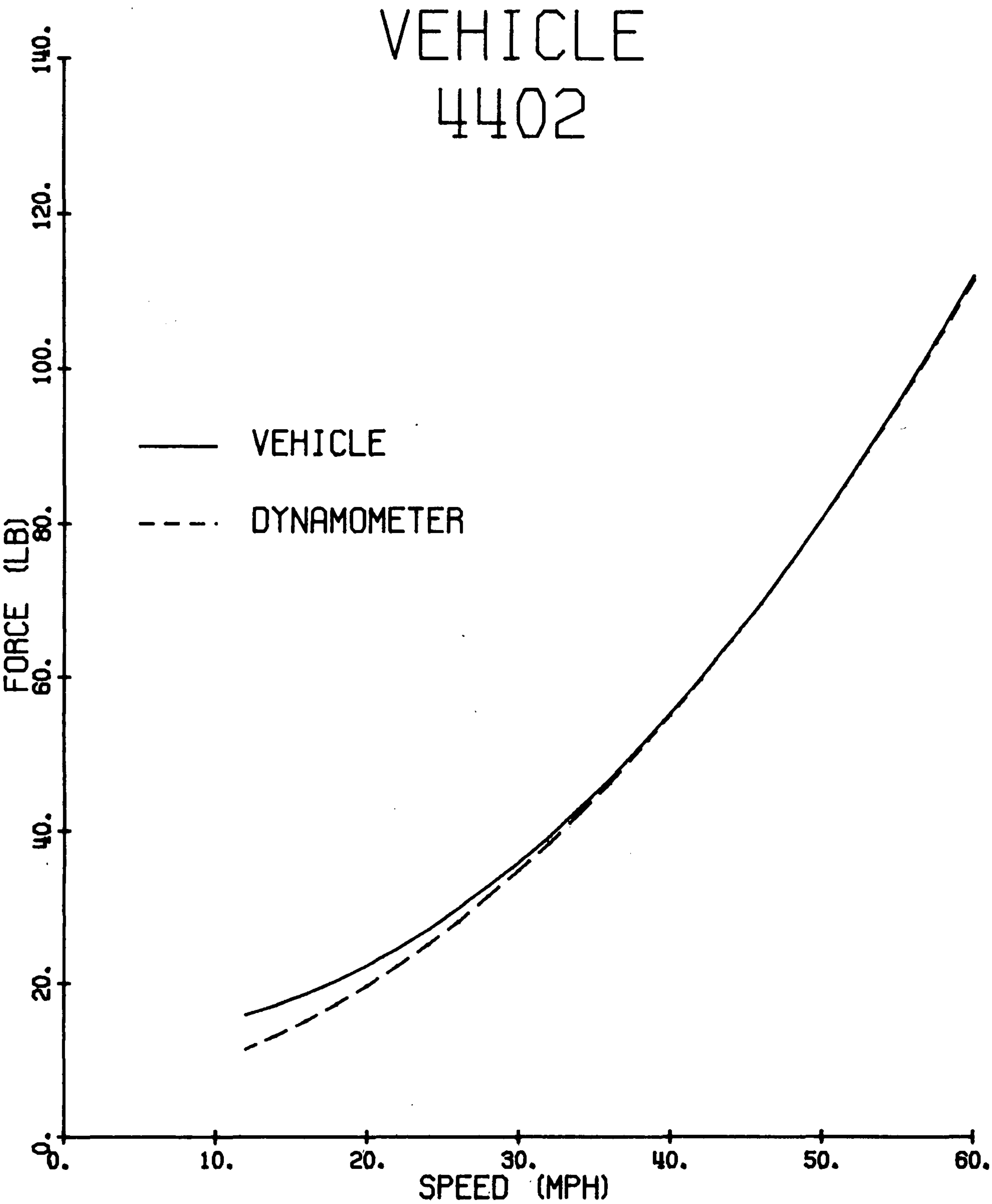

VEHICLE
3908
VEHICLE
DYNAMOMETER
FORCE (LB)
SPEED (MPH)
0.
20.
40.
60.
80.
100.
120.
140.
0.
10.
20.
30.
40.
50.
60.

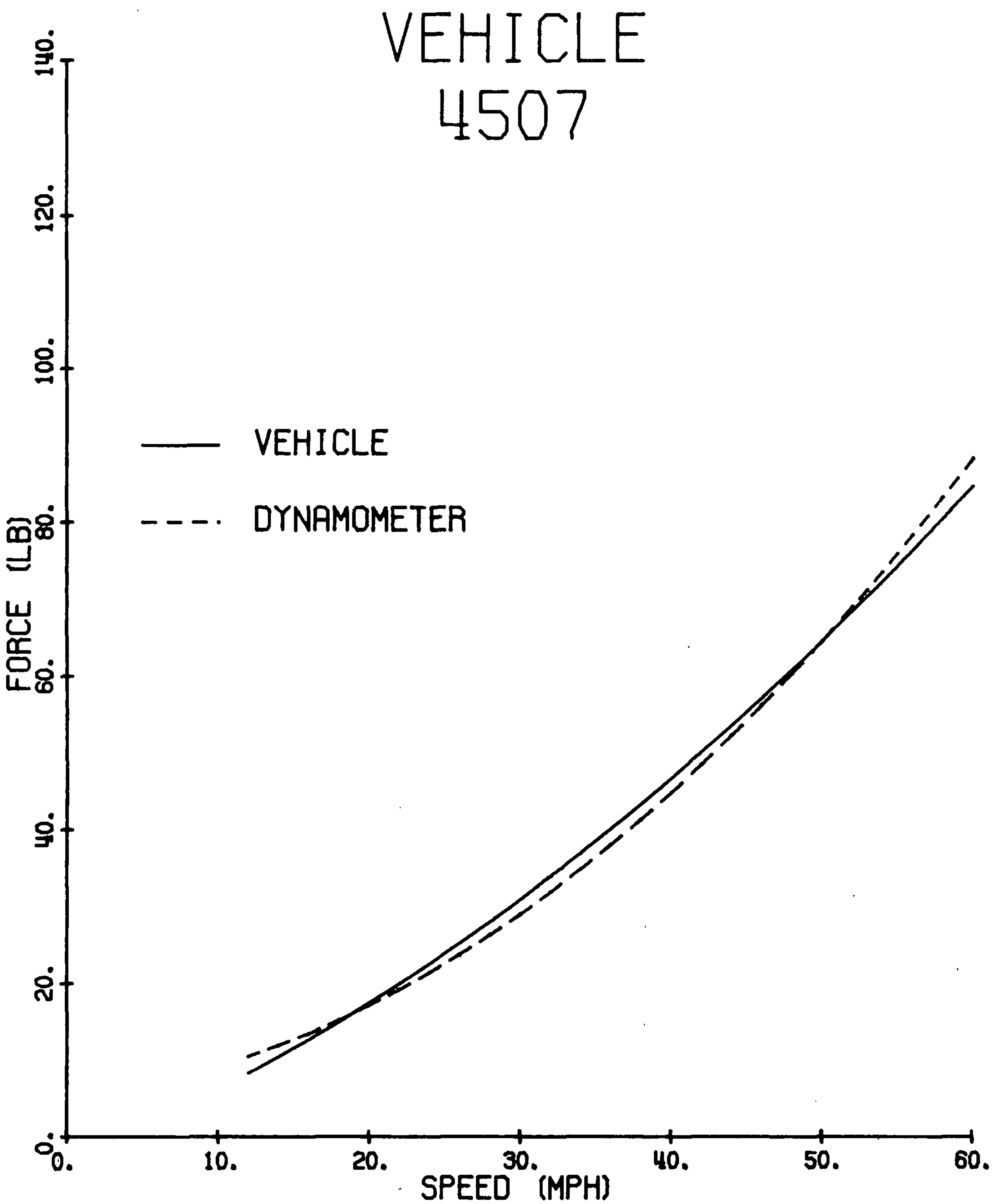

VEHICLE
4014
VEHICLE
DYNAMOMETER
FORCE (LB)
SPEED (MPH)
0.
20.
40.
60.
80.
100.
120.
140.
0.
10.
20.
30.
40.
50.
60.



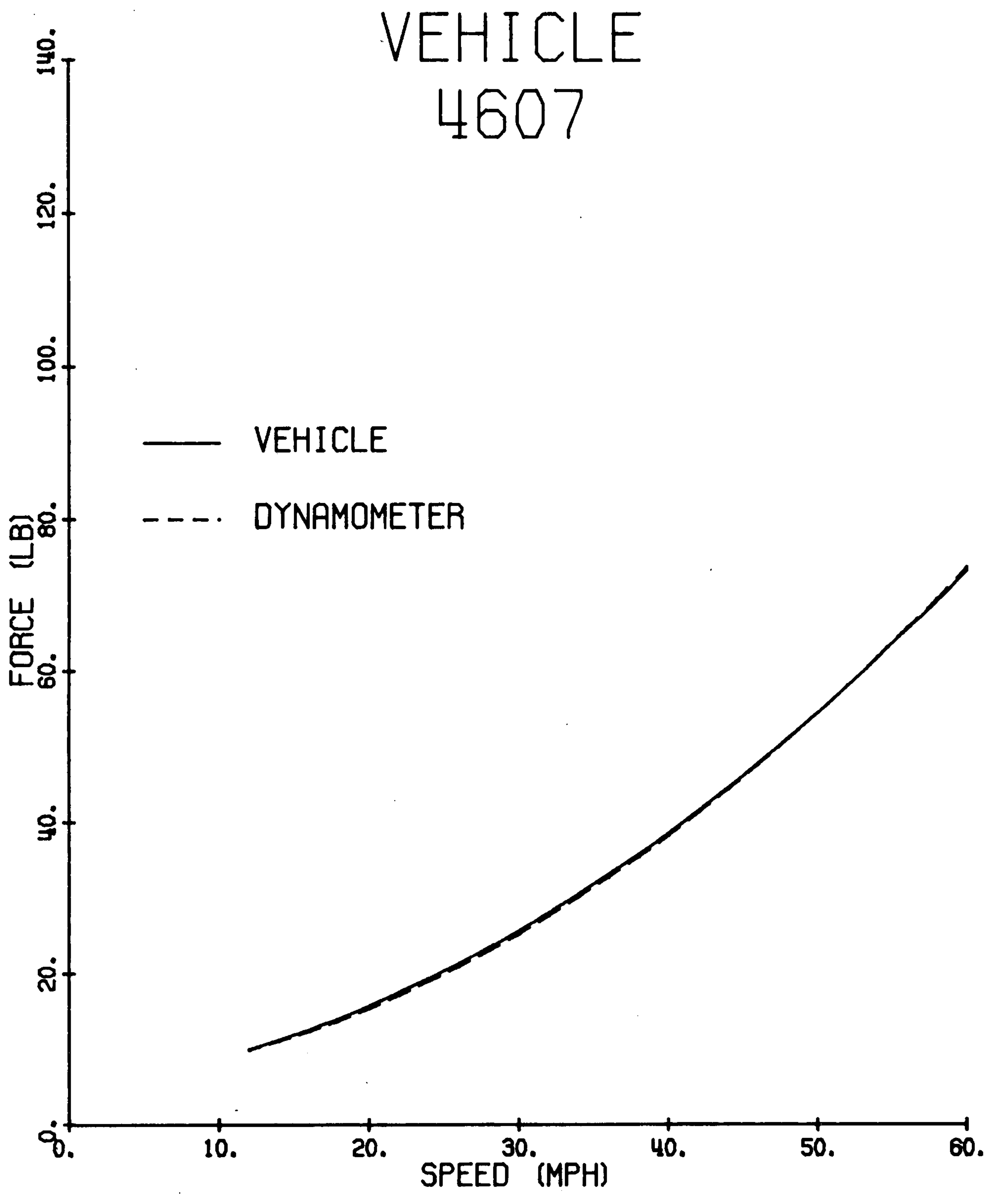
VEHICLE
4102
VEHICLE
DYNAMOMETER
FORCE (LB)
0.
20.
40.
60.
80.
100.
120.
140.
0.
10.
20.
30.
40.
50.
60.
SPEED (MPH)

