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Dynamometer and Track Measurement of Passenger Car Fuel Economy

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DYNAMOMETER AND TRACK MEASUREMENT OF PASSENGER CAR FUEL ECONOMY

by

Falcon Research & Development Co.

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1.0 INTRODUCTION

The Environmental Protection Agency (EPA) is required under Section 404 of the National Energy Conservation Policy Act of 1978 to examine and analyze the factors that contribute to the fuel economy differences achieved by actual road performance of automobiles as compared to the fuel economies estimated for these automobiles by EPA test procedures. EPA test procedures measure automobile fuel economy by operating the vehicle on a chassis dynamometer.

This report is an analysis of data obtained under a testing program conducted by EPA's Emission Control Technology Division (ECTD). The analysis deals with a subset of the wide range of factors that contribute to fuel economy differences measured on a road in consumer service as compared to EPA estimates using a dynamometer. Specifically, this report analyzes the relationship between the fuel economy of production cars tested on dynamometer equipment and the fuel economy they achieve when operated over the same driving sequence on a test track. The test track simulates a subset of driving conditions that might be encountered in actual driving.

The initial thrust of this report is to process the raw data and statistically analyze any differences. The physical significance of the results, supplemented wherever possible by other studies conducted by the ECTD, are then discussed and unresolved issues noted.

2.0 SUMMARY AND CONCLUSIONS

Analysis of the fuel economy data obtained in this program from dynamometer and track tests on eight 1976 model year production light-duty vehicles over the urban, highway, steady-state and modified highway driving cycles permitted quantification of the effects on fuel economy due to:

(1) Dynamometer and track differences, radial and bias belted tire differences;

(2) Fuel consumption measurement differences including carbon-balance-to-meter and meter-to-meter differences;

(3) Air conditioning;

(4) Air conditioning simulation procedure for dynamometer; and

(5) Coast-down time differences between dynamometer and track.

Results of the analysis showed:

- Fuel economy in miles per gallon, as determined from fuel consumption measurements over the urban and highway cycles, ranged from 5% to 12% higher on the dynamometer compared to track for vehicles tested with radial tires. For vehicles tested with bias tires fuel economy over the urban and highway cycles ranged from 5% to 15% higher on the dynamometer compared to track.

- On dynamometer tests over all cycles, vehicles equipped with radial tires obtained generally lower fuel economies than vehicles equipped with bias tires. On track tests vehicles equipped with radial tires generally obtained a higher fuel economy than vehicles equipped with bias tires. However, the fuel economies compared in this way depend greatly on the type of radial and the type of bias tire as well as the vehicle tested.

- The relationships between fuel consumption measurements from flowmeter and carbon balance methods are reasonably well fitted by straight lines in fuel consumption space.

These lines have offsets that vary from meter to meter However, the slopes are consistent for all meters and imply that carbon balance fuel consumptions decrease relative to meter fuel consumptions at a 5% rate. In general, meter measured fuel consumptions were greater than carbon balance fuel consumptions by as much as 5% over the range of measured fuel consumptions. No conclusions could be drawn with regard to absolute accuracy of the fuel consumption and fuel economy measurement methods.

- Operation of a vehicle's air conditioner resulted in an 8% to 17% decrease in fuel economy as measured on the track over the urban cycle. Over the highway cycle the decrease in fuel economy due to air conditioning ranges from 5% to 12% as measured on the track. The simulation of air conditioning on the dynamometer by a 10% increase in the P.A.U. setting of the dynamometer above certification value produces no significant change in fuel economy as compared to certification P.A.U. setting.

- For the five variations of the EPA highway cycle investigated, fuel economy effects measured on the dynamometer were directionally consistent, and statistically equivalent in magnitude to the effects seen on the track. The results showed:

  (a) Cold starting decreases EPA highway mpg by 10%

  (b) The noisy highway schedule produces a 3% lower mpg compared to the EPA highway cycle

  (c) The redistributed highway schedule produces a 4% lower mpg compared to the EPA highway cycle

  (d) The smooth highway schedule produces a 5% increase in mpg compared to the EPA highway cycle

  (e) A 50 mph highway cruise produces an 8% increase in mpg compared to the EPA highway cycle

- Coast-down tests conducted on six of the eight vehicles in the test program permitted total road load horsepower calculations at 50 mph on each of the six vehicles for both track and dynamometer tests. The results showed that total road load horsepower estimates were generally lower on the track than on the dynamometer. This result is not consistent with the fact that the fuel economy estimates are larger on the dynamometer as compared to track. However, road load horsepower calculations were consistently higher for bias tires than for radial tires on track tests and were consistently higher for radial tires than for bias tires on dynamometer tests. This result is consistent with the fact that the rolling resistance of radial tires is generally lower than for bias tires on track tests.

Recent studies by EPA not within the scope of this program indicate that small twin-roll dynamometers do not properly simulate vehicle road loads because of velocity differences measured between the front and rear rolls of the dynamometer when operating over a driving cycle. In accordance with Federal Test Procedures, small twin-roll dynamometers operate with their rolls uncoupled from each other. The front roll is coupled to flywheels and a power absorption unit, the latter simulating the aerodynamic force experienced by a vehicle. The rear roll drives a tachometer that measures vehicle speed. When the dynamometer rolls are coupled together, preliminary tests indicate that dynamometer to track fuel economy differences may be reduced by about 6%. The remaining dyno-to-track mpg differences are probably explainable by the tire/surface interaction differences.

3.0 BACKGROUND

The fuel economy data obtained from eight 1976 light-duty passenger vehicles and analyzed in this report represent data obtained in the second phase of a program designed to investigate dynamometer/track fuel economy differences. In the initial phase of the program, six 1975 productions cars were operated on EPA dynamometers and on the Ohio-Transportation Research Center test track.[1] The EPA City and Highway cycle test results for these six cars are summarized in Table 1.

The dynamometer tests included standard EPA City tests (3-bag 1975 FTP's) and Highway tests, from which combined 55/45 dynamometer fuel economy values were calculated. Since no systematic offset between carbon balance and flowmeter mpg measurements was observed in these tests, the results of these two measurements were averaged for each car.

The city tests conducted on the track employed only hot starts, so a weighted cold start/hot start value for the track testing had to be estimated. This was done using each car's ratio of 1975 FTP fuel economy to hot LA-4 fuel economy, as observed in the dynamometer tests. The resulting "75 FTP" track mpg values were then used with the raw highway cycle track data to compute 55/45 track fuel economies.

The "dyno/track" mpg ratios in the table are thus the result of comparing dyno and track 1975 FTP mpg, highway mpg, and 55/45 mpg. The averages of these ratios are given at the bottom of the table.

Table 1

COMPARISON: DYNAMOMETER MPG VS. TRACK MPG, 1975 MODELS
SOURCE: TAEB REPORT 76-1[1]

	VW RABBIT 90-M*	FORD PINTO 140-M*	PONTIAC FIREBIRD 250-M**	FORD GRANADA 250-A*	CHEVROLET CHEVELLE 350-A**	LINCOLN CONT'L. 460-A*
A. DYNAMOMETER MPG						
'75 FTP - Carbon Bal.	24.4	17.8	17.0	13.0	14.0	9.3
- Flowmeter	23.8	17.6	17.3	13.1	13.4	9.8
Average	24.10	17.70	17.15	13.05	13.70	9.55
Hot LA-4 - Carbon Bal.	26.1	18.9	17.4	14.0	14.6	10.2
- Flowmeter	25.0	18.6	17.8	14.1	13.7	10.5
Average	25.55	18.75	17.60	14.05	14.15	10.35
Ratio, '75 FTP/ Hot LA-4	0.943	0.944	0.974	0.929	0.968	0.923
Highway - Carbon Bal.	36.9	28.1	24.4	18.2	19.4	15.0
- Flowmeter	34.5	27.6	25.3	18.9	18.7	15.5
Average	35.70	27.85	24.85	18.55	19.05	15.25
Dyno 55/45 MPG	28.23	21.17	19.93	15.06	15.68	11.48
B. TRACK MPG						
Hot LA-4 - Flowmeter	24.0	16.6	16.4	12.5	13.1	10.3
"75 FTP" Track	22.63	15.67	15.97	11.61	12.68	9.51
Highway - Flowmeter	33.7	25.5	23.8	16.5	17.7	16.2
Track 55/45 MPG	26.56	18.96	18.75	13.40	14.54	11.68
C. DYNO/TRACK RATIOS						
City	1.065	1.130	1.074	1.124	1.080	1.004
Highway	1.059	1.092	1.044	1.124	1.076	0.941
55/45	1.063	1.117	1.063	1.124	1.078	0.983

