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Technical Report

TTI Track/Dynamometer Study
Final Report

By

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Abstract

Seven passenger cars and one light truck were operated over the EPA urban and highway driving cycles to compare fuel economy measurements obtained on a test track with the fuel economy results obtained on a chassis dynamometer. The test program was designed to duplicate, as closely as possible, the track force loading (as determined by standard EPA road coastdown procedures) on the dynamometer. Experimental parameters which were investigated included loading differences between front- and rear-wheel drive vehicles, volumetric versus carbon balance fuel measurement techniques, coupled versus uncoupled roll dynamometer tests, and curved track versus straight track coastdowns.

I. Summary

Analysis of the results from this program provides the following primary conclusion:

Dynamometer fuel economy is higher than track fuel economy. Paired comparisons of the average track result and the test configuration most representative of the EPA certification test (uncoupled dynamometer rolls and the carbon balance method of measuring vehicle fuel economy) show that the fuel economy measured on the dynamometer test is higher than the track result. This difference is statistically significant at the 95 percent confidence level. The average difference for the Federal Test Procedure (FTP) test was 8.1 percent, and the average difference for the Highway Fuel Economy Test (HFET) was 11.7 percent.

Several conclusions about the reasons for the track to dynamometer difference can be deduced from analysis of the data trends. The average values presented with each of these conclusions are the best estimates of the magnitude of each effect. It is important to note, however, that because of the small sample size and the observed vehicle-to-vehicle variability, there may be large standard deviations associated with these average values. These conclusions are:

1. FTP carbon balance fuel economy measurements are higher than the corresponding volumetric fuel economy results. In 16 of 16 comparisons, the FTP fuel economy results based on carbon balance measurements are higher than corresponding volumetric fuel measurements. The average difference between FTP results is approximately 2 percent. Using the HFET cycle eight of 16 comparisons showed higher carbon balance fuel economy. Here, the average carbon balance measurement is about 0.5 percent higher than the comparable volumetric measurement.

2. Coupling the dynamometer rolls reduces the measured fuel economy. In 29 of 32 comparisons, uncoupled roll fuel economy results are higher than coupled roll results. FTP and HFET dynamometer fuel economies determined with the rolls uncoupled are about 3 percent higher than similar determinations with the rolls coupled.

3. The FTP track-to-dynamometer fuel economy discrepancy is lower for front-wheel drive vehicles than for rear-wheel drive vehicles. In all comparisons, the average difference between dynamometer and track fuel economy for the FTP cycle was higher for rear-wheel drive vehicles than front-wheel drive vehicles. For the HFET cycle this trend reverses and the discrepancy is less for rear-wheel drive vehicles.

The following general conclusions were also observed:

1. A track-to-dynamometer fuel economy difference exists even when the dynamometer force replicates the track force as accurately as possible with current test methods. An average difference of 3 percent was observed between track FTP cycle fuel economy results and dynamometer FTP results obtained with the dynamometer rolls coupled and using volumetric fuel measurement.

2. Force loading, as determined by the road coastdown procedure, did not fully explain this program's discrepancies between track and dynamometer fuel economy.

3. The discrepancies between this program's dynamometer fuel economy and official EPA-Certification results appear to be the combined effects of prototype-to-production differences and the differences between the test procedures of the two programs.

II. Introduction

It is generally acknowledged that EPA light-duty vehicle fuel economy estimates exceed real-world fuel economy results. Several EPA studies have attempted to quantify the magnitude of the difference, and more importantly, provide explanations for the existence of the observed difference. However, the results from these studies have been questioned because these studies were not specifically designed for addressing this issue and consequently the results were often inconclusive. This study was designed and performed to examine one specific aspect of the overall difference between road and dynamometer fuel economy--the difference between EPA fuel economy results when the test is conducted on a test track, versus the result when the test is duplicated on a chassis dynamometer.

The track test results were obtained by testing in a narrow range of environmental conditions at the test facility of the Texas Transportation Institute (TTI), at College Station, Texas. Dynamometer tests conducted at TTI included "standard" Federal test procedures and "modified" test procedures using a roll coupler and increased dynamometer horsepower settings.

III. Experimental Procedure

Comparisons of track and dynamometer fuel economy tests were obtained by running a sequence of urban (EPA-FTP) and highway (EPA-HFET) fuel economy tests on a test track and repeating those tests on a chassis dynamometer. Current EPA test procedures were used to adjust the chassis dynamometer to simulate the road experience of the vehicle. The following sequence of events was employed for each test vehicle: procurement/inspection, track coastdown tests, track fuel economy tests, dynamometer horsepower determinations, dynamometer fuel economy tests.

A. Procurement/Inspection

The test fleet was selected to represent a diverse group of vehicles that included a range of engine sizes, transmission types and estimated fuel economies. Both rear-wheel drive vehicles and front-wheel drive vehicles were selected. The majority of the test fleet were small vehicles, which are representative of current and future U.S. vehicles.

The vehicle test fleet used for the track/dynamometer comparisons is shown in Table 1. Most of the information in Table 1 is self explanatory. The data in the column labeled EPA Guide MPG are the fuel economy estimates published in the 1980, 1981, and 1982 Gas Mileage Guide. These are the results of the EPA urban cycle (FTP) fuel economy tests. The EPA highway MPGs are the result of the EPA highway cycle tests which are used in computing a manufacturer's corporate average fuel economy (CAFE), as required by Department of Energy fuel economy standards.

Vehicles were obtained from several sources. Some vehicles were borrowed from private owners by offering loaner vehicles and cash incentives. Others were leased from auto dealers. All vehicles were visually inspected, tuned to manufacturers specifications, checked for proper wheel alignment, and test driven prior to instrumenting for fuel

Table 1

Test Fleet Descriptives

Vehicle	Engine CID/Cyl.	Trans	Drive Wheels	Inertia (lb)	EPA Guide MPG (FTP)	EPA Highway MPG (HFET)
1. 1980 Oldsmobile Cutlass Supreme	260/8	A3	R	4,000	18	24
2. 1980 Ford Pinto Hatchback	140/4	A3	R	3,000	21	29
3. 1981 Ford Custom F-100	300/6	A3	R	4,250	18	22
4. 1980 Chevrolet Citation	173/6	A3	F	3,000	20	30
5. 1981 Ford Escort	98/4	M4	F	2,500	30	44
6. 1981 Plymouth Horizon	104/4	A3	F	2,750	26	35
7. 1981 AMC Concord	258/6	A3	R	3,500	19	26
8. 1982 Honda Civic	81/4	M5	F	2,250	41	55

economy measurement and coastdown time determinations. A detailed description of each vehicle is presented in Tables A-1 through A-8 in the Appendix.

B. Track Coastdowns

Road force measurements were determined by using the test procedures specified in EPA Advisory Circular (A/C) No. 55B, "Determination and Use of Alternative Dynamometer Power Absorption Values."[1] The test instrumentation used for recording the required velocity/time data is presented in Table B-1 of the Appendix. In addition to the typical straight track coastdowns described in A/C No. 55B, coastdown times were measured over a curved section of the TTI track. Figure B-2 of the Appendix describes the layout of the test track including the portion designated for curved coastdown tests.

C. Track Fuel Economy Tests

Track fuel economy tests included the same sequence of events required for a typical dynamometer test, including the following procedures and test conditions: 1) a preparatory warm-up cycle, 2) a 12-36 hour stabilization period at 68 to 86°F, 3) a true cold start, 4) constant specification test fuel, and 5) ambient test temperatures of between 68 and 86°F. Additional constraints for conducting track tests were winds averaging less than 15 mph with gusts less than 20 mph, zero precipitation, and a dry track.

Several minor modifications were made to the standard dynamometer fuel economy (emissions) test procedures[2] to reduce the test time. These changes included omitting evaporative emissions measurements and deleting the requirement for heating the test fuel in the vehicle from 60 to 84°F. These variations from the typical EPA test procedure were consistently made in all track and dynamometer testing. None of the deviations from standard EPA measurement procedures were expected to change the validity of the test results. Howell Hydrocarbons' EEE Clear amd AMOCO Indolene were used as the test fuels. The specifications of these fuels are summarized in Table B-3 of the Appendix.

Two technicians were required to operate a test vehicle on the track--one person controlled the vehicle speed while the second person steered the vehicle. The equipment used for the track fuel economy tests is also presented in Table B-1 of the Appendix. Following the required preparatory and stabilization periods, a typical sequence of track fuel economy tests consisted of a cold start urban fuel economy test (FTP) followed by a warm-up highway fuel economy test (HFET) and then a second HFET test. All track tests were conducted with the tires adjusted to the manufacturer's minimum recommended inflation pressure. The tire specifications are summarized in Tables A-1 to A-8 of the Appendix.

D. Dynamometer Horsepower Determinations

Track coastdown data from straight and curved track results were reduced and corrected, following the guidelines of A/C No. 55B, to calculate values of total road force and dynamometer 55-45 mph coastdown time. These data were then used to set an equivalent force loading on the dynamometer. The corresponding horsepower settings were developed from straight and curved coastdown times using a Clayton twin-roll dynamometer and the same dynamometer with the rolls coupled. Thus for each test vehicle, two values of road force were used to determine a total of four values of dynamometer force (or power) loading.