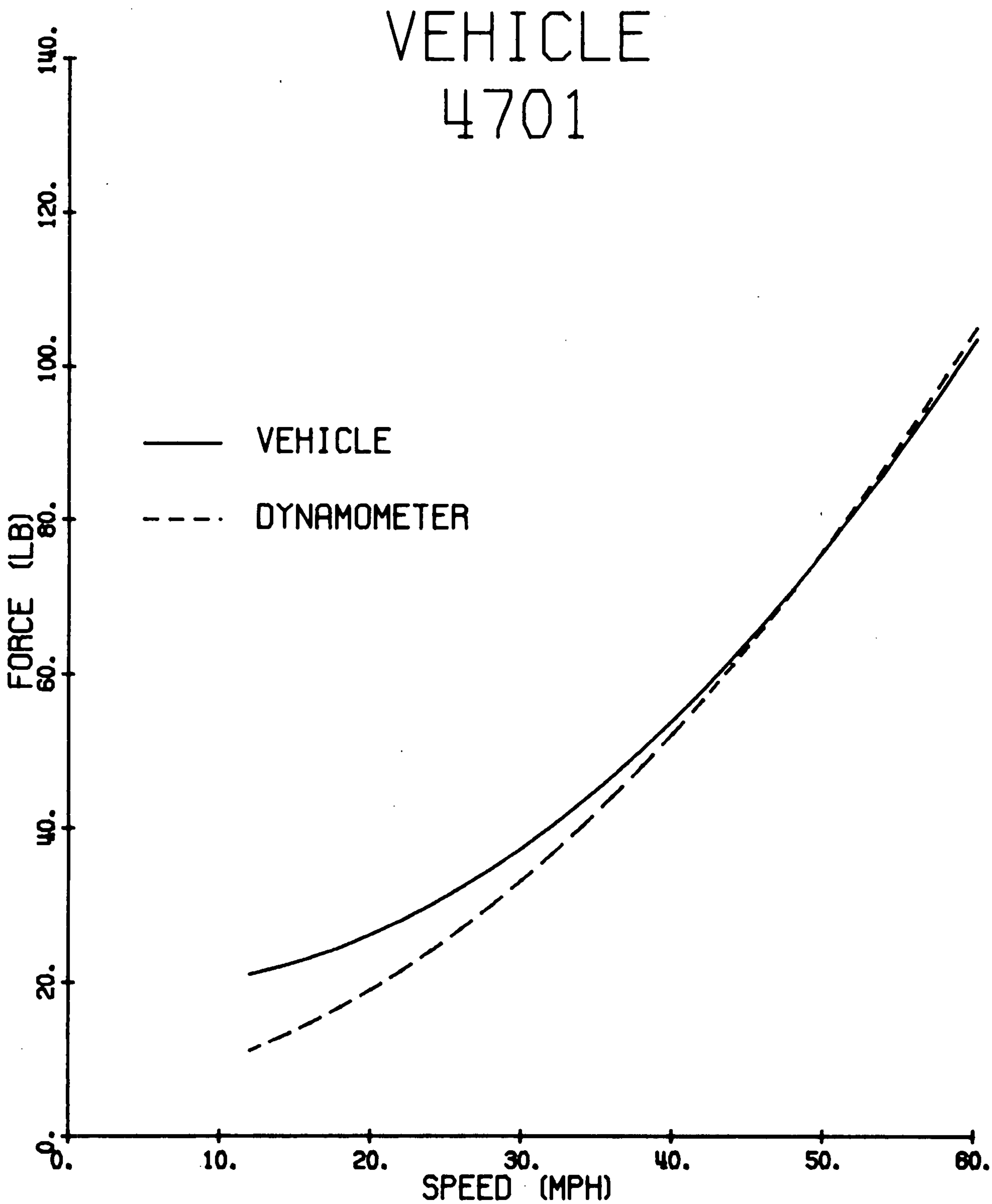

VEHICLE
4202
VEHICLE
DYNAMOMETER
FORCE (LB)
0.
20.
40.
60.
80.
100.
120.
140.
0.
10.
20.
30.
40.
50.
60.
SPEED (MPH)


VEHICLE
4402
140.
120.
100.
80.
60.
40.
20.
0.
FORCE (LB)
VEHICLE
DYNAMOMETER
0.
10.
20.
30.
40.
50.
60.
SPEED (MPH)

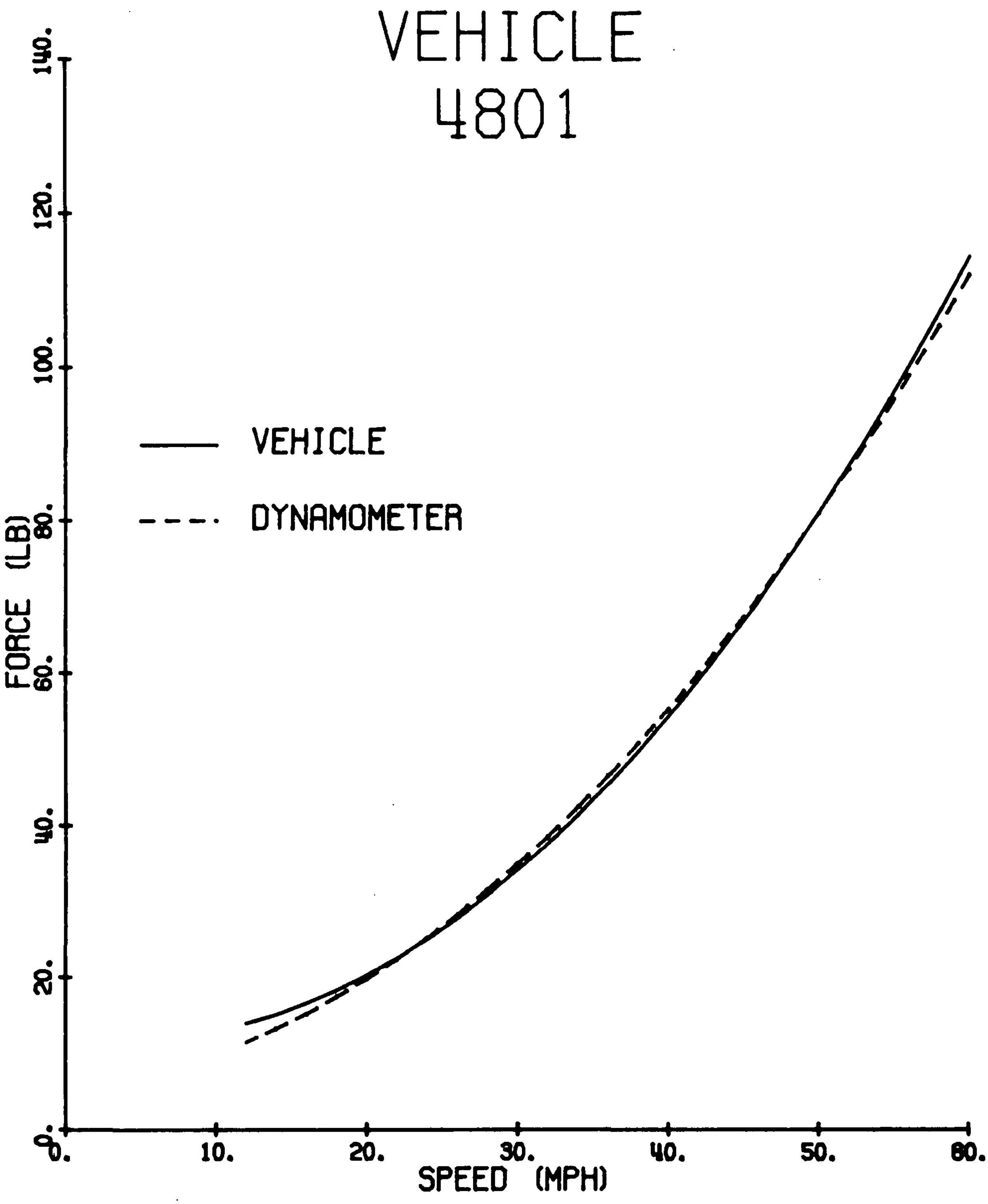


VEHICLE
4507
VEHICLE
DYNAMOMETER
FORCE (LB)
0.
20.
40.
60.
80.
100.
120.
140.
0.
10.
20.
30.
40.
50.
60.
SPEED (MPH)

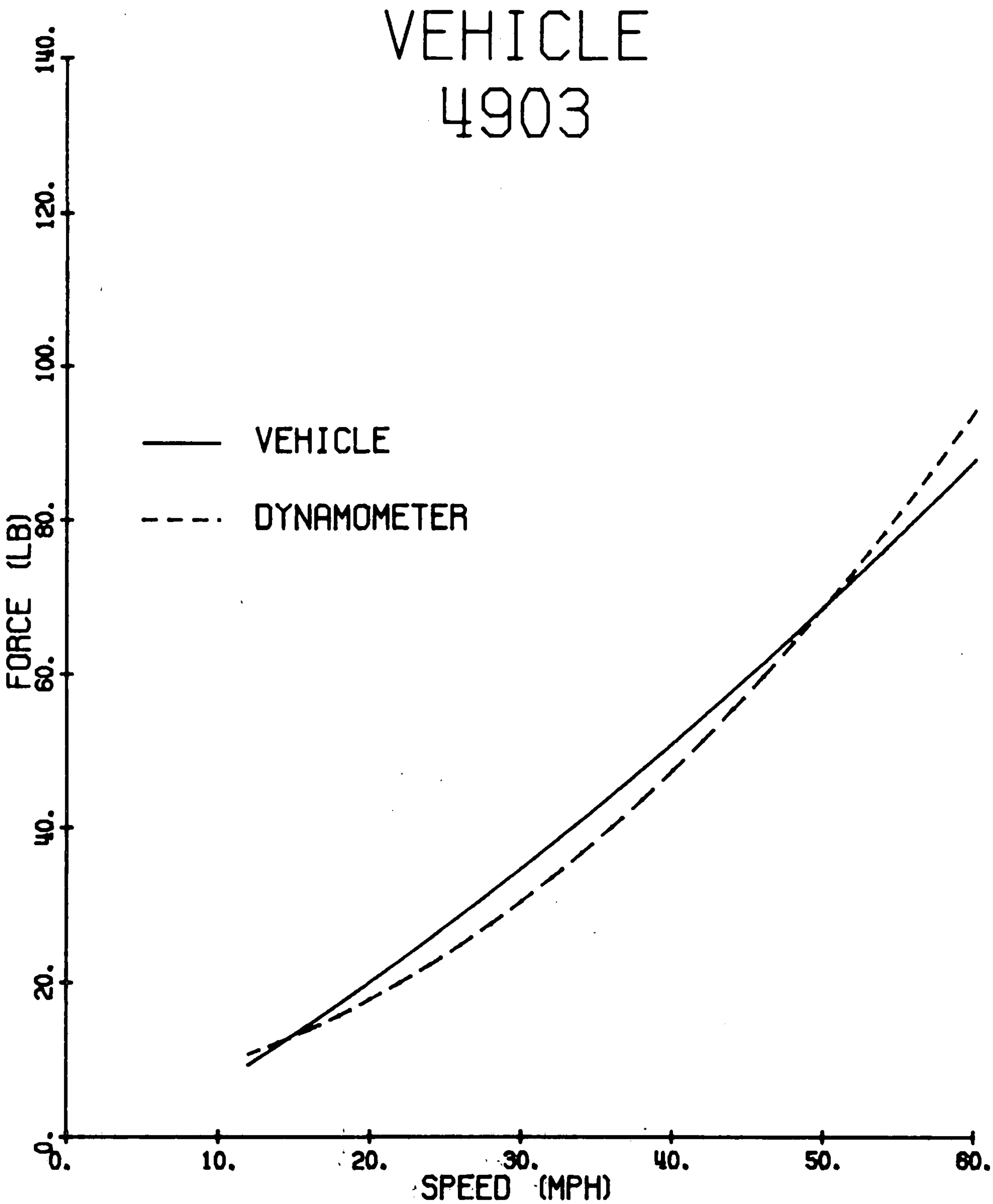

VEHICLE
4607
VEHICLE
DYNAMOMETER
FORCE (LB)
0.
20.
40.
60.
80.
100.
120.
140.
0.
10.
20.
30.
40.
50.
60.
SPEED (MPH)



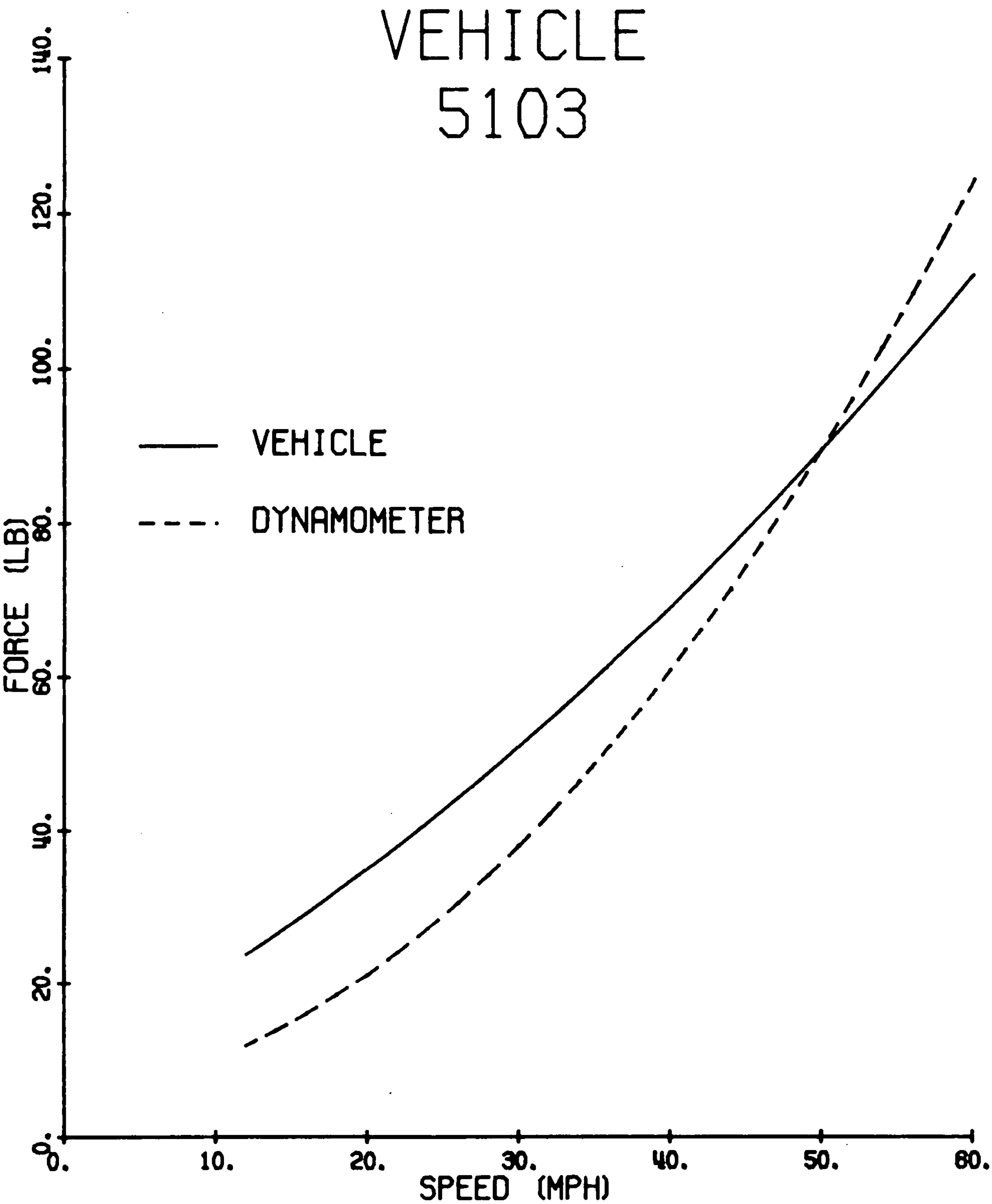
VEHICLE
4701
FORCE (LB)
140.
120.
100.
80.
60.
40.
20.
0.
VEHICLE
DYNAMOMETER
0.
10.
20.
30.
40.
50.
60.
SPEED (MPH)