SIX-CAR AVERAGE RATIOS:		
	CITY	1.080
	HIGHWAY	1.056
	55/45	1.071

* Radial Tires
** Bias Tires

4.0 TEST DESIGN

The test program was designed to produce data on the following fuel economy influences:

- Dynamometer mpg vs. track mpg
- Effects of tire type (radial vs. bias-belted) and tire pressure
- Effects of air conditioner operation and air conditioner simulation
- Effects of deviations from the standard EPA Highway Cycle
- Carbon balance vs. volumetric fuel consumption measurement

4.1 Dynamometer MPG vs. Track MPG

The same basic test cycles were run on the dyno and the track, and included:

- The EPA urban driving schedule ("city cycle" or "LA-4")
- The EPA highway driving schedule
- Steady-state cruises
- Modified versions of the EPA highway schedule
- Coastdowns from 60 to 5 mph

Fuel flowmeters were used in the dyno tests to permit comparisons with the track tests on a common fuel measurement basis. Unfortunately, the same fuel flowmeter used to measure the fuel economy of a car tested on a dynamometer was not always used to measure fuel economy of the same car tested on the test track. Thus, any flowmeter to flowmeter differences or biases due to calibration or other effects introduce additional variability or biases into the differences measured between dyno/track fuel economies. More will be discussed concerning flowmeter effects in Section 8.2.

4.2 Tire Type/Tire Pressure Effects

Each vehicle arrived equipped with OEM tires of the type (radial or bias-belted) sold as standard equipment for that model. A matched set of tires of the alternate construction type (bias-belted or radial) was acquired to provide a controlled comparison. The alternate sets--furnished for the program by the vehicle manufacturers--were also OEM tires, made by the same tire manufacturer, with the same load rating, and, if possible, with the same rolling radius as the standard equipment set.

In the case of the 1976 Honda CVCC Civic tested, however, it is noted that the bias-belted tires used were B. F. Goodrich 6.005 x 12 and the radial tires used were Michelin 155SR x 13. The fact that the two tire types had different wheel radii is expected to impact on fuel economy, because of the implied difference in N/V ratio.

The full battery of cyclic tests, steady states, and coastdowns were run on both sets of tires. The respective manufacturers' recommended cold inflation pressures were used on the track, and most dyno tests were run at 45 psi cold. A few dyno tests were run at the same cold inflation pressure as the track.

In an attempt to isolate tire warmup effects from those of the engine and drive train, "hot train, cold tire" tests were conducted by running the city cycle on fully-warmed up vehicles immediately after installing a set of tires at room temperature and the cold inflation pressure corresponding to the dyno or track test site.

4.3 Air Conditioning Effects

For those test cars equipped with air conditioners, city cycles (cold and hot), standard hot highway cycles, and hot steady states were run in the following configurations:

Dyno: A/C off
Dyno A/C "simulation"
A/C on

Track: A/C off
A/C on

For all "A/C on" tests, the air conditioner temperature and blower controls were set for maximum cooling. In the dyno A/C "simulation" tests, the air conditioner was turned off and the dyno road load* at 50 mph increased 10% in accordance with EPA certification procedure.

4.4 Effects of Highway Test Modifications

Five variations from the standard EPA highway test were investigated by means of the following:

- Cold starting, denoted as CST
- "Noisy" driving schedule, denoted as HNO
- "Redistributed" driving schedule, denoted as HRE
- "Smooth" driving schedule, denoted as HSM
- 50 mph steady state cruise

The cold start tests used the standard EPA nonurban driving schedule, so any observed mpg penalty would derive solely from vehicle warmup.

In the Noisy cycle, the distribution of speeds is virtually the same as the standard cycle (so no mpg effects of this cycle were related to road load changes), but the undulations in the cycle are amplified so that acceleration rates due to cycle "noise" are essentially doubled. Any mpg penalty for this cycle would be a function of vehicle inertia.

In the Redistributed cycle, the fine texture of the cycle is preserved, but blocks of the trace are moved either up or down, giving a wider distribution of speeds (up to 73 mph and down to 18 mph, compared to 60 mph maximum and 28 mph minimum for the standard cycle). A fuel economy penalty seen with this cycle would stem from operation in the added lower--and higher--speed regimes, both of which are well-known detriments to fuel economy.

In contrast to the above modifications, which increase the "busyness" of the cycle, the Smooth cycle consists simply of the standard cycle's initial acceleration, a constant 50 mph cruise, and the standard cycle's final deceleration; it is the smoothest possible variant of a 10-mile drive that begins and ends at idle and averages 48 mph.

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* Calibrated power abortion unit (PAU) setting.

The 50 mph cruise is the boundary case, differing from the Smooth cycle in the absence of the initial acceleration and final deceleration. The difference between the Smooth cycle and 50 mph cruise is a measure of the effect of vehicle stops. Appendix A compares the Noisy, Redistributed, and Smooth cycles with the Standard cycle.

4.5 CVS vs. Meter MPG

For all dynamometer tests, fuel economy of each vehicle was determined by the carbon balance calculation and by fuel flowmeter(s). In the carbon balance calculation of fuel economy, all of the carbon-containing compounds in the vehicle exhaust (hydrocarbons, carbon monoxide and carbon dioxide) are measured by constant volume sampling. Fuel economy is then calculated from the measured levels. In this way, the fuel economy measurements obtained from the flowmeter(s) may be compared with the fuel economy estimates obtained by carbon balance.

5.0 TEST VEHICLES

The vehicles tested in this program span a wide range of car sizes and types. The vehicles were 1976 model production cars, with a minimum of 2000 miles accumulated in routine service prior to the tests.* Summary descriptions of the vehicles with both dynamometer and track test data are given in Table 2; Appendix B gives more detailed configuration data on each vehicle.

The vehicles involved in the different effects investigated in the test program are shown in Table 3.

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* Exceptions: The Aspen Wagon and Impala had less than 2000 odometer miles at delivery, and were "aged" to 2000 miles using the EPA mileage accumulation procedure.