Full range dynamometer coastdowns (60-20 mph) were conducted for each vehicle. These data were analyzed and compared with the track coastdown data to determine the differences between the vehicle loading on the track and the loading curve obtained on the Clayton dynamometer when it was adjusted to match the 50 mph road force value.

E. Dynamometer Fuel Economy Tests

All vehicles received at least three series of FTP-HFET-HFET tests. To the extent possible, the dynamometer tests were conducted at conditions identical to the track fuel economy tests. The values for parameters such as: inertia weight, axle loading, driver, volumetric fuel measurement instrumentation, test fuel composition, and ambient temperature conditions were all identical to, or adjusted as close as possible, to the test conditions which existed for the track fuel economy measurements. For example, the mass of the vehicle, and the axle loading on the dynamometer were the same (or adjusted to be the same) as on the track. The driver and the volumetric fuel measurement equipment were also the same for track and dynamometer tests. A list of the test equipment which were used for the measurement of vehicle fuel consumption is presented in Table B-4 of the Appendix.

Table 2 is an overview of all test activities which were performed during this program.

Table 2

Test Plan

Vehicle	Track Coastdowns [1] Straight (S)	Track Coastdowns [1] Curved (C)	Track FTP-HFET Sequence [2]	Dynamometer Coastdowns [3] Rolls Uncoupled S	Dynamometer Coastdowns [3] Rolls Uncoupled C	Dynamometer Coastdowns [3] Rolls Coupled S	Dynamometer Coastdowns [3] Rolls Coupled C	Dynamometer FTP-HFET Sequence [4] Rolls Uncoupled S	Dynamometer FTP-HFET Sequence [4] Rolls Uncoupled C	Dynamometer FTP-HFET Sequence [4] Rolls Coupled S	Dynamometer FTP-HFET Sequence [4] Rolls Coupled C
1. Cutlass	7	7	3	4	4	4	4	3		3	
2. Pinto	7	7	3	4	4	4	4	3		3	
3. F-100	7	7	3	4	4	4	4	3		3	
4. Citation	7	7	9	4	4	4	4	9		9	
5. Escort	7	7	3	4	4	4	4	3		3	
6. Horizon	7	7	3	4	4	4	4	3	3	3	3
7. Concord	7	7	3	4	4	4	4	3		3	
8. Civic	7	7	3	4	4	4	4	3	3	3	3

[1] Each track coastdown run consists of one coastdown in one direction immediately followed by a coastdown in the opposite direction. Each coastdown sequence thus requires reporting data from 8 pairs (runs) of tests.

[2] A track sequence consists of one FTP followed by two HFET tests.

[3] Each dynamometer coastdown consists of eight measurements of coastdown times.
S = Straight track coastdown time.
C = Curved track coastdown time.

[4] A dynamometer sequence consists of one FTP followed by two HFET tests. Volumetric and carbon balance fuel consumption results are measured during each test.

IV. Results

A. Track and Dynamometer Coastdown Results

Table 3 summarizes the track coastdown data and presents the corresponding 50 mph force and horsepower results for each vehicle. Total force is calculated by the equation:

$$F = F_0 + F_2V^2$$

where,

F = total road force at 50 mph

F_0 = constant force term

F_2V^2 = quadratic force term.

The force coefficients F_0 and F_2 are computed from:

$$F_0 = MA_0$$

$$F_2 = MA_2$$

A_0 and A_2 are the vehicle acceleration coefficients which are determined by fitting a quadratic acceleration versus speed equation to the track or dynamometer speed versus time data. The temperature at which track coastdowns were conducted sometimes differed from the temperature of the track fuel economy tests since those tests were conducted at different times. Therefore, in accordance with A/C No. 55B, acceleration coefficients were corrected to 68°F, 29 in. of Hg, and zero wind speed.

The terms M and V in the above equations represent the corresponding vehicle mass and velocity, respectively. The vehicle mass includes a correction factor of 1.035 to account for the rotating inertia of the four wheels and the drive axle components.

The average values for the track and dynamometer coastdown force coefficients are included in Appendix E.

Table 4 summarizes the dynamometer coastdown results. Since two separate sets of dynamometer coastdowns were conducted, care must be taken in understanding these results. The first set of dynamometer coastdowns were the 55 to 45 mph coastdowns which are used to determine the dynamometer adjustment necessary to reproduce the measured road force at 50 mph. The dynamometer adjustments which resulted from these

Table 3

Track Coastdown Results

Vehicle	Type[1]	Vehicle Mass (lbm)[2]	55-45 Coastdown Time (sec)[3]	Total Road Force @ 50 mph (lbf)	Total Road Horsepower @ 50 mph (hp)
1. Cutlass	S	4113/1702	15.81	118.1	15.7
	C	4091/1686	15.34	121.4	16.2
2. Pinto	S	3199/1341	11.78	118.4	15.8
	C	3192/1338	11.60	120.6	16.1
3. F-100	S	4298/1707	12.61	157.3	21.0
	C	4317/1726	12.24	161.6	21.5
4. Citation	S	3217/1989	13.90	100.5	13.4
	C	3222/1978	13.79	101.4	13.5
5. Escort	S	2519/1444	13.87	83.8	11.2
	C	2513/1433	13.32	87.4	11.7
6. Horizon	S	2789/1690	13.52	94.8	12.6
	C	2803/1686	13.41	95.3	12.7
7. Concord	S	3631/1493	14.39	113.2	15.1
	C	3615/1488	14.11	115.6	15.4
8. Civic	S	2357/1334	12.14	86.3	11.5
	C	2356/1332	11.98	87.7	11.7

[1] Coastdown type: S = Straight track section, C = Curved track section.

[2] Total mass/drive axle mass loading. Total loading includes 0.035 x vehicle mass for driving and non-driving rotating equivalences.

[3] Track coastdown times corrected to zero wind, 68°F and 29 in. Hg, and equivalent dynamometer mass loading.

Table 4

Dynamometer Coastdown Results

Vehicle	Type[1]	Vehicle Mass[2]	55-45 Coastdown Time (sec)[3]	Total Force @ 50 mph (lbf)[3]	Total Horsepower @ 50 mph (hp)[3]	Dynamometer Horsepower @ 50 mph (AHP)[4]
1. Cutlass	D-U	4071/1666	16.23	114.2	15.2	10.5
	D-C	4071/1669	16.34	114.9	15.3	10.9
2. Pinto	D-U	3056/1295	12.06	110.5	14.7	9.7
	D-C	3056/1294	11.32	117.8	15.7	10.8
3. F-100	D-U	4325/1732	13.05	151.9	20.3	15.1
	D-C	4326/1735	13.10	149.9	20.0	15.3
4. Citation	D-U	3056/2065	13.28	105.2	14.0	8.3
	D-C	3056/2061	13.29	105.0	14.0	8.4
5. Escort	D-U	2544/1497	14.15	82.0	10.9	5.8
	D-C	2544/1506	12.98	89.5	11.9	6.1
6. Horizon	D-U	2798/1734	13.21	97.2	13.0	7.9
	D-C	2798/1701	13.11	98.2	13.1	8.0
7. Concord	D-U	3563/1442	13.55	120.6	16.1	10.97
	D-C	3563/1463	13.50	120.8	16.1	11.0
8. Civic[5]	D-U	2290/1334	12.07	85.5	11.4	8.4
	D-C	2290/1335	12.07	86.3	11.5	9.0

[1] Coastdown type: D-U = Dynamometer rolls uncoupled, D-C = Dynamometer rolls coupled. D-U and D-C tests attempt to match straight track coastdown force.
[2] Total mass/drive axle mass loading. Total loading includes 0.018 x vehicle mass for driving rotating equivalences.
[3] Coastdown time, total force @ 50 mph, and total horsepower @ 50 mph measured during 60-20 mph coastdowns. Dynamometer times are <u>not</u> ambient corrected.
[4] Dynamometer AHP from PAU determination.
[5] Dynamometer horsepower inadvertantly set at equivalent AHP plus 10 percent for air-conditoning simulation.

coastdowns are given in the right-hand column of Table 4 (dynamometer horsepower at 50 mph (AHP)). These are the dynamometer adjustments which were used when the fuel economy measurements were obtained.

After completion of the fuel economy measurements, a second series of coastdowns were conducted to characterize the dynamometer performance throughout the speed range of the fuel economy tests. These coastdowns were conducted over the usual coastdown speed range, 60 to 20 mph. The data were analyzed to yield force versus speed in the same manner as the road coastdown data. However, no ambient corrections were necessary since laboratory conditions were well controlled and wind and air density effects are not present on dynamometers. A mass correction factor of 1.018 was used to account for the effects of rotating inertia. This is less than the road correction factor since the non-drive wheels of the vehicle are not in motion on the dynamometer. The force coefficients of this analysis were then used to calculate the force acting on the vehicle for all speeds below 60 mph. This force versus speed information is plotted in Figures 1 through 8. Each figure contains force versus speed curves based on 60-20 mph straight track, coupled roll dynamometer, and uncoupled roll dynamometer coastdown data.