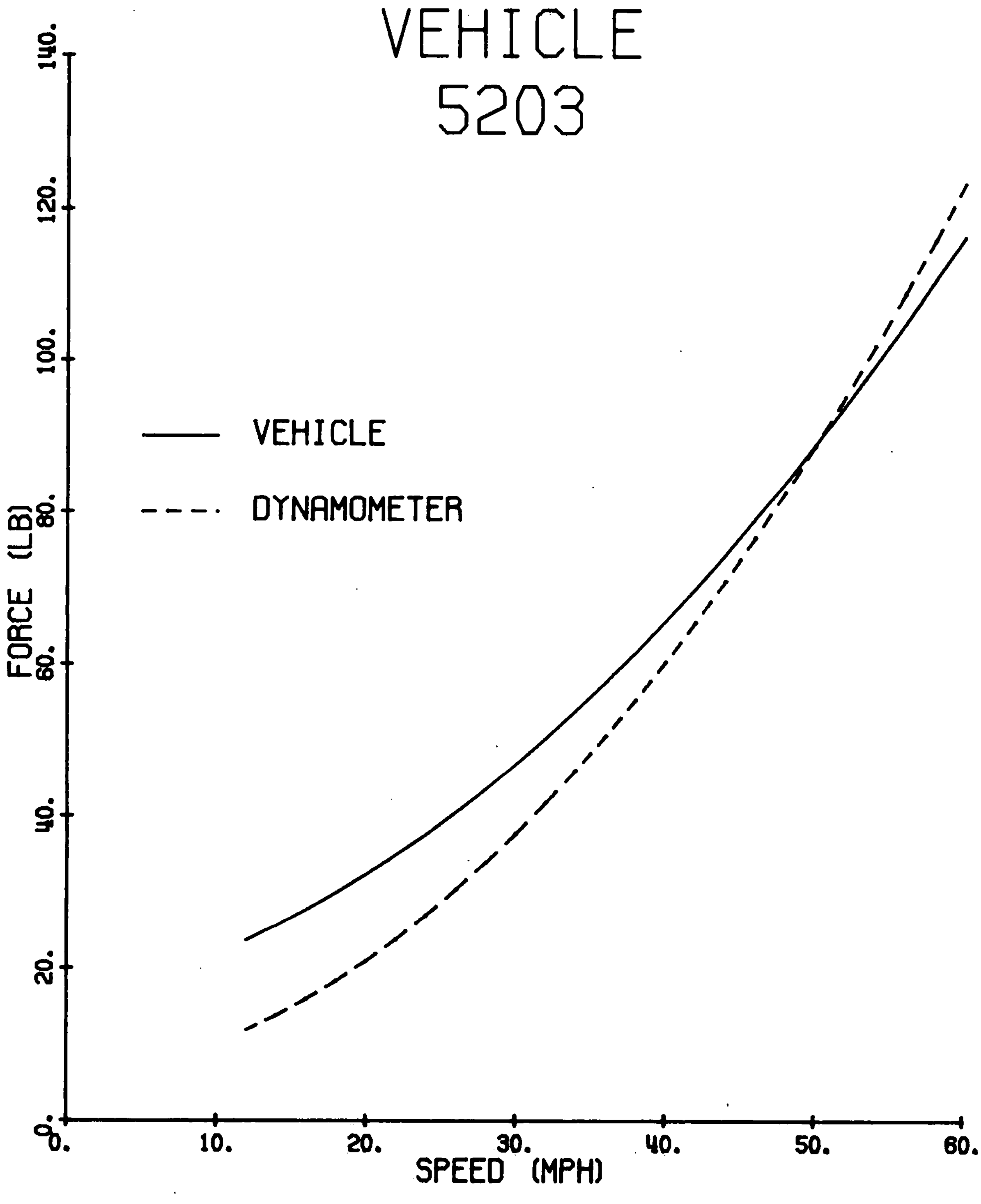


VEHICLE
4801
VEHICLE
DYNAMOMETER
FORCE (LB)
SPEED (MPH)
0.
20.
40.
60.
80.
100.
120.
140.
0.
10.
20.
30.
40.
50.
60.

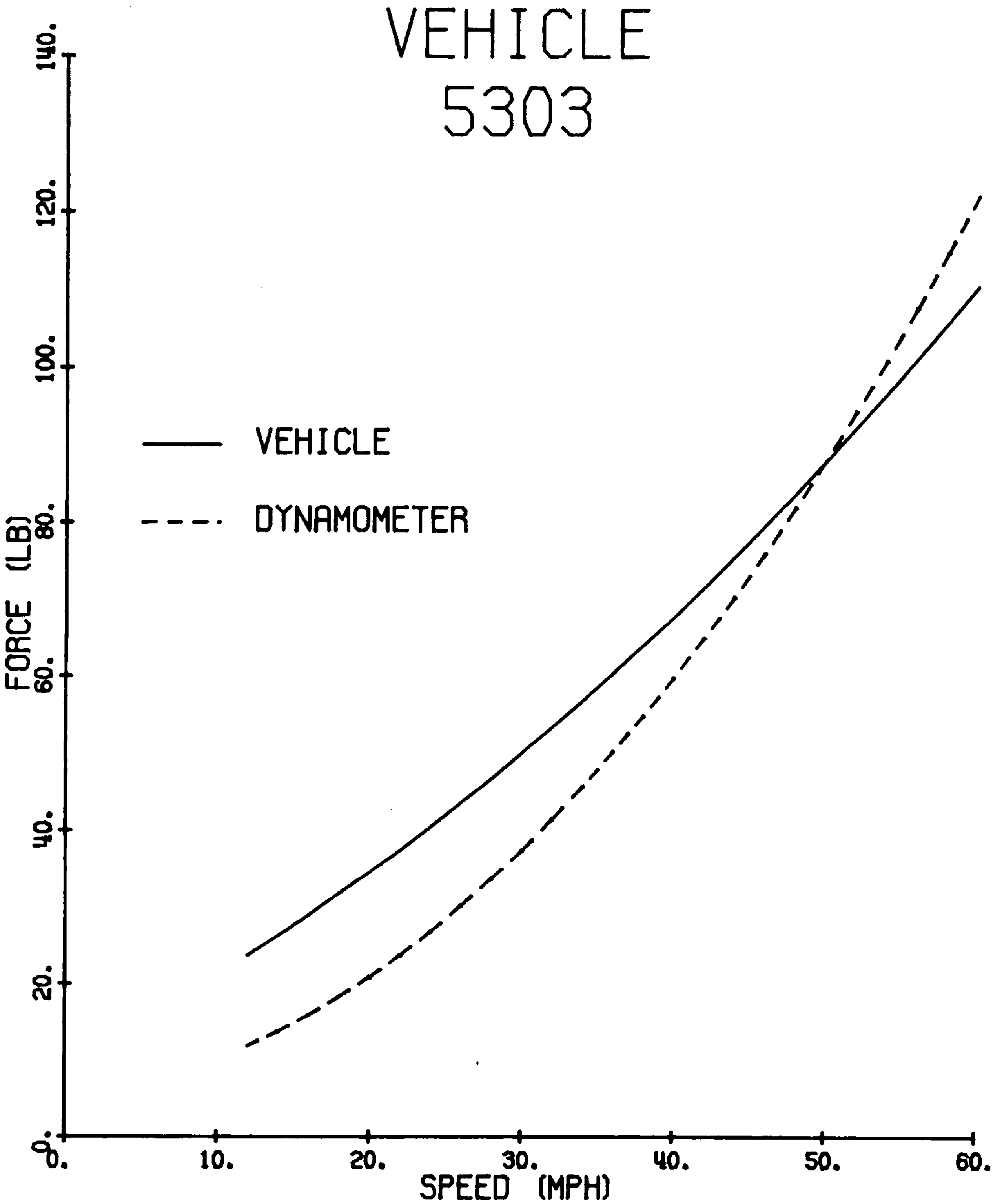


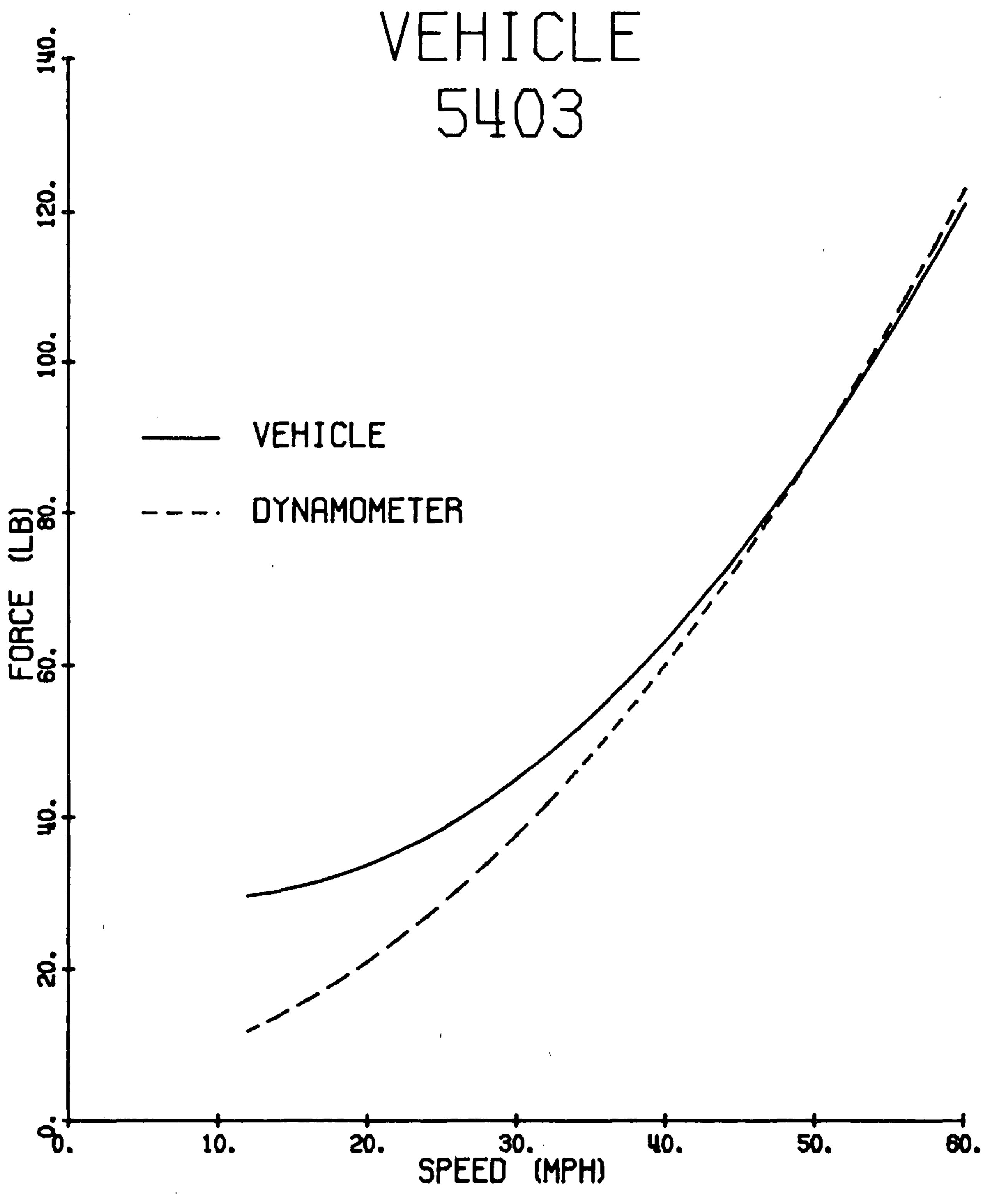
VEHICLE
4903
VEHICLE
DYNAMOMETER
FORCE (LB)
SPEED (MPH)
0.
20.
40.
60.
80.
100.
120.
140.
0.
10.
20.
30.
40.
50.
60.


VEHICLE
5103
VEHICLE
DYNAMOMETER
FORCE (LB)
SPEED (MPH)
0.
20.
40.
60.
80.
100.
120.
140.
0.
10.
20.
30.
40.
50.
60.