Table 2

TEST VEHICLES

MAKE/MODEL	ENGINE	WEIGHT CLASS	TRANSMISSION	AIR CONDITIONED
Honda Civic	91 CID CVCC	2000	4-Speed Manual	No
Datsun B-210	85 CID	2250	4-Speed Manual	No
Ford Pinto	140 CID	3000	3-Speed Automatic	No
AMC Pacer	232 CID	3500	3-Speed Automatic	Yes
Ford Granada	250 CID	4000	3-Speed Automatic	Yes
Dodge Aspen Wagon	225 CID	4000	3-Speed Automatic	Yes
Chevrolet Impala	350 CID	5000	3-Speed Automatic	Yes
Chevrolet Chevette	98 CID	2250	3-Speed Automatic	Yes

Table 3

RELATIONSHIP BETWEEN EFFECTS INVESTIGATED AND TEST VEHICLES

CAR	DYNO (METER MPG) VS. TRACK	RADIALS VS. BIAS-BELT	AIR CONDITIONING	CVS VS. METER (DYNO)	TIRE WARMUP	MOD. HIGHWAY CYCLES	FUEL FLOWMETER NO. DYNO/TRACK
Honda CVCC	No	Dyno	No	Yes	Dyno, Bias	Dyno, Radials	1514 / Unknown, 2099
Datsun B-210	Radial, Bias	Dyno, Track	No	Yes	Dyno, Track Radial, Bias	Dyno, Track Radials	1513, 2099, 1514 / 1472
Ford Pinto	Radial, Bias	Dyno, Track	No	Yes	Track, Radial, Bias	Dyno, Track Bias	1514 / 1513, 1514, Unknown
AMC Pacer	Bias	Track	Dyno, Track	Yes	Dyno (Bias), Track (Radial, Bias)	Dyno,(Bias), Track (Radial, Bias)	Unknown, 1514 / 1513, 1514, 1358
Ford Granada	Radial, Bias	Dyno, Track	Dyno, Track	Yes	Dyno (Radial), Track (Radial, Bias)	Dyno (Radial) Track (Radial, Bias)	Unknown / Unknown, 1514, 1472
Dodge Aspen Wagon	Radial, Bias	Dyno, Track	Dyno, Track	Yes	Dyno, Track Radial, Bias	Dyno (Radial, Bias) Track (Radial)	Unknown / Unknown, 1514
Chevrolet Impala	Radial, Bias	Dyno, Track	Dyno, Track	Yes	Dyno, Track Radials	Dyno, Track Radials	Unknown, 1514 / 1472
Chevrolet Chevette	Radial	Track	Track	Yes	No	Track (Radials, Bias)	Unknown / 1472

6.0 TEST PROCEDURES

At arrival, each test car was inspected, and tuning and condition of vacuum and EGR lines compared to manufacturers' specifications. Five of the cars required minor adjustments; none of the vehicles was found to be significantly out of specification.

Following this incoming inspection, each vehicle was given a standard dyno FTP and HFET test series, using certification-type preconditioning and the certification city and highway procedures. These baseline tests were used as a go/no-go screening prior to committing the cars to the full series of dyno and track testing. Results of the baseline tests are shown in Table 4.

The emissions column in Table 4 gives the highest value for each pollutant in any one baseline test, not the average values for all baseline tests. The only instance in which any pollutant exceeded the levels of the 1976 Federal Emission Standards* was in one Pacer test, where NO_x was 5% high; average NO_x for all of the baseline Pacer tests was within the Standard.

All fuel economy values for the test cars were within 3% of certification car test results. The Pinto yielded the largest shortfalls between test car mpg and certification car mpg; 7% city and 8% highway; nevertheless, the Pinto was accepted for testing in view of its admirable assault on the 1980 Emission Standards.

Most of the dynamometer tests were performed on the same twin-roll water brake certification dynamometer, denoted #5 (some tests were conducted on twin-roll dynamometer denoted #207), using the same inertia weight and road load settings as each test car's certification couterpart. Vehicle speed measurements were taken from the rea dyno roll.

The track tests were run on the 7.5 mile high-speed oval at Ohio's Transportation Research Center, using a 5th wheel for speed indication.

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* HC = 1.5 g/m; CO = 15 g/m; NO_x = 3.1 g/m

Table 4

BASELINE TEST RESULTS

VEHICLE	MAXIMUM 1975 FTP EMISSIONS, gm/mi[a]			CARBON BALANCE FUEL ECONOMY, MPG	
				Test Car	Cert. Car
Honda (Bias-Belt)	HC	0.80	City	29.9	31.9
	CO	4.88	Hwy	41.5	41.8
	NO_x	1.54	55/45	34.2	35.7
Datsun (Bias-Belt)	HC	0.99	City	27.7	27.9
	CO	8.97	Hwy	39.5	39.8
	NO_x	2.46	55/45	32.0	32.2
Pinto (Bias-Belt)	HC	0.42	City	21.0	22.5
	CO	2.51	Hwy	29.0	31.5
	NO_x	1.79	55/45	24.0	25.8
Pacer (Bias-Belt, A/C Sim)	HC	1.06	City	17.8	17.5
	CO	11.84	Hwy	21.6	22.3
	NO_x	3.27[b]	55/45	19.4	19.4
Granada (Radial, A/C Sim)	HC	1.21	City	16.5	15.7
	CO	3.72	Hwy	18.9	19.2
	NO_x	1.46	55/45	17.5	17.1
Aspen (Radial, A/C Sim)	HC	0.68	City	17.4	17.6
	CO	3.03	Hwy	22.8	22.6
	NO_x	2.54	55/45	19.4	19.5
Impala (Radial, A/C Sim)	HC	0.57	City	12.3	13.0
	CO	12.57	Hwy	18.0	18.6
	NO_x	2.50	55/45	14.3	15.0

(a) Highest value obtained for each pollutant in any replicate test.

(b) Average NO_x for all Pacer baseline tests was 2.95.

Volumetric fuel consumption measurements were made using Fluidyne Model 1250 flowmeters; these meters have a rated accuracy within ± 1%, and incorporate fuel temperature sensing for density corrections. All meters were calibrated prior to the test program, and calibration was reverified after the conclusion of the tests. However, meter to meter differences were detected as described in Section 8.2.

All of the city and highway driving schedules were run using pre-printed driver's aid traces and a Varian strip chart recorder. In the track tests, distance measurements were taken manually, using the mile markers posted every 1/10 mile; distances between the markers were eye-balled to the nearest 1/100 mile.

Cold start tests at both sites were preceded by overnight soaks indoors. For cold starts on the track, the vehicles were towed at 10 mph from the soak bay to the starting point on the oval, a distance of about 0.2 mile.

Replicates were run on some of the cycle tests at both sites. The replicate tests were conducted to give an estimation of test to test variability.

Steady state tests on the dynamometer consisted of a 5-minute cruise at each speed from 10 mph to 60 mph in 10-mph increments; on the track, steady states were run in opposite-direction pairs on the straightaway segments of the oval, at speeds from 10 mph to 80 mph (or wide-open throttle, whichever came first) in 10-mph increments. Because of the 1.9 mile straightaway lengths, test times for the higher speed track steady states had to be limited to durations less than 5 minutes.

Speed-time traces of the coastdowns on both the dyno and the track were recorded on a Honeywell strip chart recorder; as in the other tests, a 5th wheel was used for speed measurements on the track.

Ambient conditions recorded at both sites included dry and wet bulb temperatures and barometric pressure. At the track, wind speed and direction at the edge of the South straightaway were recorded for each test.

7.0 RESULTS OF FUEL ECONOMY TESTS

Major test parameters are:

Location (Dynamometer No./Track)
Vehicle
Tire Type (Radial/Bias Belted)
Tire Pressure(s)
Air Conditioner Status (Off/On/Simulated*)
Fuel Flow Meter Number
Driving Cycle (CC/HH/HC/FTP/HST/CST/HNO/HRE/HSM -
Steady State: 10/20/30/40/50/60/70/80 mph)

Over urban driving cycles, CC/HH/HC/FTP, fuel economy values were recorded for the individual transient and stabilized segments, viz. BAG1 (cold transient), BAG2 (hot stabilized) and BAG3 (hot transient), included in the cycle. The BAG1, BAG2, and BAG3 fuel economies were considered the basic data, rather than the overall cycle composite fuel economies.

As will be described in Section 8.3, an analysis of dynamometer and fuel flowmeter effects led to the conclusion that the two dynamometer test cells used were essentially equivalent and that certain fuel flowmeters could be validly aggregated after application of specified corrections in fuel consumption space.

Tests which matched in all of the above parameters were then considered replicated, and sample mean fuel economy values were computed. In case of two or more replications, the coefficient of variation (unbiased estimate of standard deviation divided by the sample mean) was also computed. These aggregated results are presented in Appendix C.