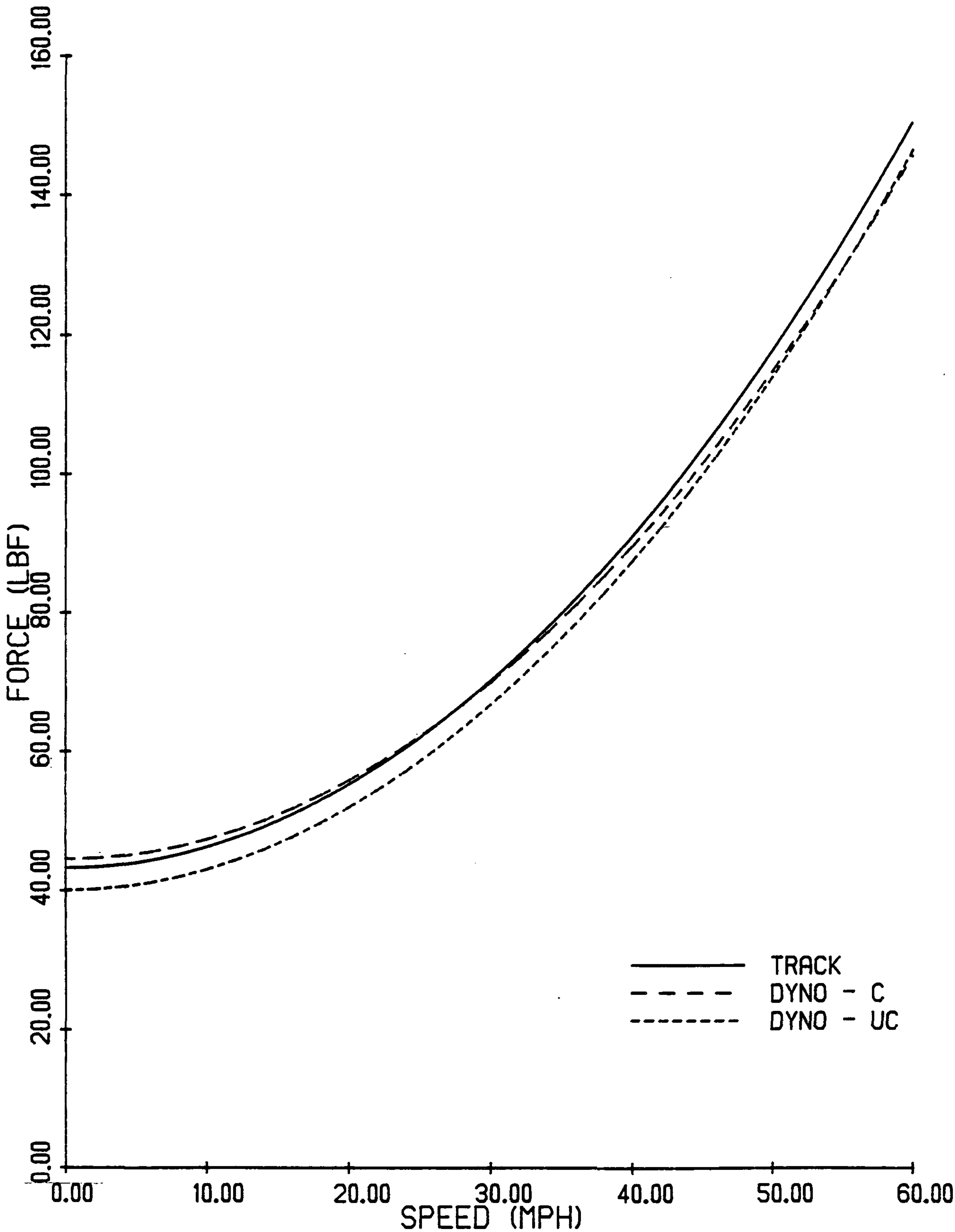
The force coefficients were used to calculate the total vehicle-dynamometer force at 50 mph, the power for the system at 50 mph, and the 55-45 mph coastdown times for the vehicle on the dynamometer. The coastdown time for the vehicle on the dynamometer is a cross-check against the track coastdown time of Table 3. These are all presented in Table 4.

B. Track and Dynamometer Fuel Economy Results

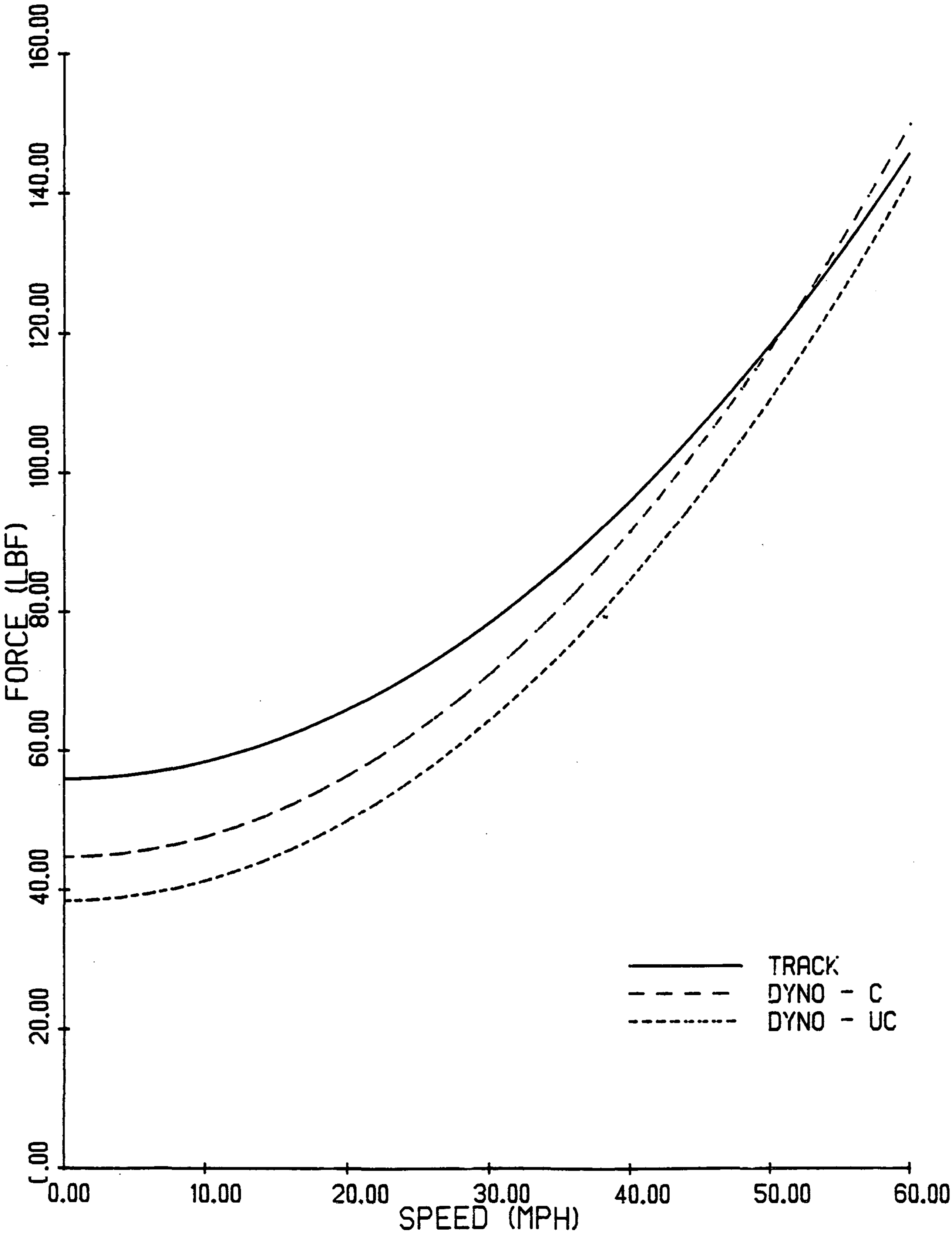
Table 5 is a summary of the average fuel economy results (track and dynamometer) for each test vehicle.

Track and dynamometer volumetric fuel economy measurments are calculated using an average fuel flowmeter temperature for a segment of the FTP (e.g., Bag 1) or the entire HFET, and the gasoline density correction factors (C_3) in SAE recommended practice J1256. The average fuel flowmeter temperature is based on the temperature at the start and end of an FTP segment or an HFET. FTP composite fuel economy is then calculated using the EPA cold/hot weighting factors to provide a correct comparison with the weighted carbon balance fuel economy measurements.

Individual track and dynamometer results for the test vehicles are presented in Tables D-1 to D-48 of the Appendix.