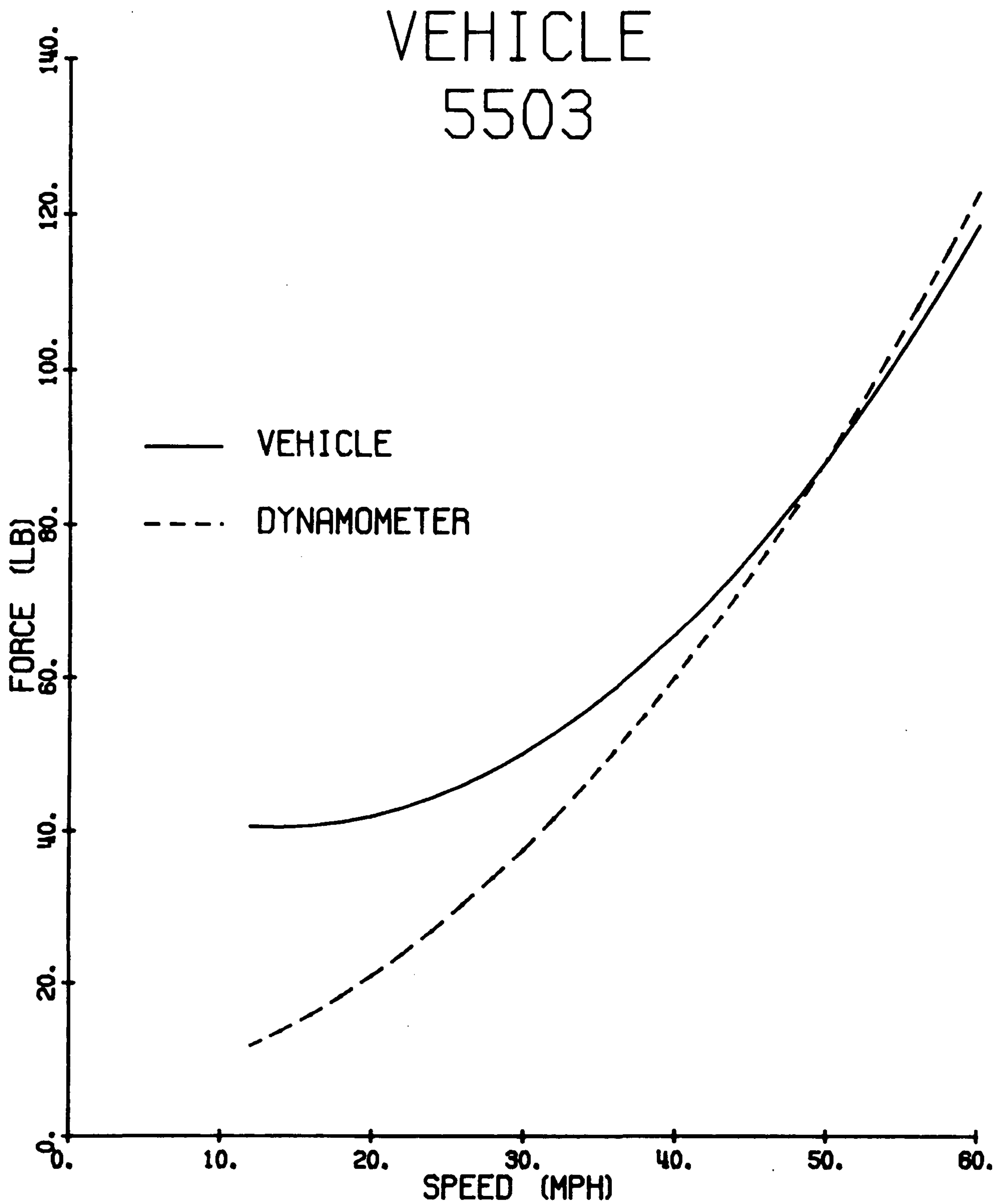


VEHICLE
5203
VEHICLE
DYNAMOMETER
FORCE (LB)
SPEED (MPH)
0.
20.
40.
60.
80.
100.
120.
140.
0.
10.
20.
30.
40.
50.
60.


VEHICLE
5303
VEHICLE
DYNAMOMETER
FORCE (LB)
0.
20.
40.
60.
80.
100.
120.
140.
0.
10.
20.
30.
40.
50.
60.
SPEED (MPH)



VEHICLE
5403
VEHICLE
DYNAMOMETER
FORCE (LB)
0.
20.
40.
60.
80.
100.
120.
140.
0.
10.
20.
30.
40.
50.
60.
SPEED (MPH)


VEHICLE
5503
VEHICLE
DYNAMOMETER
FORCE (LB)
SPEED (MPH)
0.
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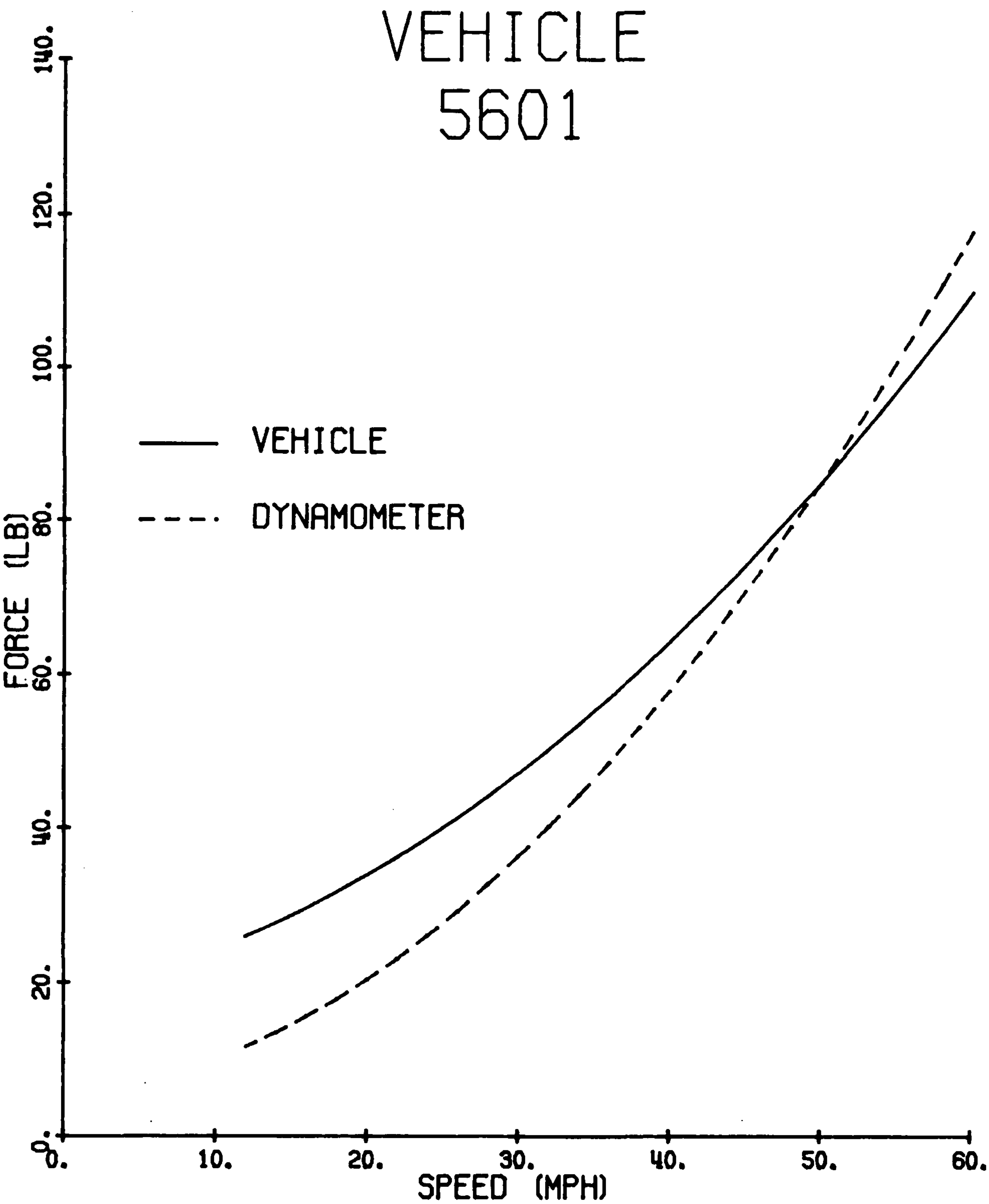
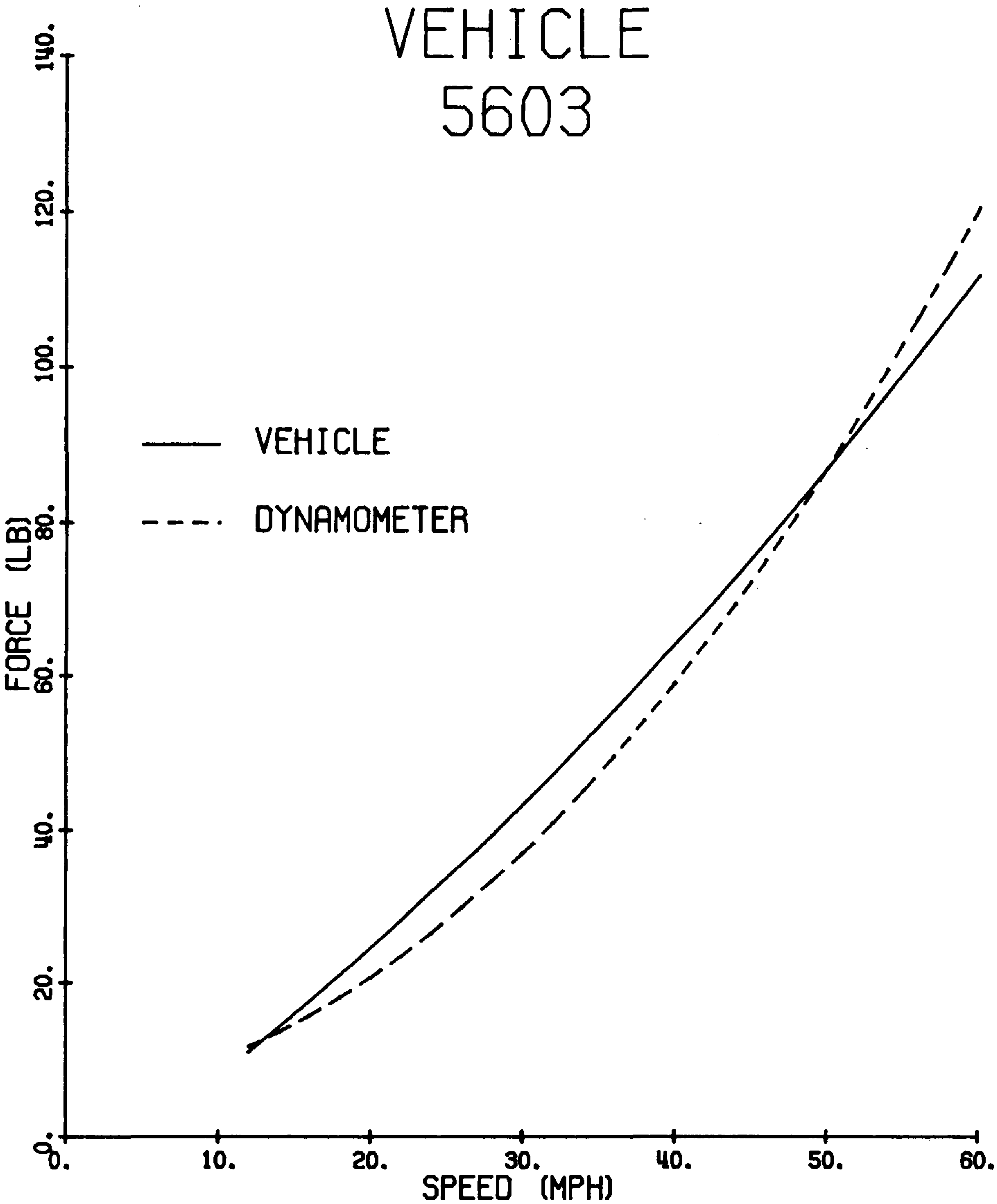
60.
80.
100.
120.
140.
0.
10.
20.
30.
40.
50.
60.