Included in the results presented are FTP and HH (i.e., hot-start urban cycle) fuel economies. These were derived from the individual bag results by application of the standard FTP formulas.

$$\text{FTP mpg} = \frac{1}{\left[\frac{0.21}{\text{BAG1 mpg}}\right] + \left[\frac{0.52}{\text{BAG2 mpg}}\right] + \left[\frac{0.27}{\text{BAG3 mpg}}\right]}$$

$$\text{HH mpg} = \frac{1}{\left[\frac{0.52}{\text{BAG2 mpg}}\right] + \left[\frac{0.48}{\text{BAG3 mpg}}\right]}$$

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* Dynamometer runs only.

8.0 ANALYSIS OF RESULTS

8.1 Use of Ratio Measure for Fuel Economy Comparisons

Fuel economy differences between dyno and track runs (as well as between radial and bias-belted tires, air conditioning off and on, and other factor comparisons) were measured over a wide range of absolute fuel economy levels, reflecting the various test vehicles and driving sequences employed. It is desirable, therefore, to display fuel economy differences in a manner which most effectively unifies the observed effects throughout the test range of absolute fuel economy levels.

The two alternatives frequently considered are based on an additive model and a multiplicative model, respectively. In the former the measure is the arithmetic difference in fuel economies; in the latter it is their ratio. Mathematically, if E_1 and E_2 are the two fuel economies being compared, these measures are defined as:

$$\Delta_E = E_2 - E_1$$

and

$$\rho_E = \frac{E_2}{E_1} = 1 + \frac{E_2 - E_1}{E_1} = 1 + \frac{\Delta_E}{E_1}$$

Basically, the additive model is most appropriate when a given influential factor produces a change in fuel economy from E_1 to E_2 which tends to be independent of the magnitude of E_1; the multiplicative model is appropriate when the change tends to be proportional to E_1.

Actually, the use of fuel economy E (in mpg) as a measure of fuel efficiency is somewhat arbitrary. An equally meaningful variable is its inverse, fuel consumption C (in gpm). Application of the additive and multiplicative models to the fuel consumption variable yields:

$$\Delta_C = C_2 - C_1$$

$$\rho_C = \frac{C_2}{C_1}$$

Note, now, that the assumption of a multiplicative model in E is fortuitously equivalent to a multiplicative model in C. By definition of $C = 1/E$, it is easily seen that

$$\rho_C = 1/\rho_E$$

On the other hand, suppose an additive model in E were assumed. One can then write

$$\Delta_C = C_2 - C_1 = \frac{1}{E_2} - \frac{1}{E_1} = \frac{E_1 - E_2}{E_1 E_2} = -\Delta_E \cdot C_1 C_2 \approx -\Delta_E C_1^{\,2}$$

which indicates that constant small fuel economy differences imply fuel consumption differences proportional to the square of fuel consumption level. By analogous reasoning, an additive model in C implies fuel economy differences proportional to the square of fuel economy level.

Inasmuch as the same information is conveyed by Δ_E or ρ_E, either measure may be selected. However, the above considerations suggest that ρ_E may be more physically meaningful. Another argument for choosing ρ_E is that, under the reasonable assumption of constant measurement error coefficient of variation[4] ρ_E would have constant error variance, whereas Δ_E would not. It is further noted that the ratio measure was employed in the previous dynamometer/track fuel economy study by EPA[1] and hence its use here would also facilitate comparison of results.

A final consideration is how well the ratio measure fits the observed data. Figure 1 is a plot of dynamometer fuel economy to track fuel economy under matched experimental conditions (same car, same tires, same driving sequence, etc.). Note that a ratio regression line is reasonably compatible with the data.

8.2 Comparison of Carbon Balance and Volumetric Measurement

Past EPA studies[2,3] have noted systematic differences between carbon balance and volumetric method of fuel economy determination. Inasmuch as the FTP and HFET dynamometer procedures specify use of the carbon balance method, whereas in track runs practical considerations dictate reliance on a fuel flowmeter, any realistic comparison of dynamometer to track fuel economies must include possible systematic effects of using different measurement techniques.

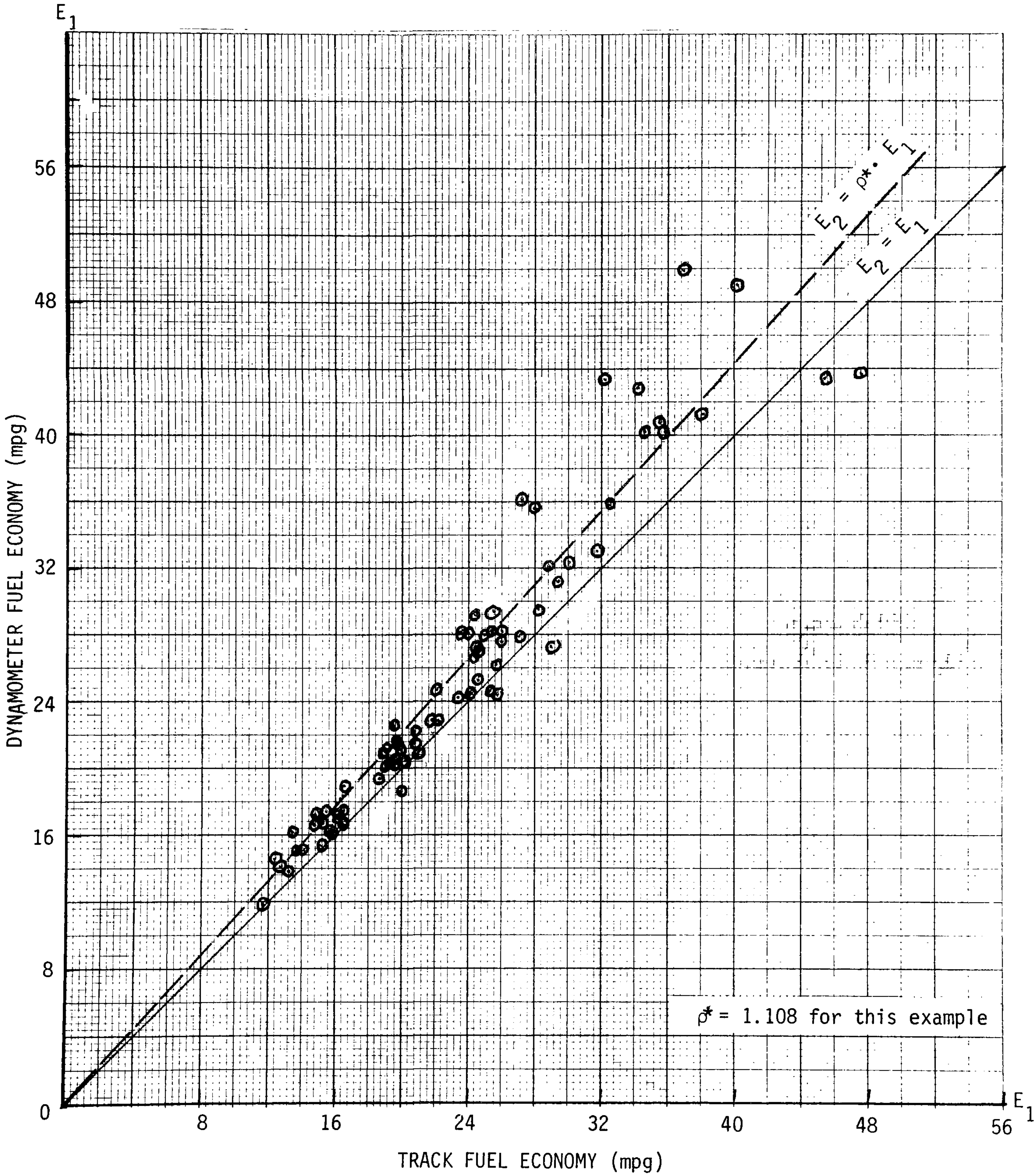


FIGURE 1. Relationship Between Dynamometer and Track Fuel Economies

Since all dynamometer runs in the test program were set up to measure both carbon balance and volumetric fuel consumptions, it is technically feasible to calculate the carbon balance to meter systematic difference as a separate effect. All subsequent analyses could then be simplified to direct comparison of metered fuel economies in both dynamometer and track runs.