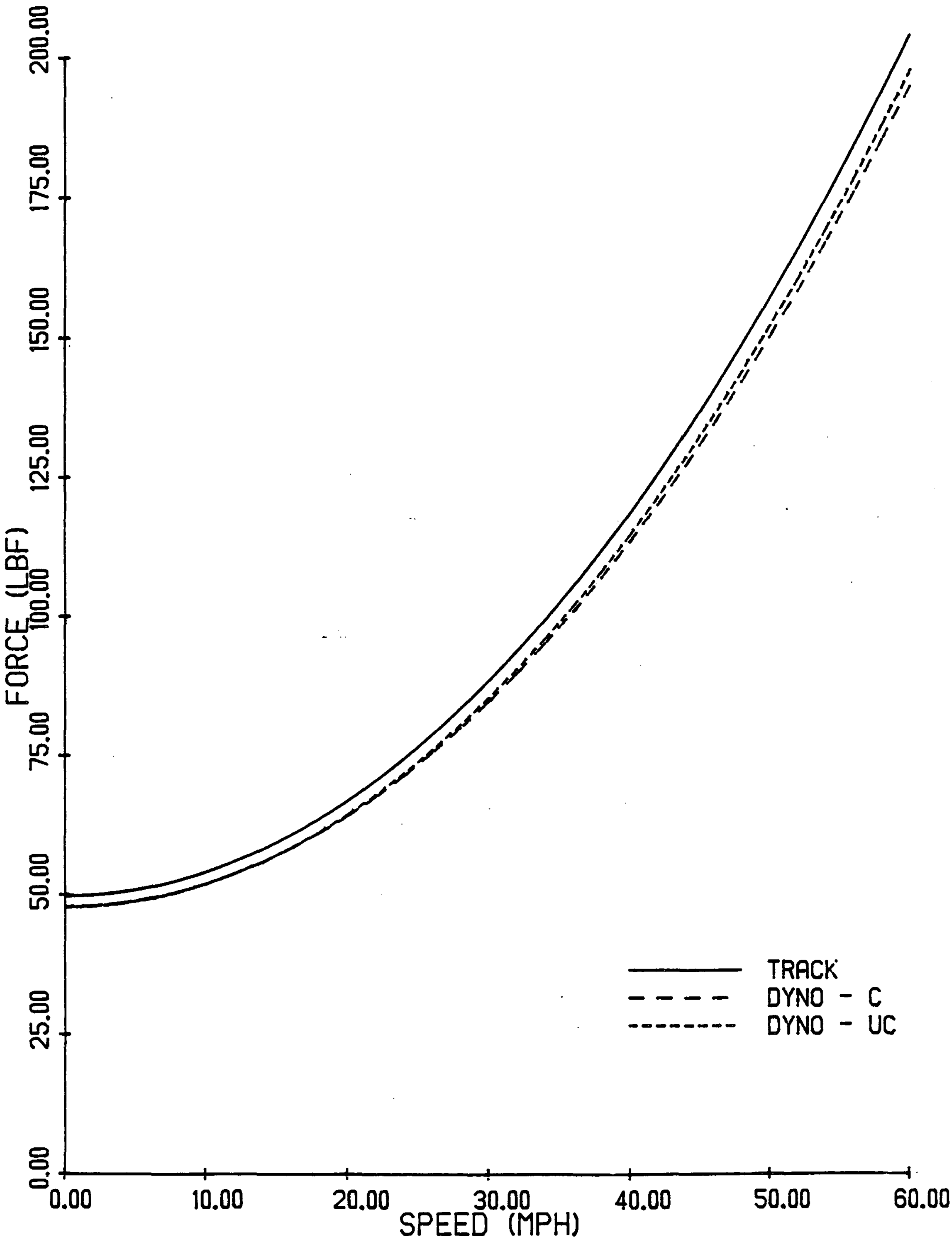


CUTLASS - TRACK/DYNAMOMETER COASTDOWNS
FIGURE 1



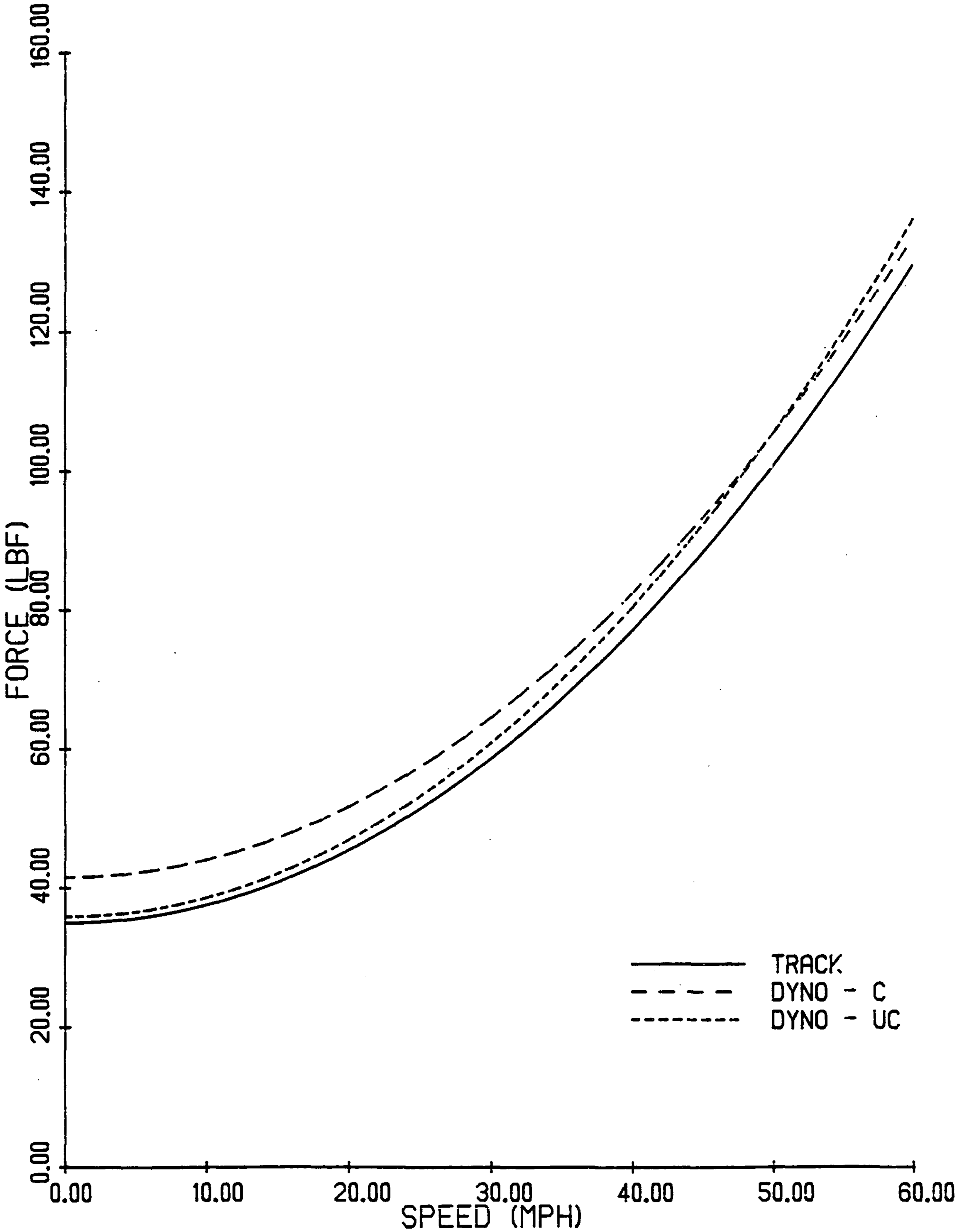
PINTO - TRACK/DYNAMOMETER COASTDOWNS

FIGURE 2



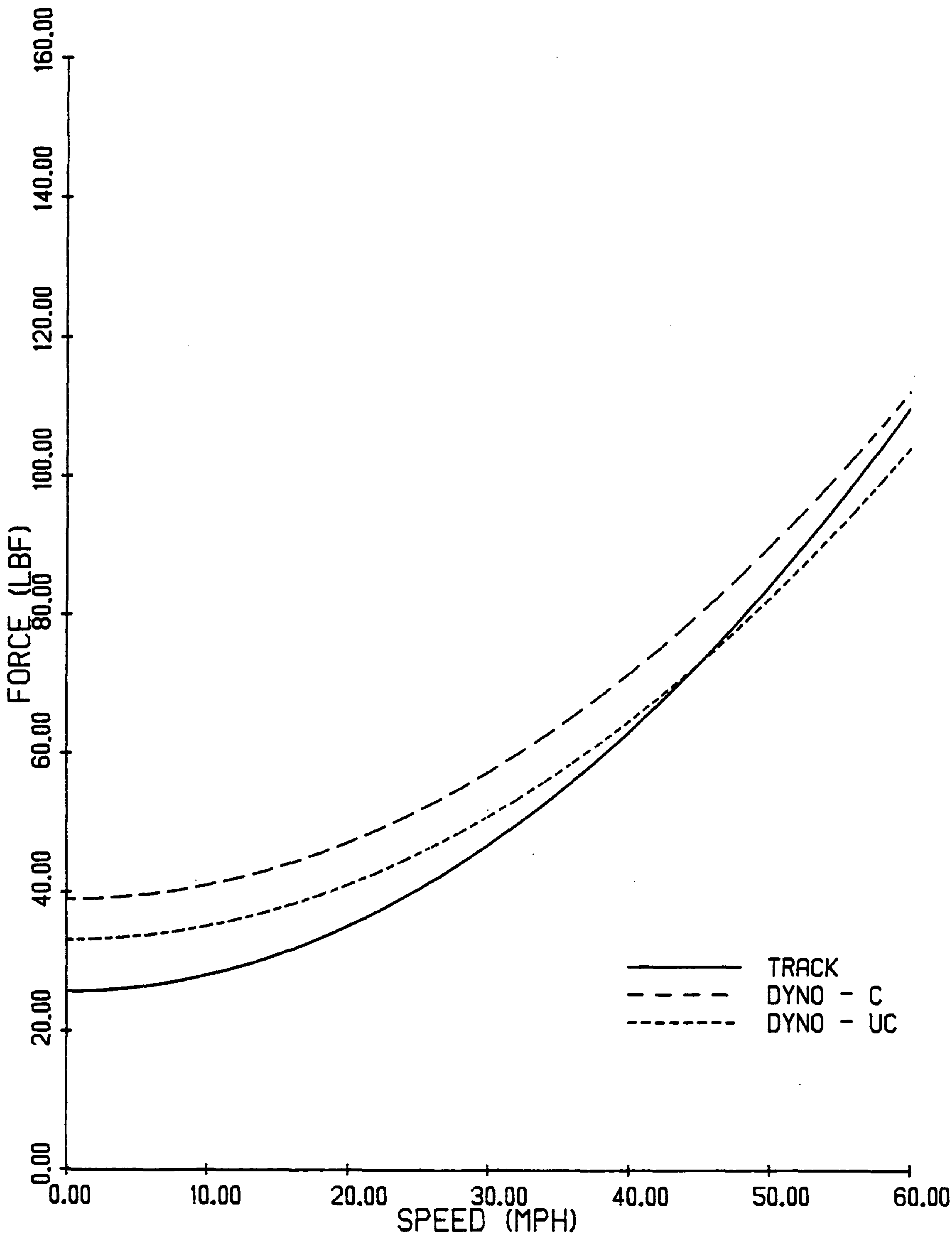
F100 - TRACK/DYNAMOMETER COASTDOWNS

FIGURE 3



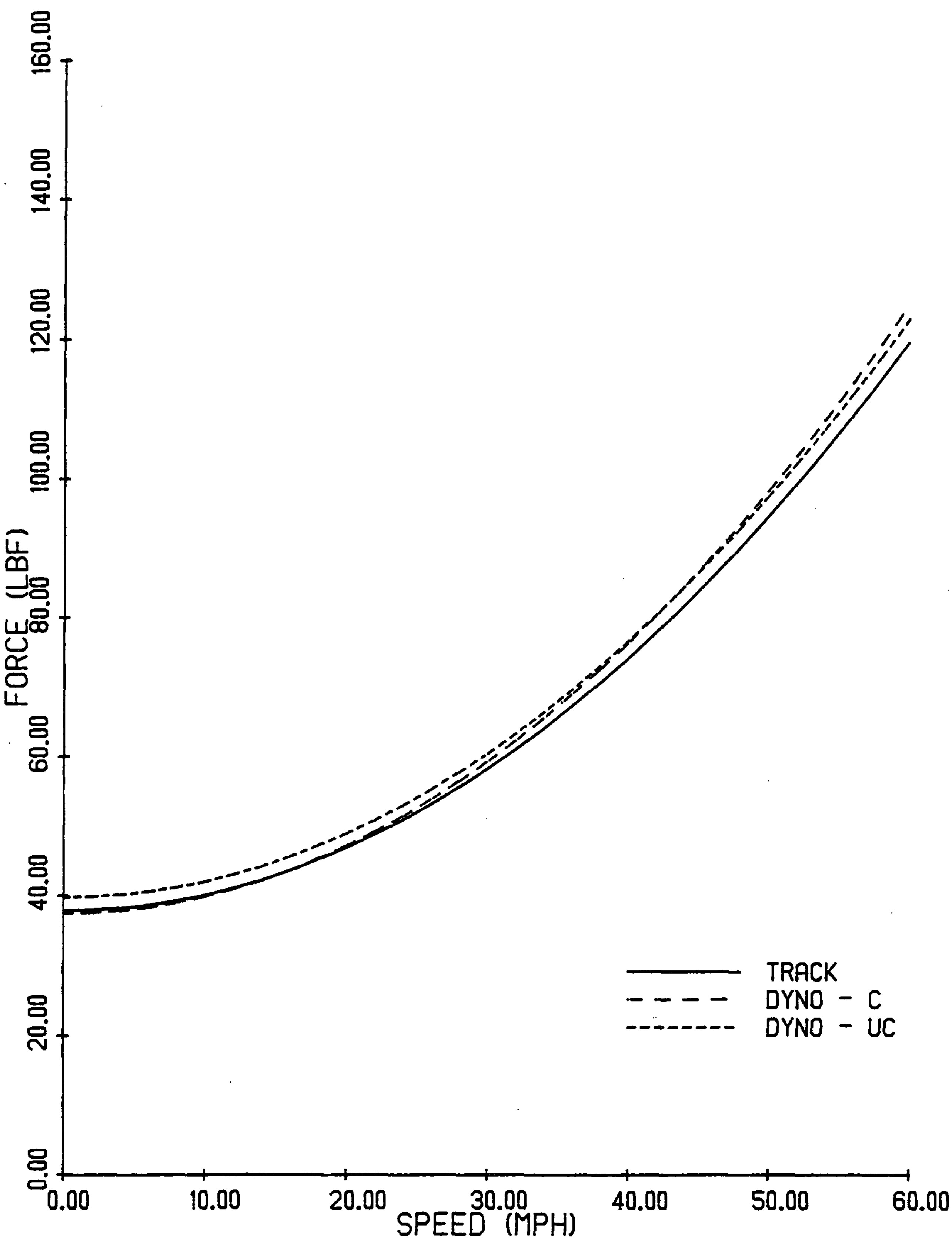
CITATION - TRACK/DYNAMOMETER COASTDOWNS

FIGURE 4



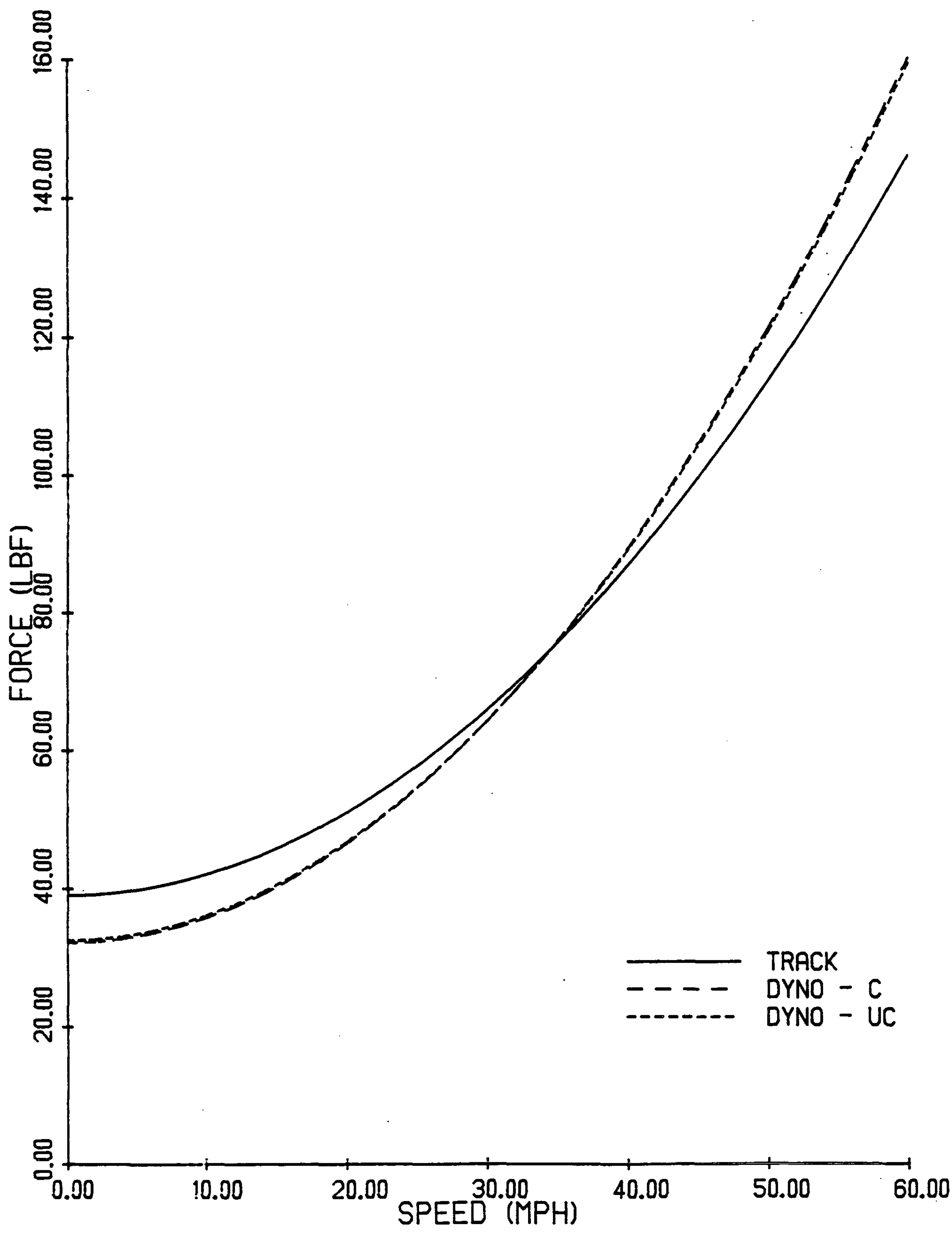
ESCORT - TRACK/DYNAMOMETER COASTDOWNS

FIGURE 5



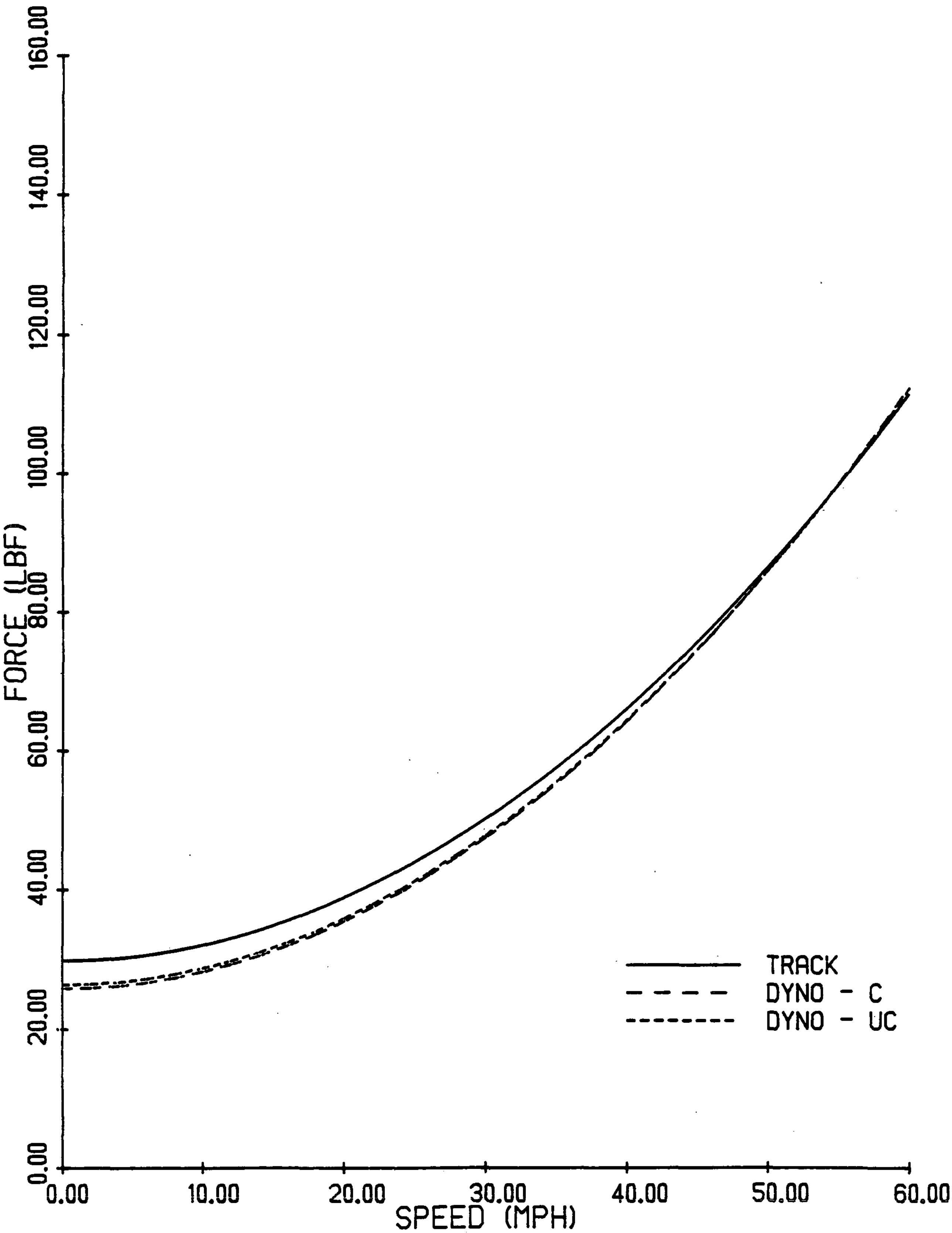
HORIZON - TRACK/DYNAMOMETER COASTDOWNS

FIGURE 6



CONCORD - TRACK/DYNAMOMETER COASTDOWNS

FIGURE 7



CIVIC - TRACK/DYNAMOMETER COASTDOWNS

FIGURE 8

Table 5

Fuel Economy Results, mpg[1]

Cycle	Vehicle	Track	Coupled Roll Dynamometer Volumetric	Coupled Roll Dynamometer Carbon Balance	Uncoupled Roll Dynamometer Volumetric	Uncoupled Roll Dynamometer Carbon Balance	Official EPA Results
FTP	Cutlass	13.68	13.98	14.56	14.09	14.49	18
	Pinto	17.04	18.18	19.36	19.45	19.46	21
	F-100	14.62	15.16	15.25	15.68	15.85	18
	Citation	18.83	19.02	19.06	18.83	19.06	20
	Escort	23.33	24.11	24.21	24.65	24.81	30
	Horizon	20.77	21.60	22.89	22.22	23.42	26
	Concord	18.24	18.60	18.83	18.65	19.36	19
	Civic[2]	33.33	34.03	35.27	36.62	37.88	41
HFET	Cutlass	19.19	20.23	20.72	20.31	20.89	24
	Pinto	23.53	25.75	26.84	26.68	27.60	29
	F-100	18.47	20.51	20.42	21.60	21.29	22
	Citation	26.70	28.79	28.21	29.43	28.75	30
	Escort	34.48	39.93	39.21	40.57	39.97	44
	Horizon	30.18	33.04	33.04	33.87	33.82	35
	Concord	28.08	28.63	28.83	29.33	29.38	26