VEHICLE
5601
FORCE (LB)
0.
20.
40.
60.
80.
100.
120.
140.
VEHICLE
DYNAMOMETER
0.
10.
20.
30.
40.
50.
60.
SPEED (MPH)


VEHICLE
5603
VEHICLE
DYNAMOMETER
FORCE (LB)
0.
20.
40.
60.
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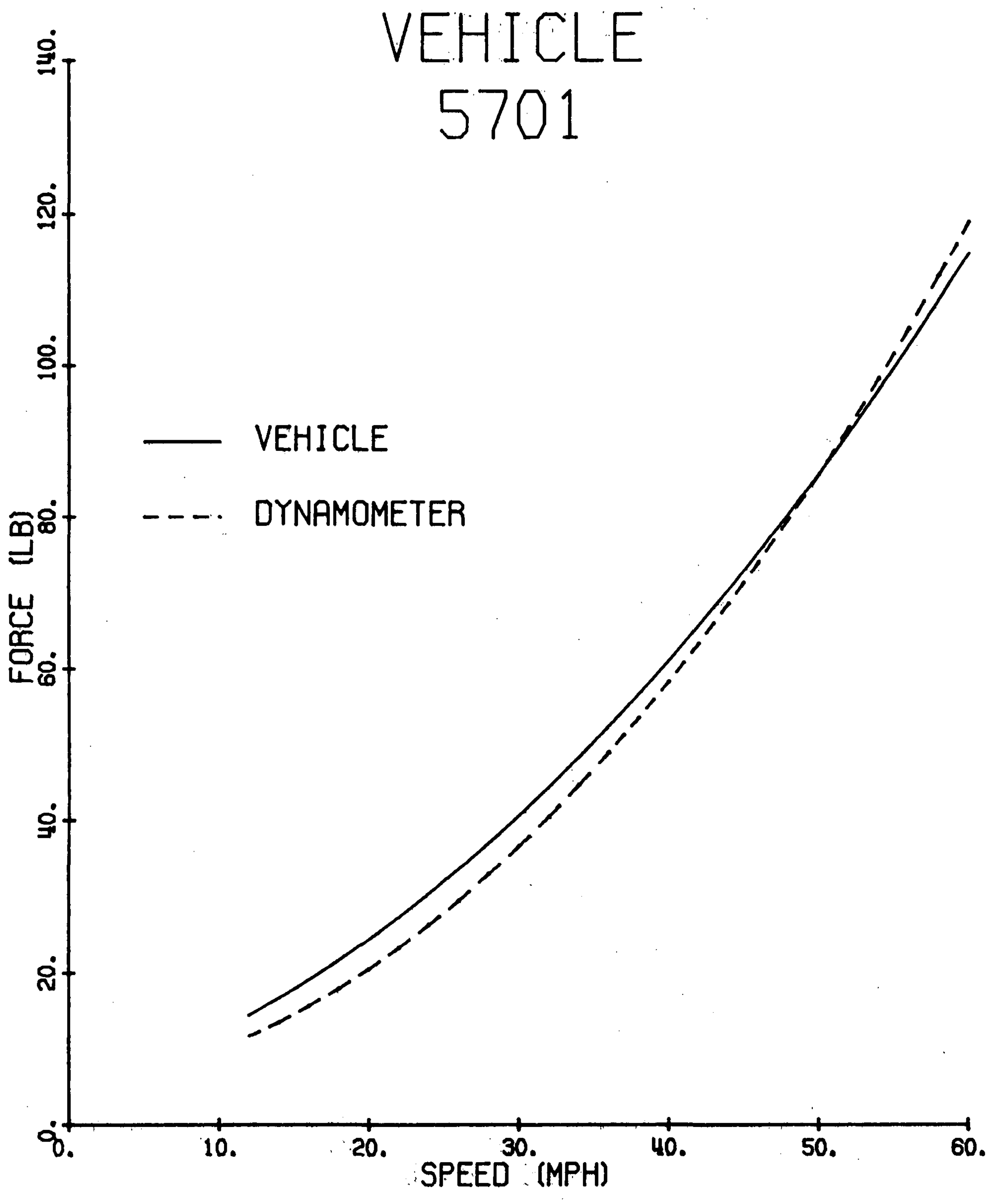
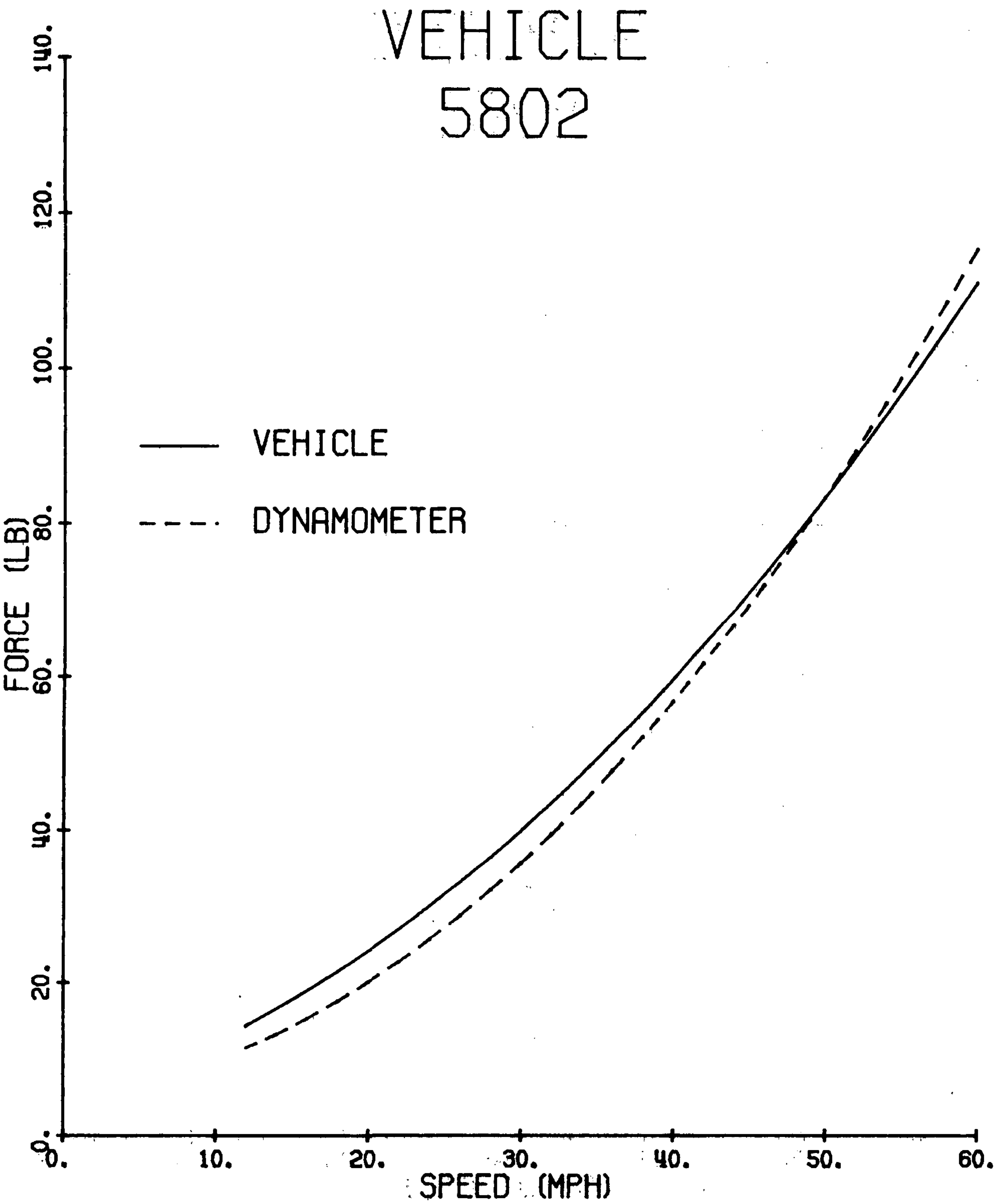
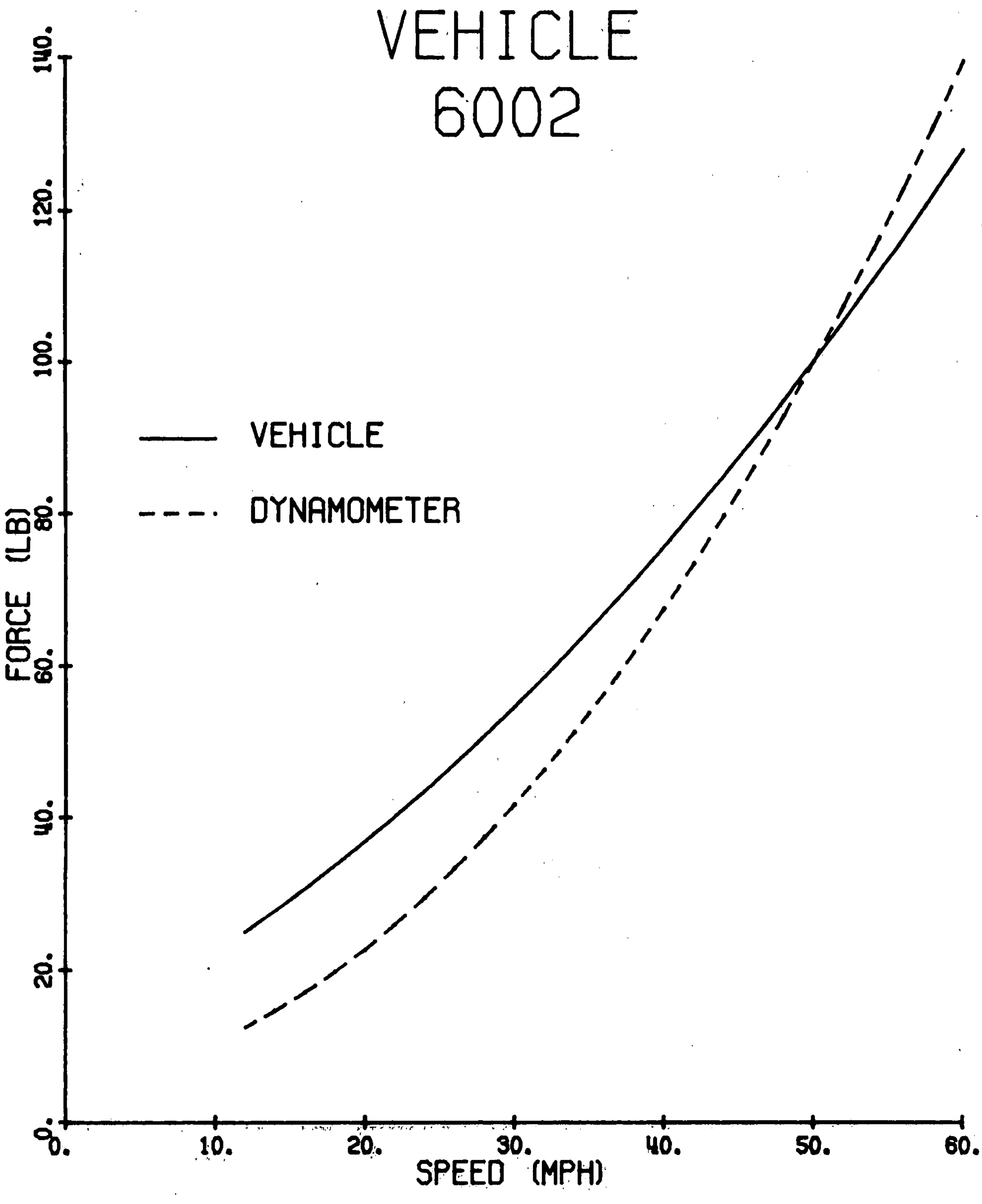
100.
120.
140.
0.
10.
20.
30.
40.
50.
60.
SPEED (MPH)

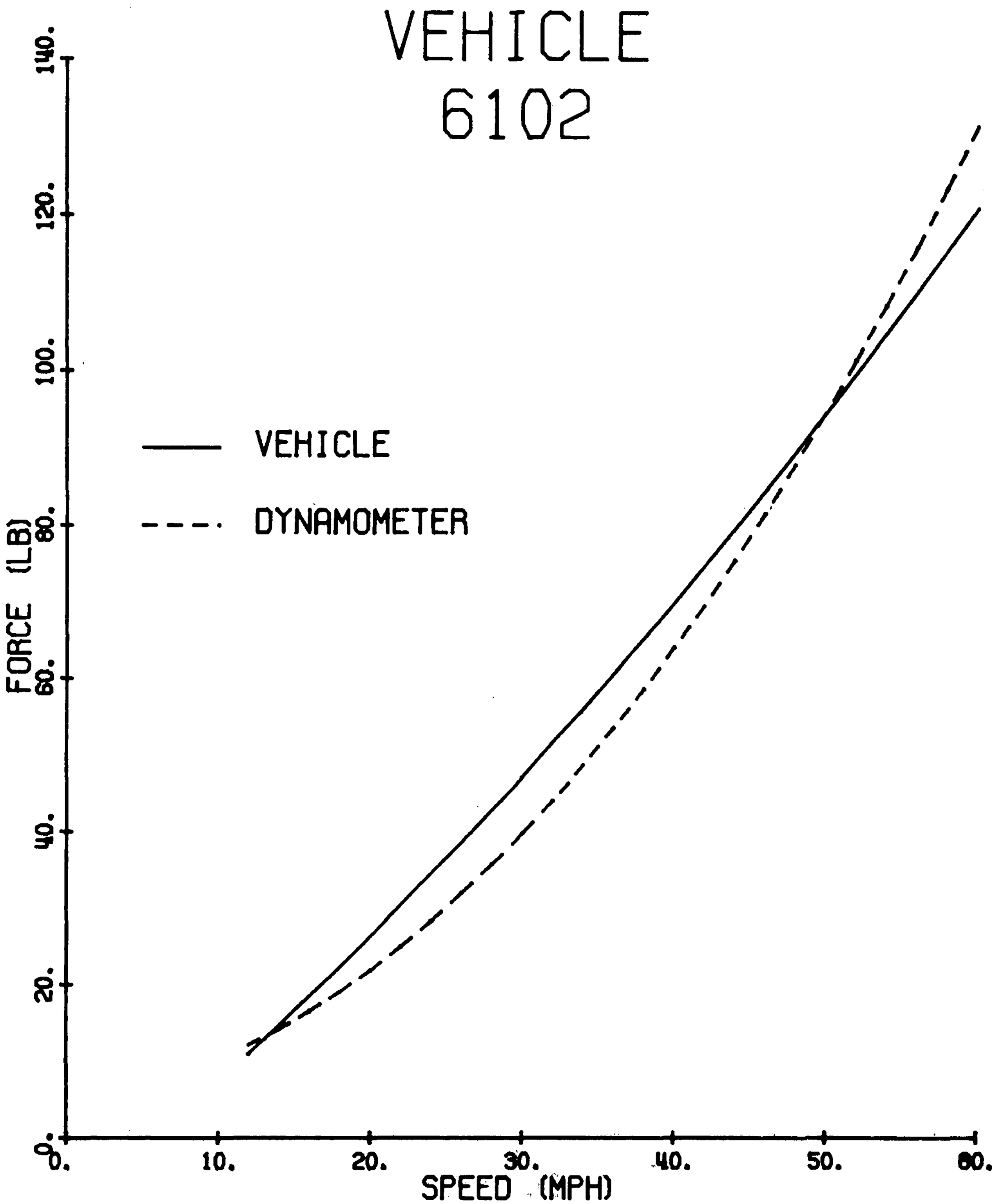


VEHICLE
5701
VEHICLE
DYNAMOMETER
FORCE (LB)
0.
20.
40.
60.
80.
100.
120.
140.
0.
10.
20.
30.
40.
50.
60.
SPEED (MPH)



VEHICLE
5802
VEHICLE
DYNAMOMETER
FORCE (LB)
SPEED (MPH)
0.
20.
40.
60.
80.
100.
120.
140.
0.
10.
20.
30.
40.
50.
60.