However, an additional complication which developed in the experimental program was the use of several different fuel flowmeters with potentially significant systematic differences amongst themselves. Three of the meters were employed in both dynamometer and track runs and can therefore be related to carbon balance measurements as a reference. Unfortunately, three other meters were used only in track runs and are therefore not accessible to analyses for systematic differences.

There follows below the results of a statistical analysis of systematic carbon balance to volumetric measurement differences.

Dynamometer runs were identified as having been performed on either of two dynamometers (#5 or #207) and as using one of three fuel flowmeters (#1513, #1514, or #2099); in a significant number of instances the meter identification was missing. The runs were grouped into eight separate classes (2 dynamometer x 4 meters) to allow for the possibility of both dynamometer test cell and fuel flowmeter effects. The distribution into the eight classes was very uneven, and two classes were empty. Within each class, replicated runs (same car, tires, air conditioning status, driving sequence, etc.) were averaged. The occupancy of the eight classes, by numbers of individual runs and numbers after averaging, is shown in Table 5.

Table 5.

NUMBERS OF INDIVIDUAL/AVERAGED DYNAMOMETER RUNS

DYNO NO. \ METER NO.	1513	1514	2099	UNKNOWN
5	0	95/58	21/21	77/40
207	12/11	4/2	0	7/4

For each class two alternative linear models were considered:

$$\Delta E = E_c - E_m = a + bE_m$$

$$\Delta C = C_c - C_m = r + sC_m$$

where E denotes fuel economy (mpg), C denotes fuel consumption (gpm) and subscripts c and m refer to carbon balance measurements and volumetric measurements, respectively. Weighted least squares regressions were then carried out to estimate parameters a, b, r, and s. The weighting was based on the assumption of a constant coefficient of variation for the difference between carbon balance and meter readings (relative to the meter reading as a base) over all individual runs within a class, and statistical independence of replicated runs. Details of the regression analyses are given in Appendix D. Figures 2 and 3 present the regression lines obtained for the linear fuel consumption models and linear fuel economy models, respectively. The lines are extended to cover only the data range, and the $\pm 1\sigma$ ranges for midpoint estimates are shown. For comparison purposes the two alternative regression lines obtained in a recent EPA study are also reproduced in Figure 2.

It is concluded from an examination of the results, including residual coefficients of variation (which range from 1 to 3.5%), that: (1) the linear fuel consumption model provides a somewhat better fit to the data than the linear fuel economy model; (2) there is no appreciable effect associated with the use of two different dynamometers; (3) all classes including the earlier EPA study[2,3] showed remarkably similar slopes in the variation of measured carbon balance to meter differences as a function of absolute fuel consumption; and (4) there are significant differences in intercept between meters 1513 and 1514 and between meters 2099 and 1514.

It was accordingly decided to adjust meter 1513 and meter 2099 readings so as to be consistent with meter 1514 readings. The unknown meter class (presumably a mixture of meters 1513, 1514, and 2099 readings) was sufficiently similar to meter 1514 as not to require any adjustment. The adjustment formulas developed were:

$$E_{adj.} = \frac{1}{\frac{1}{E} + K}$$

where $K = -0.00041$ for Meter 1513

$= +0.00063$ for Meter 2099

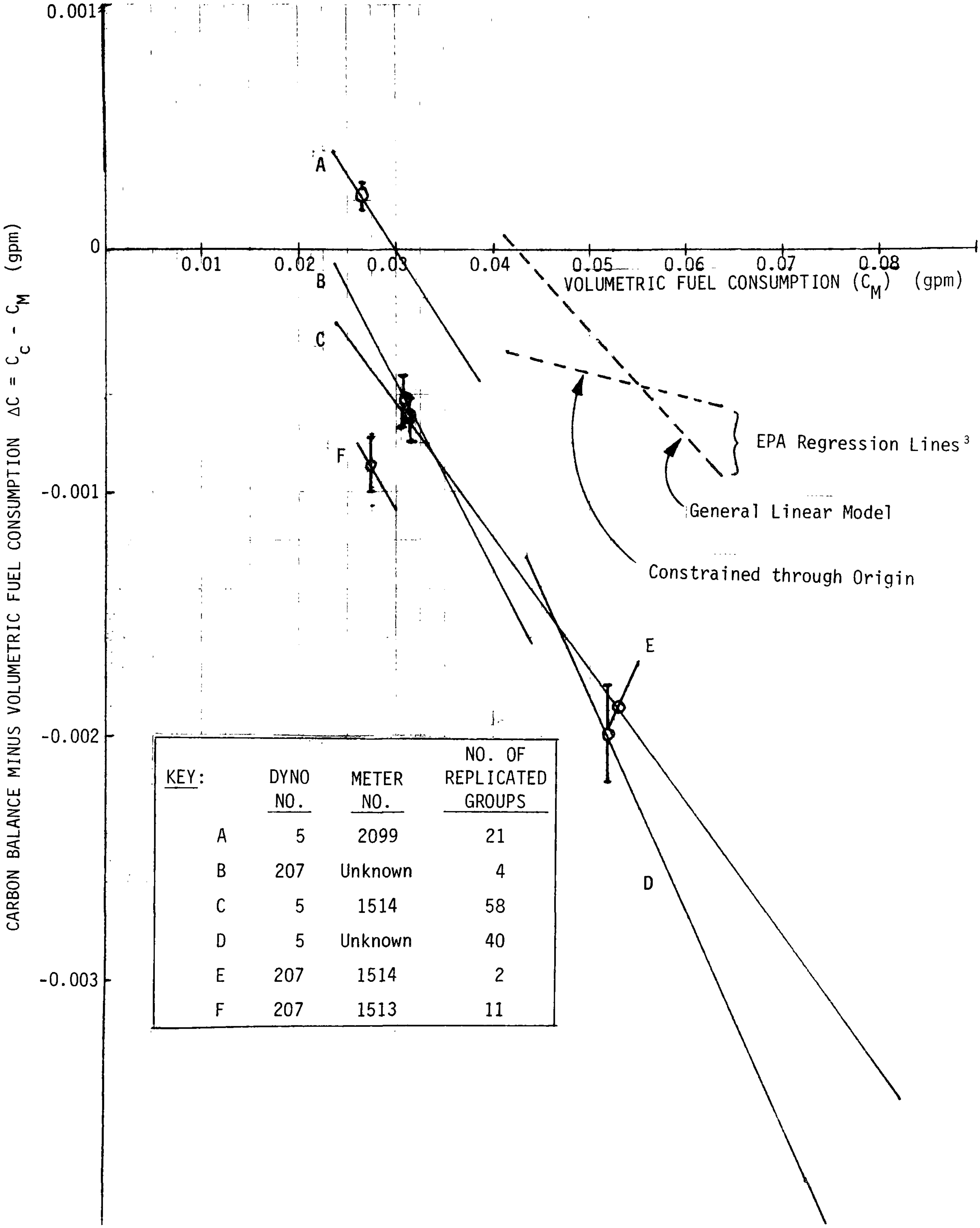
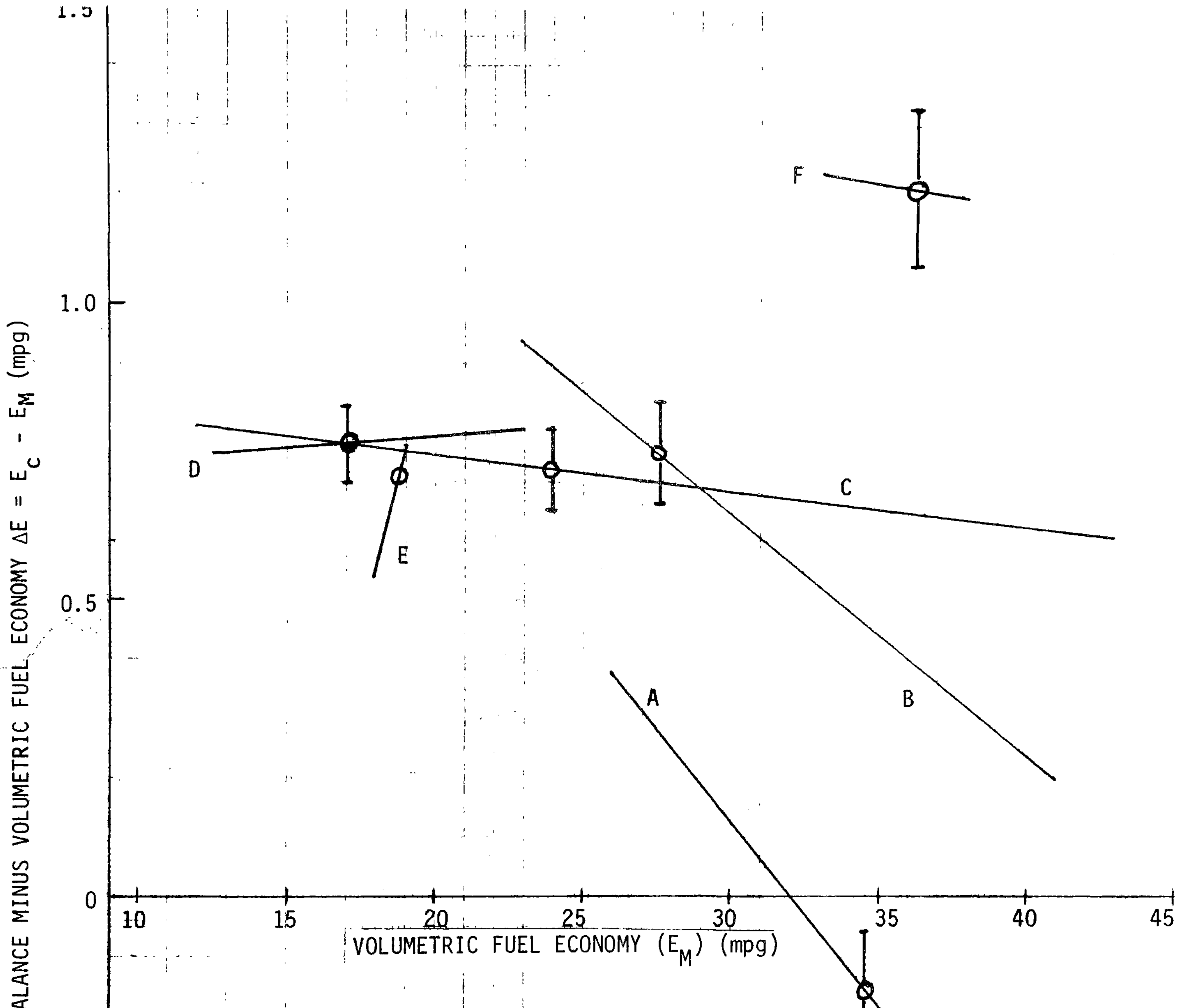