	Civic[2]	43.52	42.88	43.41	48.38	48.86	55

[1] Each mpg value is a 3-vehicle average, with the exception of the Chevrolet Citation results which are average values based on nine repeat tests. Offical EPA results are the corresponding FTP or HFET values from offical EPA certification tests.

[2] Dynamometer horsepower inadvertantly set at equivalent AHP plus 10 percent for air-conditioning simulation.

These tables include actual distance measurements and fuel economy and fuel consumption calculations for the three segments (Bag 1, Bag 2, and Bag 3) of the FTP, and composite calculations for the FTP. Similar results are presented for the warm-up HFET, and the official HFET, which immediately follows the warm-up HFET. Tables C-1 through C-8 of the Appendix present the statistics of the composite FTP results and the official HFET results (in miles/gallon) for all vehicles and all test configurations. Included are calculations of the mean, standard deviation, and coefficient of variation for each vehicle/test configuration.

Table 6 summarizes the dynamometer and track fuel economy results as the percent fuel economy deviation from the track fuel economy. Thus, for the Oldsmobile Cutlass, the coupled roll dynamometer volumetric result is 2.2 percent higher than the corresponding track measured fuel economy. The data are referenced to the track fuel economy result because it is most representative of an actual driving experience, and therefore the most logical method of comparison. The official EPA results from emission certification and highway fuel economy tests are also compared to the track test data. The data are stratified according to drive axle type in order to characterize the higher tire losses expected for front-wheel drive vehicles.

V. Analysis of Results

A. Findings Based on Comparisons within TTI Data

Tables 5 and 6 demonstrate that large vehicle-to-vehicle variations were observed. Thus, the mean values discussed in the following analysis may have large values of standard deviation associated with them because of the combination of inherent variability of fuel economy measurements and the small sample sizes. Consequently, statistical confidence is obtained only for the larger effects, such as the differences between the track results and the carbon balance results obtained on the dynamometer with the rolls uncoupled. The individual vehicle results, however, show less variation. For example, the overall coefficient of variation, based on samples of nine track and 36 dynamometer tests with the Citation, is 1.7 percent. This value, approximately 2 percent, is believed to be typical. Therefore most of the analysis for the individual steps of this program, such as coupling the dynamometer rolls, is presented in terms of the data trends. When a majority of the test results show a directionally consistent shift, this is judged to be of engineering importance, even if the amount of the shift is similar in magnitude to the coefficient of variation.