VEHICLE
6002
VEHICLE
DYNAMOMETER
FORCE (LB)
0.
20.
40.
60.
80.
100.
120.
140.
0.
10.
20.
30.
40.
50.
60.
SPEED (MPH)



VEHICLE
6102
VEHICLE
DYNAMOMETER
FORCE (LB)
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20.
40.
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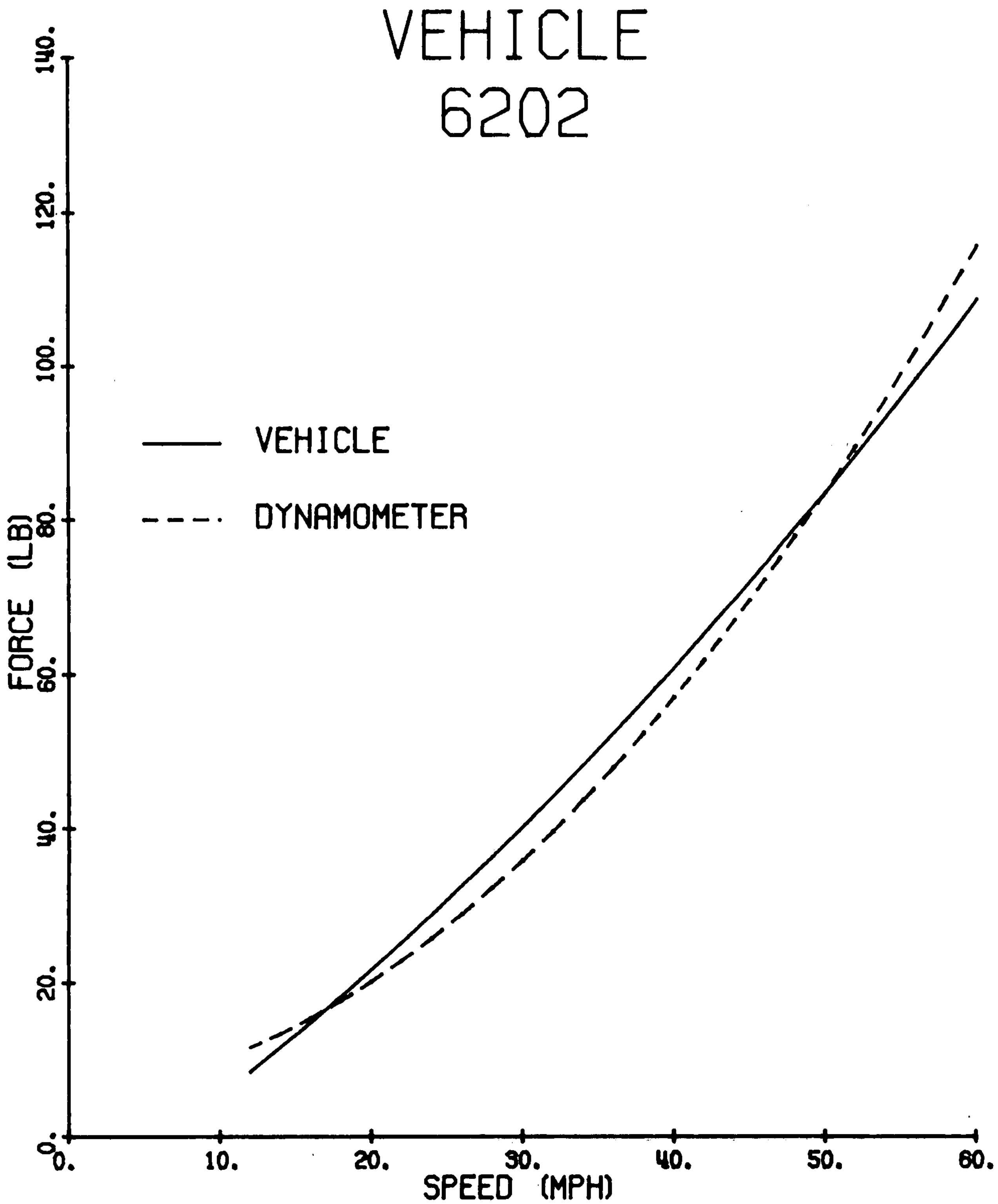
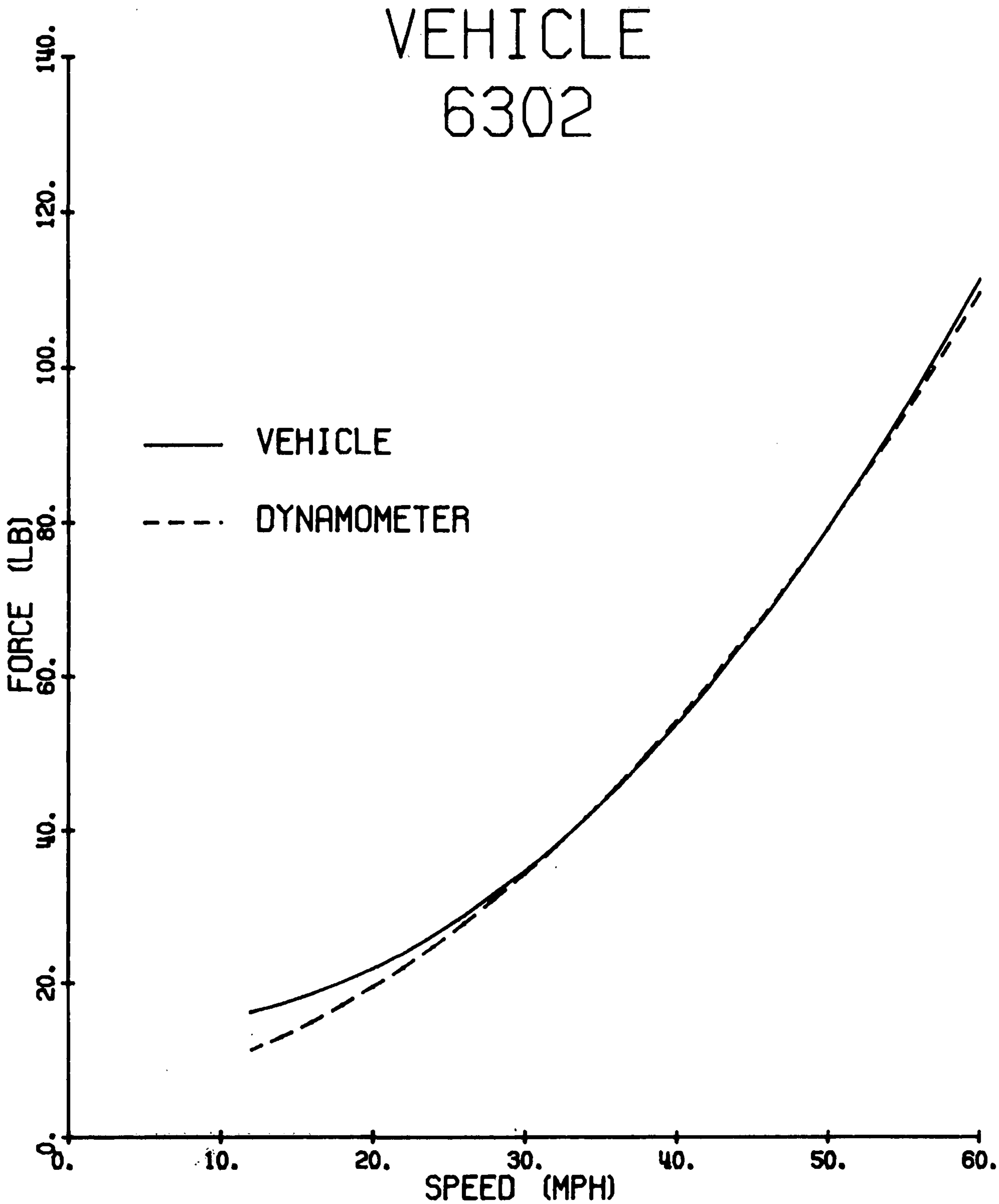
100.
120.
140.
0.
10.
20.
30.
40.
50.
60.
SPEED (MPH)


VEHICLE
6202
VEHICLE
DYNAMOMETER
FORCE (LB)
SPEED (MPH)
0.
20.
40.
60.
80.
100.
120.
140.
0.
10.
20.
30.
40.
50.
60.



VEHICLE
6302
VEHICLE
DYNAMOMETER
FORCE (LB)
SPEED (MPH)
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60.
80.
100.
120.
140.
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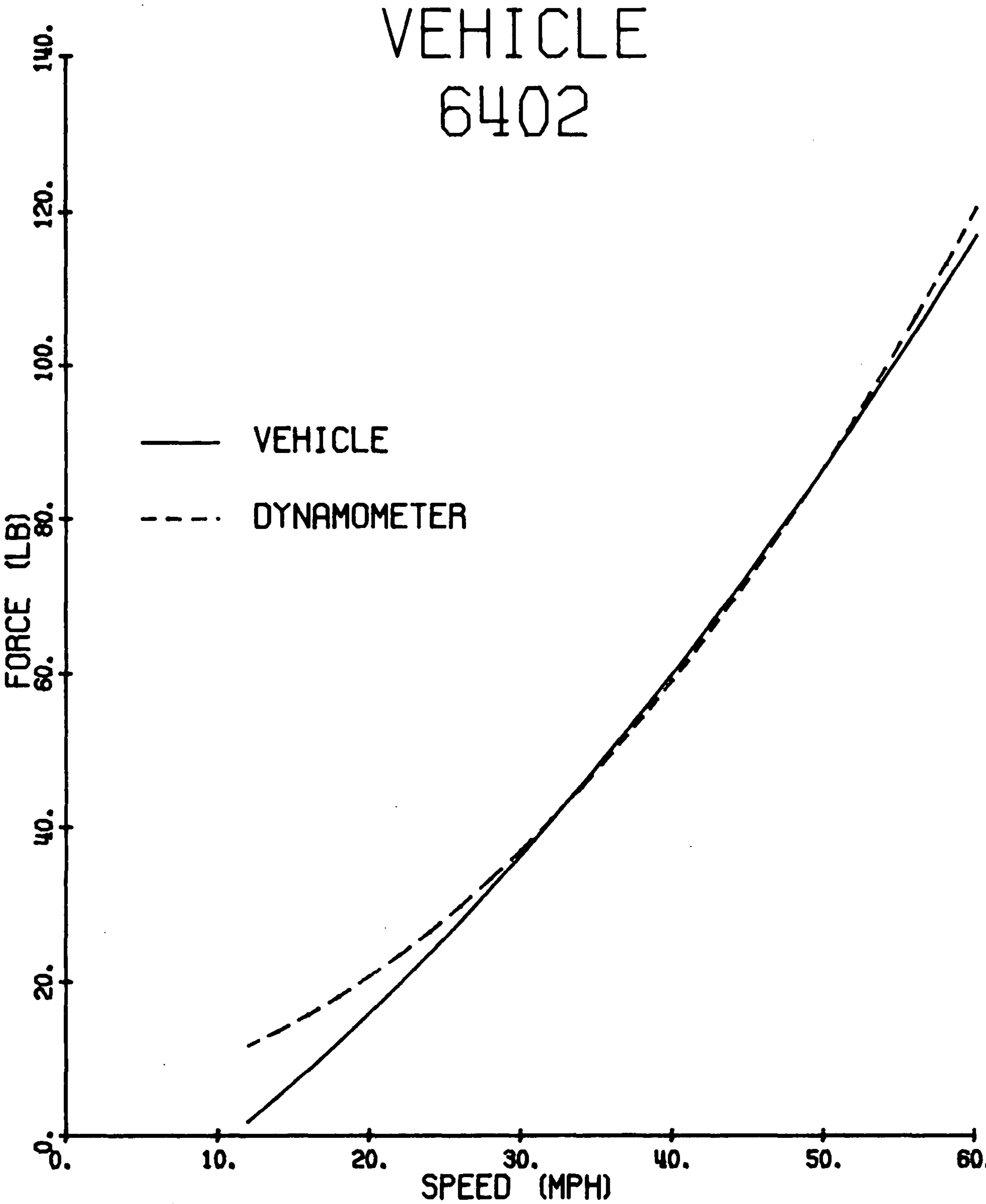
10.
20.
30.
40.
50.
60.