FIGURE 2. Regression Lines for Differences Between Carbon Balance and Volumetric Fuel Consumption



KEY:	DYNO NO.	METER NO.	NO. OF REPLICATED GROUPS
A	5	2099	21
B	207	Unknown	4
C	5	1514	58
D	5	Unknown	40
E	207	1514	2
F	207	1513	11

FIGURE 3. Regression Lines for Difference Between Carbon Balance and Volumetric Fuel Economy

These adjustments were also made in all track runs using meters 1513 or 2099. Unfortunately, as previously noted, three other meters were used on many of the track runs. The calibration of these meters relative to 1514 is unknown. Inasmuch as fuel economy ratios involving these "uncalibrated" meters could involve an error of appreciable magnitude just resulting from meter discrepancy, it was decided that ratios would only be computed where both numerator and denominator readings are from meter 1514 or adjusted to meter 1514.

The question as to which of the measurements are most accurate in an absolute sense, however, cannot be determined from this investigation. The fact that the carbon balance method is indirect whereas the fuel flowmeters measure volume directly by positive displacement of an essentially incompressible fluid suggests that the volumetric method is apt to be more accurate. However, the observed meter-to-meter discrepancies certainly argue against placing any more confidence in the meter data actually obtained than in the carbon balance results. These considerations further support the decision to express all ratios on the basis of a common meter reference.

If one wished to proceed further and attempt to estimate real dyno-to-track fuel economy ratios where dyno fuel economy is measured by the carbon balance method, then one could multiply the ratios presented later in this report by the ratio of measured carbon balance to meter 1514 derivable from Figure 2. The latter is seen to vary from about 1.04 at fuel consumption levels of 0.08 gpm (12.5 mpg) to about 1.015 at fuel consumption levels of 0.025 gpm (40 mpg). However, it should be kept in mind that the composite ratios so derived are meaningful only in the context of meter 1514 (or one with similar calibration) employed in measuring track fuel economy. The composite ratios would change if the track meter had substantially different calibration. In the final analysis, proper resolution of this whole problem requires the application of a fuel measurement technique of validated high accuracy against which all other measurements could be compared.

8.3 Estimates of Test-to-Test Variability

The presence of replicated runs in the data base permits estimation of the basic variability from test to test in volumetric fuel economy measurement. Such estimates are necessary for statistical analysis of significant effects. The assumed model is that of a constant coefficient of variation (COV), i.e., standard deviation divided by mean fuel economy over the range of measured fuel economies.[4] However, one must allow for the possibility of different COV's over track and dyno runs and also over various driving sequences. The latter were partially aggregated into BAG1/BAG3, BAG2, HST/CST, HNO/HRE, HSM, and CRUISE classes, based on the judgment that hot vs. cold start has no impact on measurement error, similarity of noisy and redistributed highway sequences, and insufficient numbers of CRUISE replications at individual speeds.

Table 6 presents estimated COV's for each of the indicated classes, determined as a weighted average of estimates from individual replicate groups. As a result of the meter adjustments described in Section 8.2, all dynamometers were rendered comparable; however, track runs with uncalibrated meters additionally had to agree in meter number to qualify as replicates. The number of degrees of freedom for estimation is given by d.f. = $\Sigma(n_i - 1)$ where n_i is the number of replications in the i^{th} replicate group and summation is over all replicate groups in a class.

Analysis revealed that differences among BAG2, HST/CST, HNO/HRE, HSM, and CRUISE estimates of $(COV)^2$ were not statistically significant. Accordingly, these classes were pooled. Differences between BAG1/BAG3 and the pooled results were statistically significant. We are thus left with distinct estimates of $(COV)^2$ for four cases: Dyno-BAG1/BAG3, Dyno-Other, Track-BAG1/BAG3, Track-Other. Fortuitously, these were found to be well-approximated by

	DYNO	TRACK
BAG1/BAG3	$2\ (COV)_0^2$	$4\ (COV)_0^2$
OTHER	$(COV)_0^2$	$2\ (COV)_0^2$

Table 6

ESTIMATES OF TEST-TO-TEST SQUARED COEFFICIENT OF VARIATION

	DYNAMOMETER		TRACK	
DRIVING SEQUENCE	$(COV)^2$ $(\%)^2$	d.f.*	$(COV)^2$ $(\%)^2$	d.f.*
BAG1/BAG3	7.34	56	14.36	64
BAG2	2.25	32	7.78	73
HST/CST	3.69	32	8.76	44
HNO/HRE	3.42	30	2.37	30
HSM	4.02	15	5.24	12
CRUISE	4.97	24	7.56	106
BAG2/HWY/CRUISE**	3.53	133	7.13	265

* Number of degrees-of-freedom for estimation.