Table 6

Percent Deviation from Track Fuel Economy Results[1]

Cycle	Vehicle	Coupled Roll Dynamometer Results: Volumetric	Coupled Roll Dynamometer Results: Carbon Balance	Uncoupled Roll Dynamometer Results: Volumetric	Uncoupled Roll Dynamometer Results: Carbon Balance	Official EPA Results
R-FTP[2]	Cutlass	2.2	6.7	3.0	6.2	39.2
	Pinto	6.7	15.0	14.1	15.6	30.6
	F-100	3.7	4.5	7.3	8.6	23.3
	Concord	2.0	3.2	2.3	6.1	4.1
	$\bar{x}$	3.7	7.4	6.7	9.1	24.3
	s	2.2	5.3	5.4	4.7	15.0
F-FTP	Citation	1.0	1.2	0.0	1.2	6.2
	Escort	3.3	3.7	5.7	6.3	28.6
	Horizon	4.3	10.2	7.0	12.8	25.2
	$\bar{x}$	2.9	5.0	4.2	6.8	20.0
	s	1.7	4.6	3.7	5.8	12.1
R-HFET	Cutlass	5.4	8.0	5.8	8.9	20.0
	Pinto	9.4	14.1	13.4	17.3	23.2
	F-100	11.0	10.6	16.9	15.3	19.1
	Concord	2.0	2.7	4.5	4.6	-7.4
	$\bar{x}$	7.0	8.9	10.2	11.5	13.7
	s	4.1	4.8	6.0	5.8	14.2
F-HFET	Citation	7.8	7.8	10.2	7.7	12.4
	Escort	15.8	13.7	17.7	15.9	27.6
	Horizon	9.5	9.5	12.2	12.1	16.0
	$\bar{x}$	11.0	10.3	13.4	11.9	18.7
	s	4.2	3.0	3.9	4.1	7.9

[1] Positive numbers indicate dynamometer fuel economy is <u>higher</u> than track fuel economy.
[2] R = Rear-wheel drive and F = Front-wheel drive

Four findings are apparent from an examination of the data from these eight vehicles: 1) vehicle fuel economy on the dynamometer is greater than the vehicle fuel economy on the track, even when the 50 mph dynamometer force is matched to the track force as accurately as possible, 2) vehicle fuel economy when the dynamometer rolls are coupled is less than corresponding measurements made without the roll coupler, 3) fuel economy measurements obtained by the carbon balance method are greater than those obtained by volumetric methods, in general, and 4) dynamometer fuel economy is higher than track fuel economy even when dynamometer force versus speed loading appears to exceed track loading conditions.

1. Dynamometer vs. Track Fuel Economy

Table 6 shows that dynamometer fuel economy measured with a volumetric flowmeter is always greater than the track fuel economy results when the 50 mph road force was matched to the 50 mph dynamometer force as accurately as possible.

A paired statistical t-test analysis using the data of Table 5 proves that dynamometer fuel economy as determined in the manner most representative of the EPA certification test (uncoupled dynamometer rolls and the carbon balance measurement method) is significantly higher than the corresponding track fuel economy. This finding is statistically significant at the 95 percent confidence level and is especially noteworthy because much care was taken to duplicate the total road force on the chassis dynamometer. The average difference between these test configurations was 8.1 percent for the FTP cycle and 11.7 percent for the HFET.

A difference exists between the fuel economy measured on the track and on the dynamometer even when the dynamometer replicates the track experience as accurately as possible with current methods. With fuel economy measured with a volumetric flow meter to provide a consistent comparison, the results obtained on the dynamometer with the rolls coupled are still considerably greater for all vehicles than the results obtained on the track. The average difference was 3.3 percent for the FTP cycle, and 8.7 percent for the HFET.

Rear-wheel drive vehicles showed a greater fuel economy difference between the track and dynamometer results for the FTP cycle than occurred for front-wheel drive vehicles. This was observed for all four possible comparisons--volumeteric and carbon balance measurement methods with the dynamometer rolls coupled or uncoupled. In the case of the HFET cycle, exactly the reverse trend was observed. Front-wheel drive vehicles showed a greater difference between the track and the dynamometer results than was observed from rear-wheel drive vehicles. Again, this observation was consistent for all four possible comparisons.

The data from the Honda Civic is not included in Table 6, and was not used in the previous analysis, since in the case of the Civic the dynamometer was not adjusted to match the measured road force of the vehicle. For this vehicle, the dynamometer adjustment was inadvertantly increased by 10 percent, the factor used to simulate air-conditioning usage in the official EPA certification test procedure. Interestingly, even with a 10 percent increase in the dynamometer actual horsepower, all average values of the FTP fuel economy of the Civic measured on the dynamometer still exceed the average fuel economy measured on the track. In the case of the HFET results, the average dynamometer measured fuel economy was still greater than the average track fuel economy for those tests in which the dynamometer rolls were not coupled. Only in the case of the HFET results with the dynomometer rolls coupled, did the track fuel economy results exceed those obtained on the dynamometer.

2. <u>Coupled vs. Uncoupled Roll Results</u>

The effects of coupling the dynamometer rolls can also be observed from an examination of the fuel economy data reported in Table 5. In 29 of 32 paired comparisons, coupled roll fuel economy is lower than uncoupled roll fuel economy. Volumetric measurements on rear-wheel drive vehicles produced an average fuel economy decrease of 2.7 and 2.9 percent for the FTP and HFET, respectively, when the dynamometer rolls were coupled. The corresponding carbon balance fuel economy decreases are 1.6 and 2.4 percent. A similar analysis for front-wheel drive vehicles shows fuel economy decreases of 2.8 and 4.4 percent for volumetric measurements conducted over the FTP and HFET, respectively, and decreases of 2.9 and 4.3 percent for FTP and HFET results, respectively, when carbon balance is used to determine fuel economy. This study produced an overall 3.0 percent decrease in fuel economy with a roll coupler device. This result is in good agreement with previously reported results obtained at the EPA-MVEL in 1978, where a small number of tests produced coupled roll effects of 1.8 and 3.8 percent for the FTP and HFET, respectively.[3]

It should be recalled that throughout this study, coupled roll dynamometer tests were based on an independent coupled roll PAU determination. Thus, the coupled and uncoupled roll <u>total</u> horsepower at 50 mph should be in good agreement. This is demonstrated in Table 4, where the values of total horsepower agree within the engineering precision of the procedure currently used for determining PAU adjustment.

Previous studies investigating dynamometer velocity and acceleration simulation concluded that the roll coupler provides a more accurate method of simulating the road driving experience of a vehicle by reducing the speed simulation/tire slip errors.[4] Thus, it is not surprising that the coupled roll fuel economy more closely agrees with the track fuel economy results, as this test program demonstrates.

An analysis of the fuel economy data indicates that the magnitude of the coupled roll difference is slightly higher over the HFET cycle. Coupling the dynamometer rolls reduces or eliminates tire-roll slip which is responsible for vehicle speed simulation errors. Computer modeling indicates that the accumulated speed error, the distance error, is greater over the HFET cycle. This may be the reason that coupling the dynamometer rolls produced a greater fuel economy effect on the HFET cycle than on the FTP. Similar experimental results have been observed by researchers at Ford Motor Company.[5]

3. Carbon Balance vs. Volumetric Measurements

Table 5 presents 32 paired comparisons of carbon balance and volumetric fuel economy measurements. The data are analyzed and partitioned according to FTP and HFET results because there is no logical basis for expecting differences in fuel measurement method as a function of roll configuration or vehicle drive axle type. In all comparisons, the FTP fuel economy results based on carbon balance measurements are higher than corresponding volumetric fuel measurements, while eight of 16 comparisons using the HFET cycle showed higher carbon balance fuel economy. This study finds an average 2.5 percent (standard deviation of 2.0) and 0.4 percent (standard deviation of 2.0) fuel economy increase for the FTP and HFET results, respectively, when fuel economy is calculated using the carbon balance technique. These results corroborate the findings of earlier EPA laboratory studies. For example, the average carbon balance to volumetric difference of 2.5 and 0.4 percent for the FTP and HFET, respectively, are similar to the average FTP and HFET values of 1.6 and 0.2 percent previously reported by Newell.[6]

While both fuel measurement methods contain sources of possible error, the flow meter approach is direct and simpler. Many known potential errors of the carbon balance method, such as fuel lost by evaporation, carbon particles lost in the exhaust system or in the sampling system, the assumptions of values of density and H/C ratio, which may be too high, and the inability of the flame ionization detector to measure oxygenated hydrocarbons, all result in higher measured fuel economy.

Additional analysis of the individual fuel economy data in Appendix D shows that Bag 1 results have the largest carbon balance to volumetric difference. A bag-by-bag analysis shows average fuel differences of 8.4, 1.4, and 3.9 for Bags 1, 2, and 3 of the FTP, respectively. Previous experimental studies have determined that a significant portion of the carbon balance/volumetric differences in Bag 1 can be attributed to fuel which must be replenished to the fuel float bowl at the beginning of the cold-start portion of the FTP.[7]

Experimental results usually indicate that carbon balance measurements are subject to greater variability than volumetric measurements.[7,8] However, the data of Appendix D indicate that the variability of carbon balance and volumetric measurements were similar during the course of this program.

4. Track/Dynamometer Loading Comparison

Since the results of this study show that vehicle fuel economy obtained from a dynamometer test is greater than that obtained on a test track, the data were analyzed for possible reasons for this difference.

The fuel economy differences were first examined for the presence of any systematic factors which would result in lower dynamometer loading. To assist in this examination, the plots of total force versus speed (Figures 1-8) were examined. Inspection of the force curves does not show a systematic underloading effect on the dynamometer. The dynamometer force curves are higher than the corresponding road force curves for some vehicles and lower for others. This is true for both front and rear-wheel drive vehicles.