VEHICLE
6402
VEHICLE
DYNAMOMETER
FORCE (LB)
SPEED (MPH)
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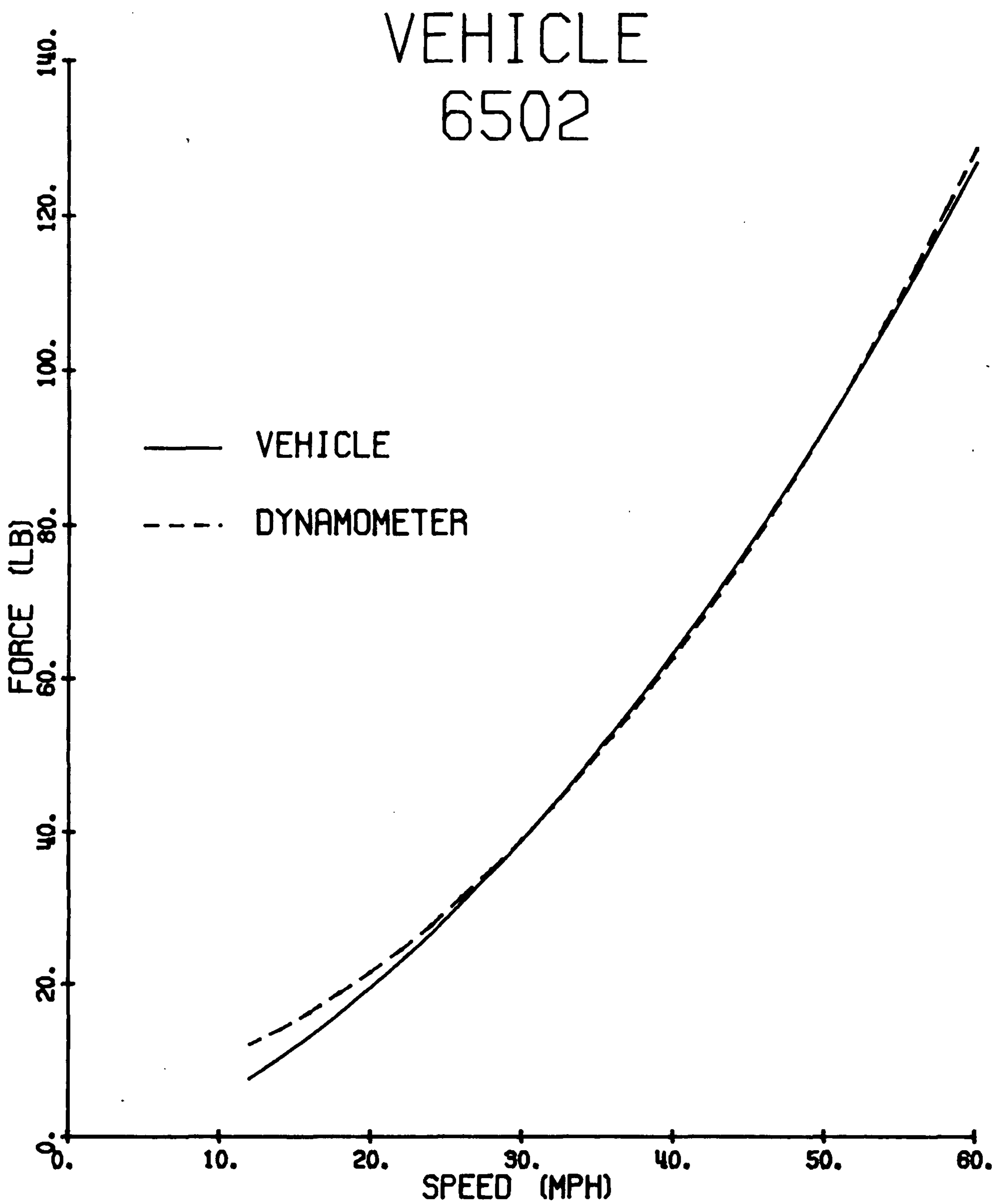
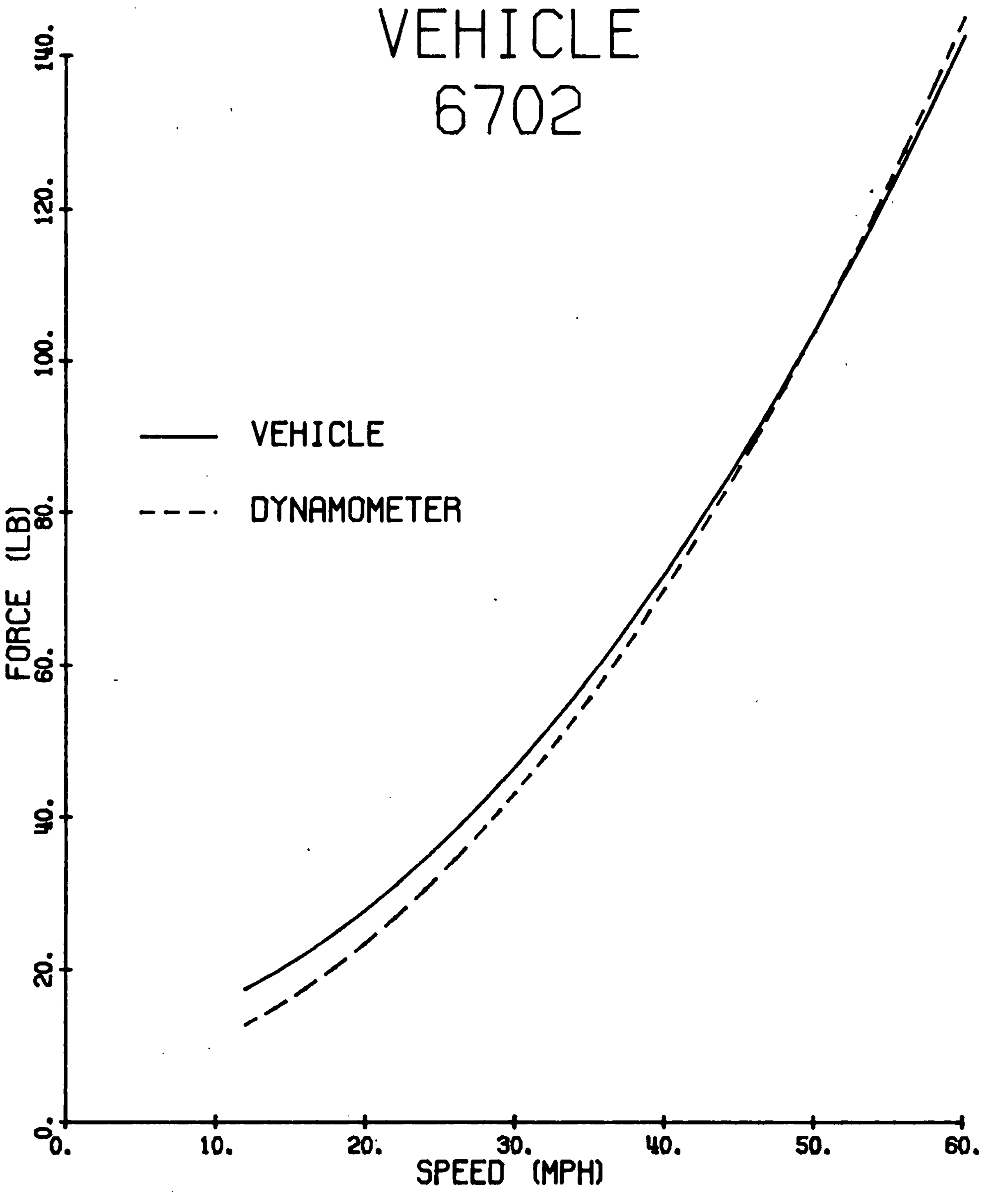
60.
80.
100.
120.
140.
0.
10.
20.
30.
40.
50.
60.



VEHICLE
6502
VEHICLE
DYNAMOMETER
FORCE (LB)
0.
20.
40.
60.
80.
100.
120.
140.
0.
10.
20.
30.
40.
50.
60.
SPEED (MPH)


VEHICLE
6702
VEHICLE
DYNAMOMETER
FORCE (LB)
SPEED (MPH)
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120.
140.
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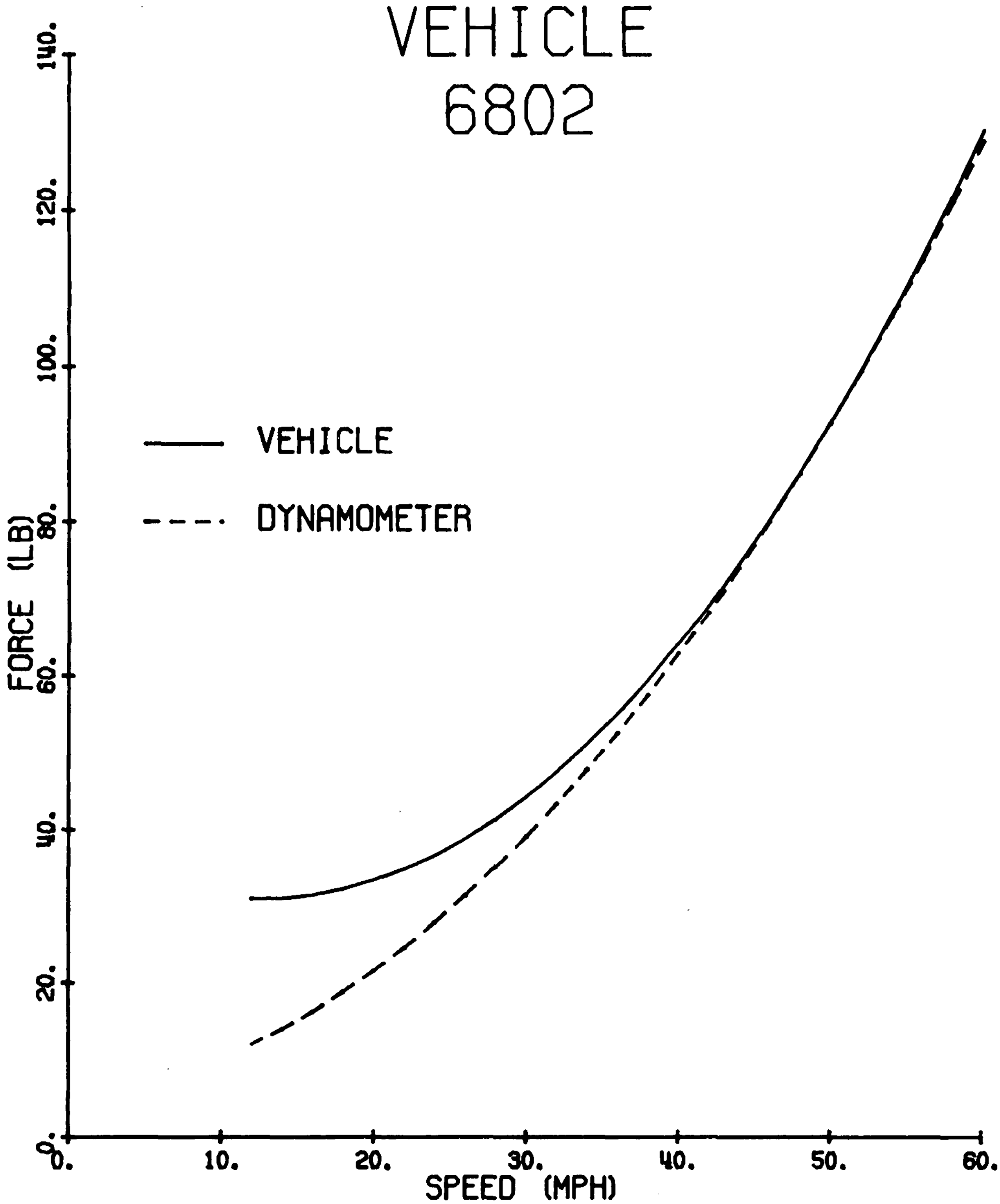
10.
20.
30.
40.
50.
60.



VEHICLE
6802
VEHICLE
DYNAMOMETER
FORCE (LB)
0.
20.
40.
60.
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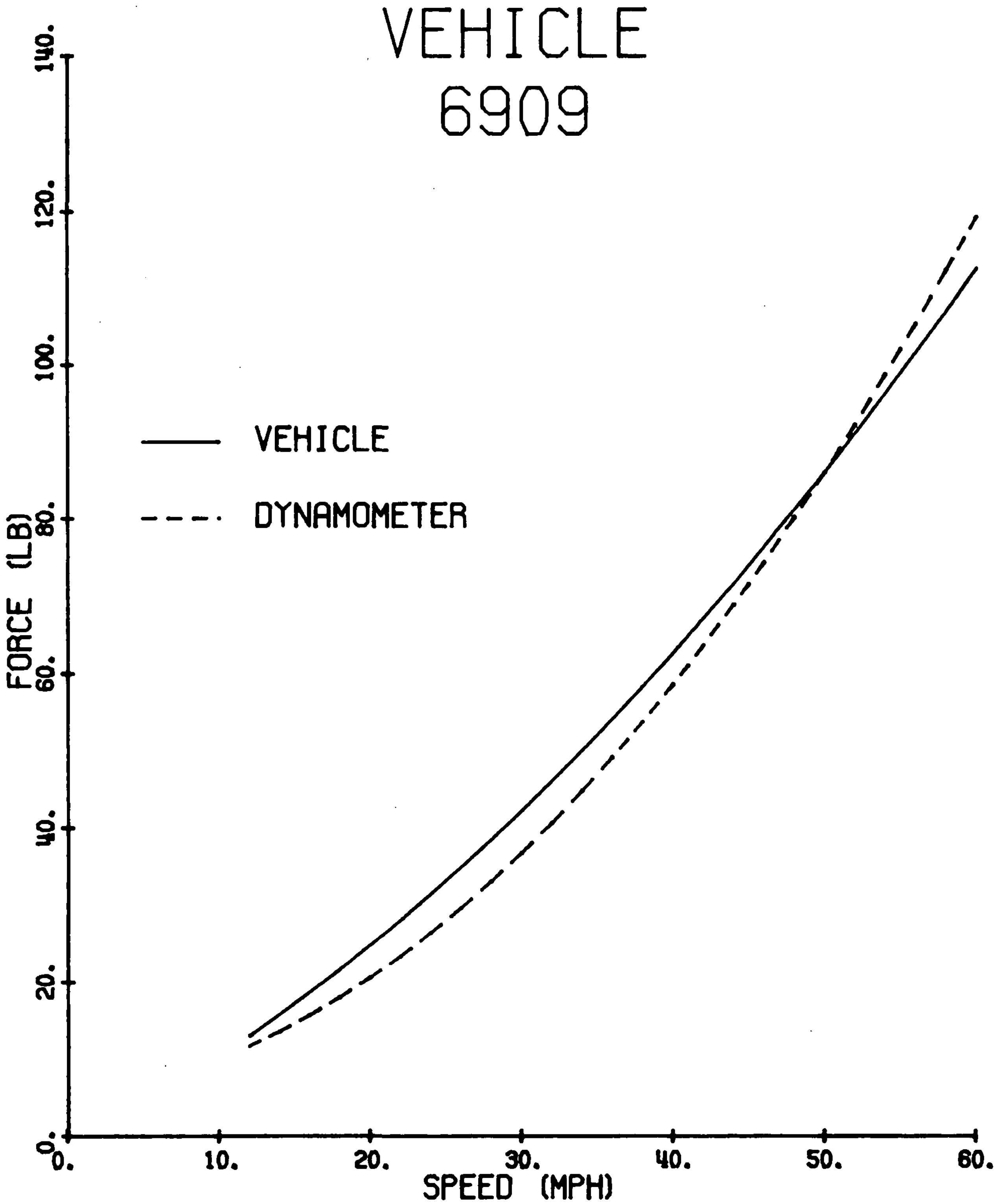
100.
120.
140.
0.
10.
20.
30.
40.
50.
60.
SPEED (MPH)