** Pooling of BAG2, HST/CST, HNO/HRE, HSM, and CRUISE.

or in terms of COV by

	DYNO	TRACK
BAG1/BAG3	$\sqrt{2}\,(COV)_0$	$2\,(COV)_0$
OTHER	$(COV)_0$	$\sqrt{2}\,(COV)_0$

where $(COV)_0 = 1.9\%$.

To investigate the consistency of these dynamometer test-to-test variability estimates with previously obtained results, we note first that the COV estimate for FTP fuel economy (0.21 BAG1 + 0.12 BAG2 + 0.27 BAG3) derived from the above is $[(0.21)^2 \cdot 2\,(COV)_0^2 + (0.52)^2 \cdot (COV)_0^2 + (0.27) \cdot 2\,(COV)_0^2] = 1.35\%$. The HFET (Highway) fuel economy COV is, of course, just 1.9%. Reference 4 indicates COV's reported in the literature ranging from 0.75 to 4.8% and also includes an analysis of recent EPA tests on thirty-one automobiles[5] which yielded FTP and HFET fuel economy COV's of 1.5% and 1.9%, respectively. COV estimates based on data from the present program are therefore very much in line with other estimates.

In subsequent sections, ratios of sample mean fuel economies are calculated. The above results for test-to-test coefficient of variation are used to estimate the standard error of the mpg ratios as follows:

$$\rho = \frac{\overline{mpg_1}}{\overline{mpg_2}}$$

where $\overline{mpg_1}$ and $\overline{mpg_2}$ are sample means of N_1 and N_2 measurements, respectively, and the squared coefficient of variation of single test results are $(COV)_1^2$ and $(COV)_2^2$, respectively. Then the standard error of the estimate ρ is given by:

$$(s.e.)\rho = \sqrt{\frac{(COV)_1^2}{N_1} + \frac{(COV)_2^2}{N_2}}$$

For example, if mpg is dynamometer BAG2 value with 3 replications and $\overline{mpg_2}$ is a track BAG2 value with 4 replications then

$$(s.e.)\rho = \sqrt{\frac{(COV)_0^2}{3} + \frac{2\,(COV)_0^2}{4}} = 0.91\,(COV)_0 \cong 0.015.$$

The standard error for FTP and HH ratios derived from replicated BAG measurements is somewhat more involved. For example, if dynamometer FTP is derived from an N_{11}-replicate BAG1 value, an N_{12}-replicate BAG2 value, and an N_{13}-replicate BAG3 value, the standard error for ρ = FTP (dyno)/FTP (track) is

$$(s.e.)\rho = \left[\frac{(0.21)^2\,2\,(COV)_0^2}{N_{11}} + \frac{(0.52)^2\,(COV)_0^2}{N_{12}} + \frac{(0.27)^2\,2\,(COV)_0^2}{N_{13}} + \frac{(0.21)^2\,4\,(COV)_0^2}{N_{21}} + \frac{(0.52)^2\,2\,(COV)_0^2}{N_{22}} + \frac{(0.27)^2\,4\,(COV)_0^2}{N_{23}}\right]^{\frac{1}{2}}$$

$$= 0.019\sqrt{\frac{0.0882}{N_{11}} + \frac{0.2704}{N_{12}} + \frac{0.0882}{N_{13}} + \frac{0.1764}{N_{21}} + \frac{0.5408}{N_{22}} + \frac{0.1764}{N_{23}}}$$

With only one replication for each BAG, the dyno/track FTP ratio standard error would become $(s.e.)\rho = 0.022$. The modest numbers of replications appearing in the data generally result in ratio standard errors in the range of 0.01 to 0.015, i.e., 1 to 1.5%.

8.4 Dynamometer/Track Effects--Dynamometer Measured Fuel Economy Compared to Track Measured Fuel Economy

The prime focus of this program is to quantify when possible the magnitudes of the differences between fuel economy as measured on a dynamometer and on a test track. As previously discussed, the parameter chosen to quantify the dyno/track effect is the ratio of the fuel economy as measured by fuel flowmeter on a dynamometer, to fuel economy as measured by fuel flowmeter on a test track. These ratios have been computed where meter 1514 (or a meter that could be corrected to #1514) was used for both the dynamometer and track measurements (i.e., meter 1514 was used as the basis to which all the meters were corrected where possible).

Tables 7 through 10 present the calculated ratios with their standard errors for the four tire-type/air-conditioning configurations: radial tire/air off, radial tire/air on, bias tire/air off, and bias tire/air on. Ratios were calculated for the above four groups to consider possible effects due to either tire type and/or air conditioning. Once the ratios are computed by group, an analysis of variance may be used to test whether significant differences exist between the ratios of any two groups. For instance, it is reasonable to expect that the dynamometer-to-track effect (i.e., the ratio) should be the same when the vehicle is tested with air conditioning on and air conditioning off.

To test our hypothesis that the ratios between two groups are the same, we assume a model of the form:

$$\bar{y}_{ij} = \mu + b_i + t_i + e_{ij}$$

where:

- $\bar{y}_{ij}$ are the computed ratios for each i^{th} vehicle in the j^{th} group (i.e., air or no air conditioning),
- μ is the mean ratio over all vehicles and groups,
- b_i is the deviation from the mean ratio due to each i^{th} vehicle,
- t_j is the deviation from the mean ratio due to each j^{th} group, and
- e_{ij} is the random component of error due to both measurement and test variance for the i^{th} vehicle in the j^{th} group.

In the above model the e_{ij} are assumed independent. By a weighted analysis of variance, we may test for vehicle-to-vehicle differences in the ratios $(b_i \neq b)$ and group-to-group differences in the ratios $(t_j \neq t)$. A complete

Table 7

RATIO ± 1 STANDARD ERROR OF DYNAMOMETER MPG TO TRACK MPG

(Radial, Air Off, Windows Up, Meter 1514 or Corrected)

	PINTO	HONDA*	ASPEN
BAG1	0.992 ± 0.033	1.122 ± 0.029	1.100 ± 0.029
BAG2	1.055 ± 0.018	1.111 ± 0.015	1.100 ± 0.016
BAG3	1.103 ± 0.029	1.115 ± 0.022	1.066 ± 0.027
FTP	1.051 ± 0.014	1.114 ± 0.011	1.092 ± 0.012
HH	1.078 ± 0.017	1.113 ± 0.013	1.080 ± 0.015
HST	1.063 ± 0.022	1.118 ± 0.016	1.066 ± 0.016
CST		1.100 ± 0.030	1.053 ± 0.033
HND		1.159 ± 0.022	1.053 ± 0.019
HRE		1.170 ± 0.022	1.016 ± 0.016
HSM		1.084 ± 0.029	1.053 ± 0.017
10	0.911 ± 0.030		1.011 ± 0.033
20	1.023 ± 0.030		0.991 ± 0.033
30	1.040 ± 0.030		0.942 ± 0.033
40	1.074 ± 0.030		1.021 ± 0.033
50	1.045 ± 0.030		1.016 ± 0.033
60	1.027 ± 0.030		0.993 ± 0.033

* Combined meter unknown and 2099 corrected on track.