Weight variations between track and dynamometer tests were examined, but again, no systematic differences are apparent. Effective vehicle mass on the dynamometer is higher for some vehicles and lower for others than the corresponding mass during the track tests. In general, the average total vehicle mass and the drive axle mass were within 1 percent of the track loading conditions.

An energy modeling analysis was conducted to combine the effects of mass and force into a single parameter, specific energy.[9] Table 7 is a summary of the energy analysis. The actual energy consumed, e_{In}, and the predicted energy required, e_{Req}, to operate a vehicle over the FTP or HFET is presented on a BTU/mi basis for each vehicle. The energy consumed for a particular cycle is based on the weighted volumetric fuel measurement. The predicted energy requirements were calculated from a computer energy model which used the force-speed curves shown in Figures 1-8 and the vehicle mass to

Table 7

Energy Analysis

Vehicle		FTP Track	FTP D-C [1]	FTP D-U [1]		HFET Track	HFET D-C	HFET D-U
1. Cutlass	e_{In}[2] =	8,509	8,326	8,261	e_{In} =	6,066	5,754	5,731
	$e_{Req.}$[3]	857	848	834	$e_{Req.}$ =	885	863	859
	$e_{Req.}/e_I$	0.101	0.102	0.101	$e_{Req.}/e_{In}$=	0.146	0.150	0.150
2. Pinto		6,831	6,403	6,305		4,947	4,520	4,363
		796	748	712		861	857	810
		0.117	0.117	0.113		0.174	0.190	0.186
3. F-100		7,962	7,678	7,423		6,302	5,675	5,389
		995	975	979		1,152	1,106	1,120
		0.125	0.127	0.132		0.183	0.195	0.208
4. Citation		6,182	6,120	6,182		4,360	4,043	3,955
		696	708	693		750	774	777
		0.113	0.116	0.112		0.172	0.191	0.196
5. Escort		4,989	4,828	4,722		3,376	2,915	2,869
		553	607	571		622	656	608
		0.111	0.126	0.121		0.184	0.225	0.212
6. Horizon		5,604	5,389	5,239		3,857	3,523	3,437
		642	651	656		697	721	715
		0.115	0.121	0.125		0.181	0.205	0.208
7. Concord		6,382	6,258	6,241		4,145	4,066	3,969
		783	777	776		844	896	893
		0.123	0.124	0.124		0.204	0.220	0.225
8. Civic[4]		3,492	3,410	3,179		2,675	2,715	2,406
		553	534	535		633	629	629
		0.158	0.156	0.168		0.237	0.232	0.261

[1] Test type: D-U = Dynamometer rolls uncoupled, D-C = Dynamometer rolls coupled. D-U and D-C tests attempt to match straight track coastdown force at 50 mph. Theoretical FTP distance (11.03 miles) and theoretical HFET distance (10.25 miles) are used for the energy requirements calculations.

[2] e_{In} = Energy in (BTU/mi). H_C = 116,400 BTU/gal. Energy-in calculations based on weighted volumetric fuel measurements.

[3] $e_{Req.}$ = Energy required (BTU/mi) at the drive wheels.

[4] Dynamometer horsepower inadvertently set at equivalent AHP plus ten percent for air-conditioning simulation.

determine the total vehicle load during the test cycle. The ratios of required to input energy are presented as an estimate of the energy efficiency. Table 7 shows a general pattern of higher dynamometer specific energy, relative to the track condition for the front-wheel drive vehicles due to greater tire energy losses on the dynamometer. For three of four vehicles, the dynamometer required specific energy was greater than the track specific energy. All rear-wheel drive vehicles were predicted to require less specific energy on the dynamometer relative to the road test condition. In either case, however, the modeled dynamometer energy requirements were generally within 1 percent of the modeled track energy requirement. Thus, the specific energy analysis is not sufficient to explain the observed differences between road and dynamometer fuel economy results.

The energy modeling analysis was based on track coastdowns obtained on the straight segments of the track. Consequently, track curvature effects could introduce an effect which would not be observed in the previous analysis. To test the track curvature effect, all vehicles were also coasted down on curved segments of the track. Table 3 shows a consistent small increase in road force of about 2 percent due to road curvature effects.

The effect of the track curvature on the vehicle fuel economy was investigated by conducting fuel economy tests on the Horizon and Civic with the dynamometer adjusted to simulate the loadings measured during the curved track coastdowns. These results are summarized in Tables C-6 and C-8 of the Appendix. Although considerable data scatter is evident, fuel economy results are about 1 to 2 percent lower using the curved track loadings. This observed fuel economy effect is the upper bound of the anticipated track effect because these dynamometer loadings simulated operation of the vehicle on a continuous curved surface, while the test track has only several curved sections.

This analysis found no vehicle loading errors which could account for the observed fuel economy differences. But, it should be noted that the coastdown measurements are indirect quasistatic approaches to force and energy measurements--not direct measurements of the dynamic system which is acting during road and dynamometer transient tests. It is possible that a dynamic error in the dynamometer could yield a systematic fuel economy effect. However, such an error would have to be quite large to cause the observed effects and it is unlikely that errors of this magnitude exist. It should be noted that the Civic fuel economy measured on the dynamometer was higher than the track result even though the dynamometer was inadvertently adjusted to simulate a 10 percent power overload.

The energy efficiency data of Table 7 suggest that vehicles operate more efficiently on the dynamometer. This finding is consistent with previous EPA track-to-dynamometer studies.[10] This energy efficiency discrepancy may be due to differences in internal vehicle operating parameters during the track and dynamometer tests. This program collected measurements of four fluid temperatures during the road and dynamometer tests of the Citation. An inspection of the temperature data indicates that the peak temperatures of engine coolant, engine oil, and transmission oil are approximately 20°F higher on the dynamometer than are the peak temperatures achieved under track test conditions. Higher oil temperatures suggest lower lubricant viscosity and less frictional energy dissipation.

B. Findings Based on Comparisons with EPA-Certification Data

The fuel economy results of this program are compared to official EPA-Certification results in Tables 5 and 6. Table 5 compares fuel economy results on an average absolute mpg basis, while Table 6 expresses the track-to-dynamometer difference as a percentage.

The significance of the comparison to EPA-Certification results is in the magnitude of the differences between the track-to-official EPA numbers, and the carbon balance uncoupled roll results versus official EPA results. Table 6 shows an average of 24 and 14 percent higher fuel economy for official results from rear-wheel drive FTP and HFET test configurations. Similar results for the front-wheel drive FTP and HFET tests are 20 and 19 percent, respectively. Table 6 also shows a large discrepancy between official EPA fuel economy and this program's uncoupled roll, carbon balance fuel economy results (the test configuration closest to official Certification test procedures). An inspection of the data shows an increase of 15 percent and 2 percent for the rear-wheel drive vehicle FTP and HFET results, respectively. The 15 percent value for the rear-wheel drive vehicles on the FTP cycle is the difference between the 24.3 percent deviation of the official EPA rear-wheel drive FTP results from the track results, and the 9.1 percent deviation of the uncoupled roll, carbon balance results from the track. The corresponding increases for the front-wheel drive vehicle FTP and HFET results are 13 percent and 7 percent, respectively.

Historically, EPA has established the presence of a production-to-prototype vehicle difference as a mechanism of explaining the difference between EPA official fuel economy results and results obtained from the EPA Emission Factors program. The median discrepancy currently observed between the Emission Factor and Certification programs is 8 and 6 percent for the FTP and HFET, respectively.[11] The larger discrepancies of this program appear to be a combination of production-to-prototype vehicle differences and differences in the procedures of this test program and those of the EPA Certification program. For example, in this program all vehicles were operated on the track and on the dynamometer at their production weights plus the additional weight of the test instrumentation and test personnel. Table 8 summarizes the dynamometer adjustments used by TTI and EPA. Six of eight TTI test vehicles exhibit higher (4 to 10 percent) inertia loading. Overall, TTI inertia settings are 5 percent higher than EPA Certification values. Values of TTI dynamometer AHP range from 20 percent higher to 10 percent lower than EPA-Certification horsepower settings, with the average load being 6 percent higher.

The increased average loading of the vehicles in this program is at least partially caused by the increased weight of the test instrumentation and personnel. However, inconsistancies in the required weights and test weight simulation during the Certification coastdown and emissions/fuel economy test contribute to the observed fuel economy differences.

Table 8

Comparison of TTI and
EPA-Certification Dynamometer Settings

		TTI		EPA-Certification	
		IW (lbm)	AHP (hp)	IW (lbm)	AHP (hp)
1.	Cutlass	4,000	10.5	3,750	11.6
2.	Pinto	3,000	9.7	3,000	9.7
3.	F-100	4,250	15.1	3,875	14.0
4.	Citation	3,000	8.3	3,000	6.6
5.	Escort	2,500	5.8	2,375	6.4
6.	Horizon	2,750	7.9	2,500	6.4
7.	Concord	3,500	11.0	3,375	10.9[1]
8.	Civic	2,250	8.4[1]	2,125	7.8

[1] Includes 10 percent increase in horsepower to account for air-conditioning simulation.

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NOTE: THE APPENDICES TO THIS REPORT ARE AVAILABLE UPON REQUEST.