VEHICLE
6909
FORCE (LB)
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SPEED (MPH)
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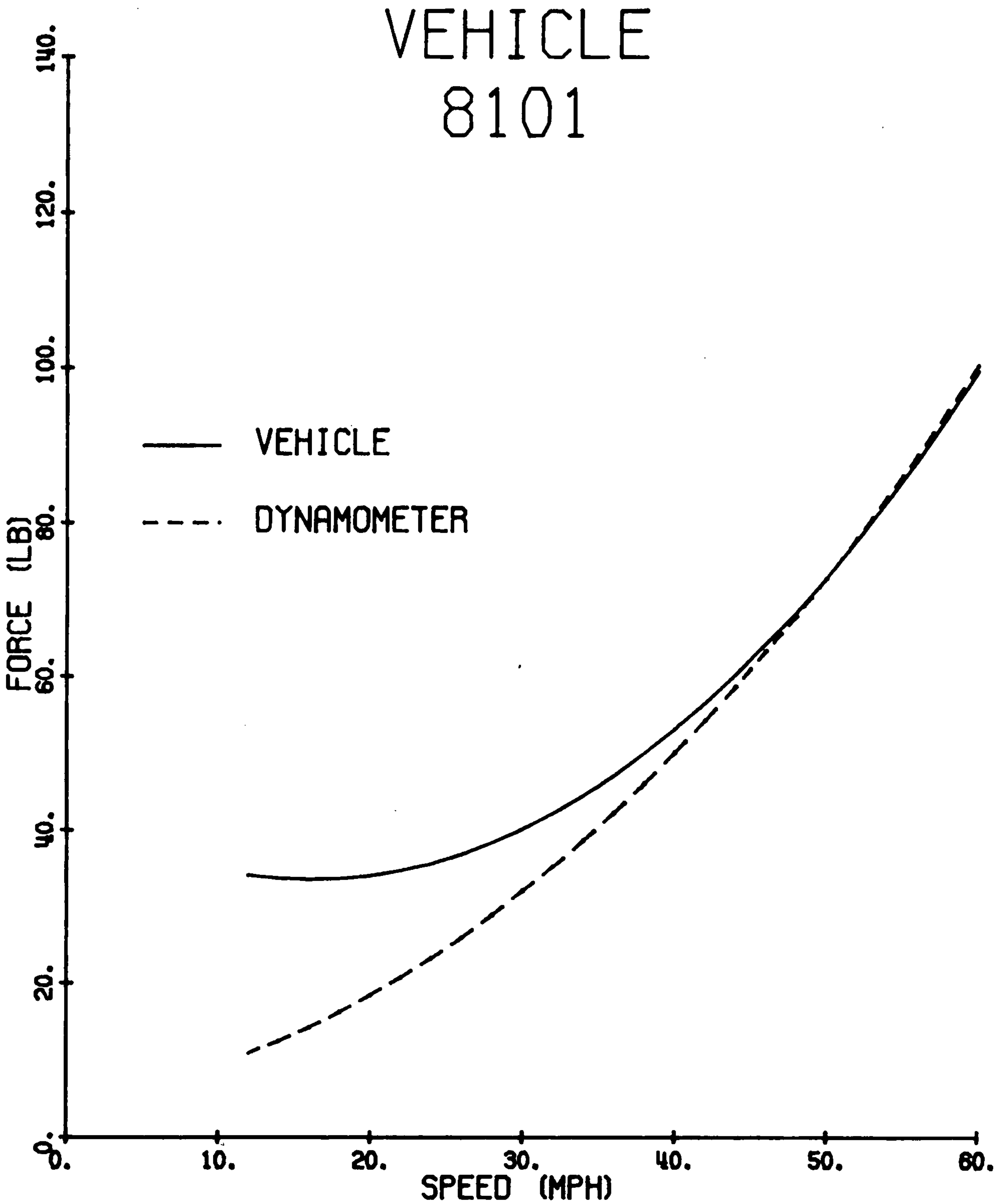
40.
50.
60.
VEHICLE
DYNAMOMETER



VEHICLE
8101
VEHICLE
DYNAMOMETER
FORCE (LB)
SPEED (MPH)
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60.
80.
100.
120.
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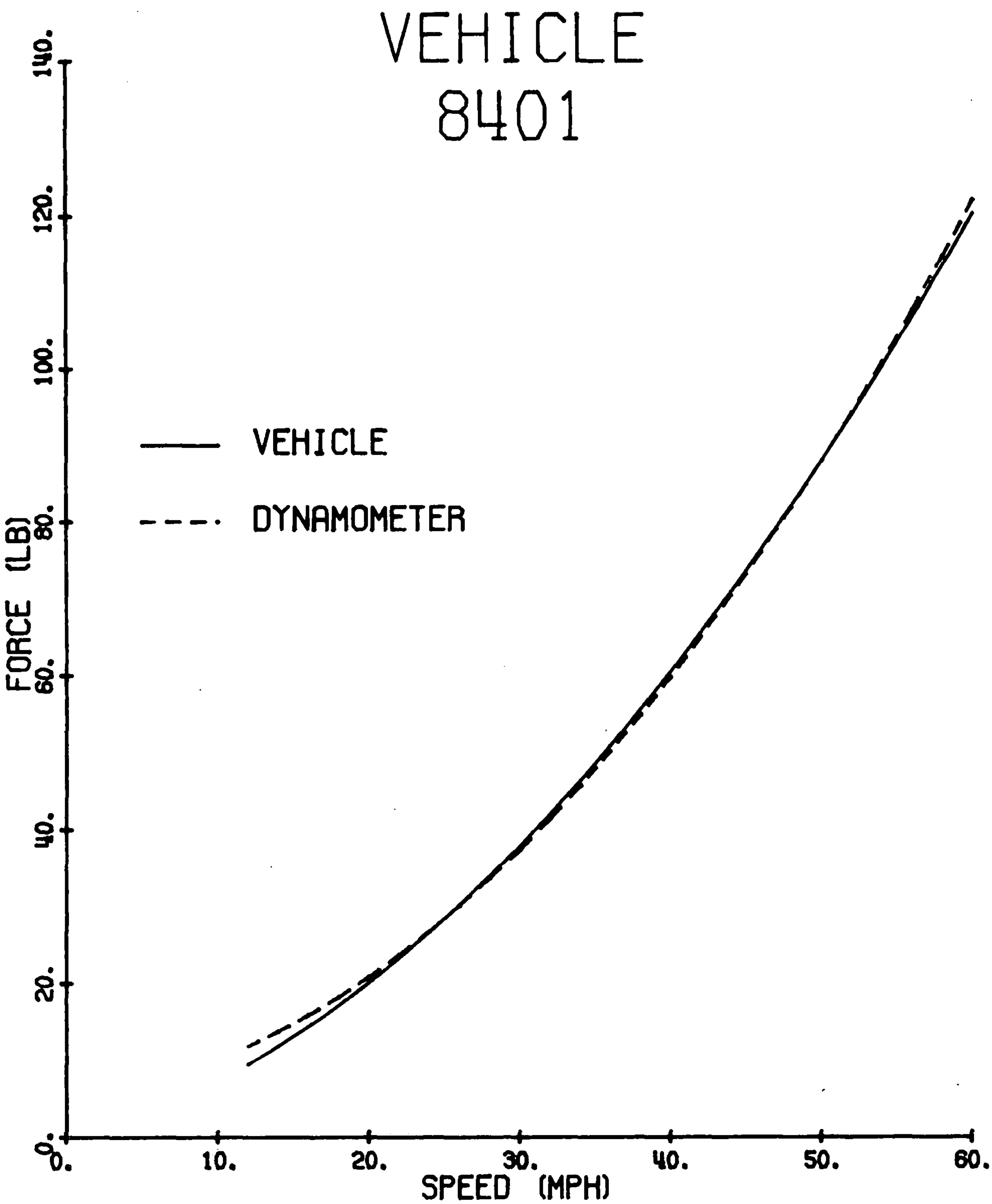
10.
20.
30.
40.
50.
60.



VEHICLE
8401
VEHICLE
DYNAMOMETER
FORCE (LB)
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20.
40.
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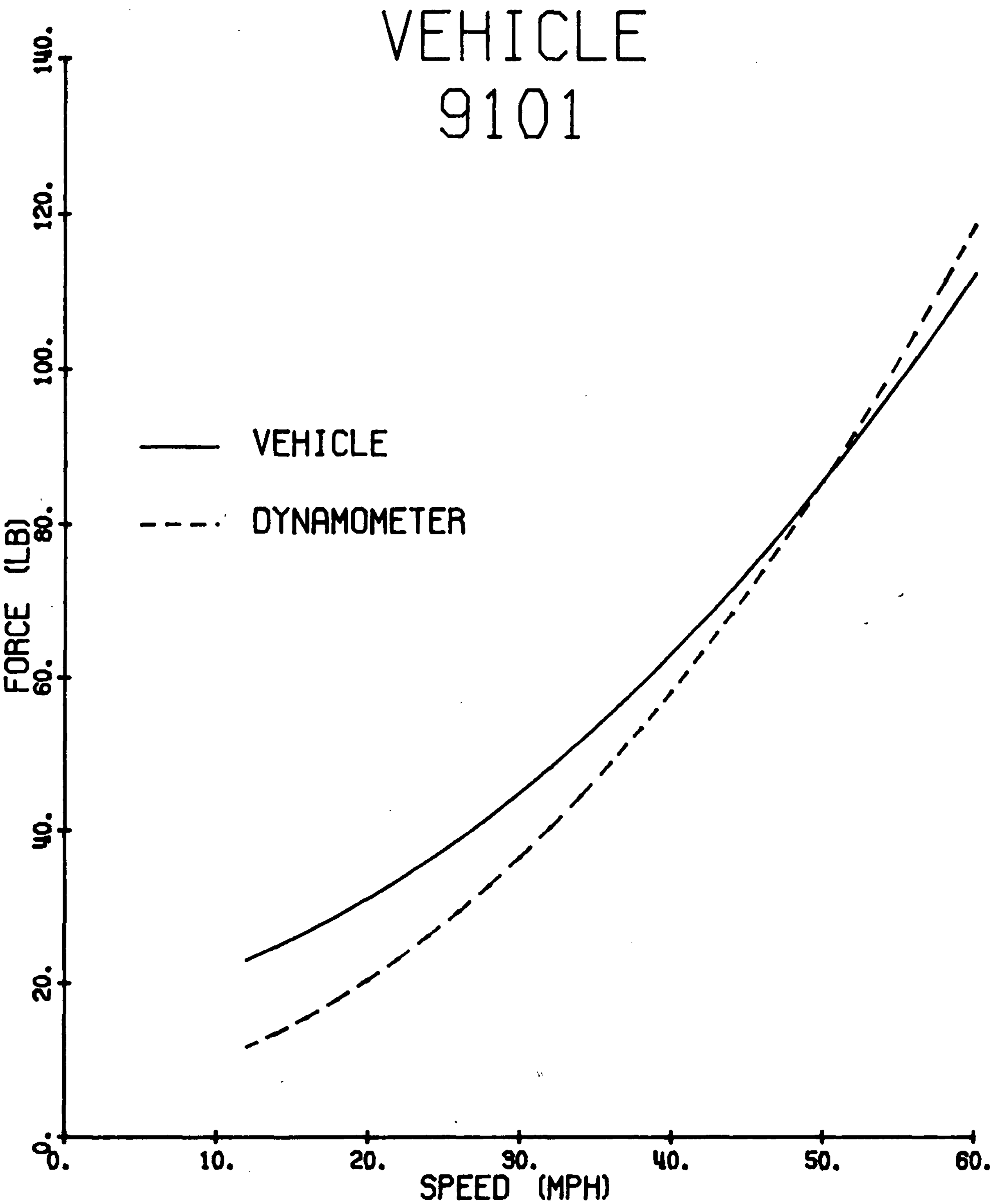
100.
120.
140.
0.
10.
20.
30.
40.
50.
60.
SPEED (MPH)



VEHICLE
9101
VEHICLE
DYNAMOMETER
FORCE (LB)
SPEED (MPH)
0.
20.
40.
60.
80.
100.
120.
140.
0.
10.
20.
30.
40.
50.
60.