Table 8

RATIO ± 1 STANDARD ERROR OF DYNAMOMETER MPG TO TRACK MPG

(Bias, Air Off, Windows Up, Meter 1514 or Corrected)

	PINTO	HONDA	PACER	ASPEN
BAG1	1.051 ± 0.042	1.191 ± 0.031		1.179 ± 0.042
BAG2	1.113 ± 0.018	1.076 ± 0.018	1.065 ± 0.030	1.131 ± 0.016
BAG3	1.152 ± 0.020	1.062 ± 0.025	1.016 ± 0.033	1.120 ± 0.025
FTP	1.106 ± 0.015	1.097 ± 0.013		1.140 ± 0.014
HH	1.132 ± 0.017	1.070 ± 0.015	1.040 ± 0.026	1.126 ± 0.014
HST	1.127 ± 0.022	1.148 ± 0.019	1.116 ± 0.029	1.086 ± 0.021
CST				
HND	1.105 ± 0.019			
HRE	1.114 ± 0.019			
HSM	1.060 ± 0.022			
10				0.825 ± 0.027
20		0.712 ± 0.027		1.117 ± 0.027
30		0.919 ± 0.027		1.035 ± 0.027
40		1.350 ± 0.027		1.099 ± 0.027
50		1.350 ± 0.027		1.118 ± 0.027
60		1.210 ± 0.027		1.066 ± 0.027

Table 9

RATIO ± 1 STANDARD ERROR OF DYNAMOMETER MPG TO TRACK MPG

(Radial, Air On, Windows Up, Meter 1514 or Corrected)

	ASPEN
BAG1	1.111 ± 0.033
BAG2	1.090 ± 0.019
BAG3	1.015 ± 0.033
FTP	1.076 ± 0.015
HH	1.052 ± 0.019
HST	1.044 ± 0.019
CST	
HNO	
HRE	
HSM	
10	0.870 ± 0.027
20	0.990 ± 0.027
30	0.950 ± 0.027
40	1.018 ± 0.027
50	1.029 ± 0.027
60	0.934 ± 0.027

Table 10

RATIO ± 1 STANDARD ERROR OF DYNAMOMETER MPG TO TRACK MPG

(Bias, Air On, Windows Up, Meter 1514 or Corrected)

	PACER	ASPEN
BAG1	1.019 ± 0.033	
BAG2	1.083 ± 0.016	1.216 ± 0.027
BAG3	1.049 ± 0.029	1.165 ± 0.038
FTP	1.057 ± 0.013	
HH	1.066 ± 0.016	1.193 ± 0.023
HST	1.150 ± 0.025	1.035 ± 0.021
CST		
HNO		
HRE		
HSM		
10		
20	0.884 ± 0.033	
30	0.967 ± 0.033	
40	1.030 ± 0.033	
50	1.038 ± 0.033	
60	1.029 ± 0.033	

derivation and explanation of this analysis is presented in Appendix E.

Application of the above analysis of variance indicates that there is no significant difference in the computed ratios (dynamometer fuel economy to track fuel economy) for vehicles with air conditioning on and for vehicles with air conditioning off. There is however, a significant car to car effect among the calculated ratios. The analysis of variance results for the FTP and HST driving cycles is presented in Table 11.

In Table 11 the quantities S/E and T/E are presented with the estimate of μ and S_0^2. The quantity S is the reduction in mean square error associated with fitting b_i, the quantity T is the reduction in mean square error associated with fitting t_j, and the quantity S_0^2 is an externally derived mean squared error (with a large number of degrees of freedom) which provides an estimate for the internal mean squared error E. The ratios S/E and T/E were then compared with F distributions of equivalent degrees of freedom at a selected significance level (i.e., 0.05).

In all instances presented in Table 11 we reject the hypothesis that vehicle effects are all the same ($b_i \equiv b$) and accept the hypothesis that a/c on and off effects are the same ($t_j \equiv t$). Thus we may combine the ratios computed with air conditioning on with the ratios computed with air conditioning off, but we may not combine the ratios computed for car A with the ratios computed for car B. The ratios are combined by inverse weighting by their standard errors for air off and air on and are presented in Tables 12 and 13 for vehicles equipped with radial and bias tires, respectively. Vehicle-to-vehicle differences within each tire type group are evident. In addition, each vehicle equipped with radial tires appears to have a different ratio when equipped with bias tires. Fuel economy differences due to tire configuration effects are discussed in the next section.

Table 11

ANALYSIS OF VARIANCE RESULTS FOR VEHICLES
WITH AND WITHOUT AIR CONDITIONING
FOR SELECTED DRIVING SEQUENCES

VEHICLE CONFIGURATION	DRIVING SEQUENCE		
	FTP	HH	HST
H_0: $b_i \equiv b$			
Bias Tires		μ = 1.103 S_0^2 = 0.8358 d.f. = 6 S/E = 9.96*	μ = 1.108 S_0^2 = 1.3365 d.f. = 6 S/E = 5.0*
Radial Tires	μ = 1.087 S_0^2 = 0.46385 d.f. = 4 S/E = 6.25*		μ = 1.076 S_0^2 = 0.9053 d.f. = 4 S/E = 3.18*
H_0: $t_j \equiv t$			
Bias Tires		d.f. = 6 T/E = 0.08	d.f. = 6 T/E = 0.73
Radial Tires	d.f. = 4 T/E = 0.68		d.f. = 4 T/E = 1.30

* Significant at 0.05 level.

Table 12

RATIO ± 1 STANDARD ERROR OF DYNAMOMETER MPG TO TRACK MPG

(Radial, Air On + Air Off, Windows Up, Meter 1514 or Corrected)

	PINTO	HONDA	ASPEN
BAG1	0.992 ± 0.033	1.122 ± 0.029	1.105 ± 0.022
BAG2	1.055 ± 0.018	1.111 ± 0.014	1.096 ± 0.012
BAG3	1.103 ± 0.029	1.115 ± 0.022	1.046 ± 0.021
FTP	1.051 ± 0.014	1.114 ± 0.011	1.086 ± 0.010
HH	1.078 ± 0.017	1.113 ± 0.013	1.069 ± 0.012
HST	1.063 ± 0.022	1.118 ± 0.016	1.056 ± 0.012
CST		1.100 ± 0.030	1.053 ± 0.033
HND		1.159 ± 0.022	1.053 ± 0.019
HRE		1.170 ± 0.022	1.016 ± 0.016
HSM		1.084 ± 0.029	1.053 ± 0.017
10	0.911 ± 0.030		0.926 ± 0.021
20	1.023 ± 0.030		0.990 ± 0.021
30	1.040 ± 0.030		0.950 ± 0.021
40	1.074 ± 0.030		1.019 ± 0.021
50	1.045 ± 0.030		1.024 ± 0.021
60	1.027 ± 0.030		0.958 ± 0.021

Table 13

RATIO ± 1 STANDARD ERROR OF DYNAMOMETER MPG TO TRACK MPG

(Bias, Air On + Air Off, Windows Up, Meter 1514 or Corrected)

	PINTO	HONDA	PACER	ASPEN
BAG1	1.051 ± 0.042	1.191 ± 0.031	1.019 ± 0.033	1.179 ± 0.042
BAG2	1.113 ± 0.018	1.076 ± 0.018	1.079 ± 0.014	1.154 ± 0.014
BAG3	1.152 ± 0.029	1.062 ± 0.025	1.035 ± 0.022	1.133 ± 0.021
FTP	1.106 ± 0.015	1.097 ± 0.013	1.057 ± 0.013	1.140 ± 0.014
HH	1.132 ± 0.017	1.070 ± 0.015	1.059 ± 0.014	1.145 ± 0.012
HST	1.127 ± 0.022	1.148 ± 0.019	1.136 ± 0.019	1.060 ± 0.015
CST				
HND	1.105 ± 0.019			
HRE	1.114 ± 0.019			
HSM	1.060 ± 0.022			
10				0.825 ± 0.027
20		0.712 ± 0.027	0.884 ± 0.033	1.117 ± 0.027
30		0.919 ± 0.027	0.967 ± 0.033	1.035 ± 0.027
40		1.350 ± 0.027	1.030 ± 0.033	1.099 ± 0.027
50		1.350 ± 0.027	1.038 ± 0.033	1.118 ± 0.027
60		1.320 ± 0.027	1.019 ± 0.033	1.066 ± 0.027

8.5 Tire Effects--Fuel Economy Measured with Radial Tires Compared to Fuel Economy Measured with Bias Tires

Testing of the vehicles with both bias belted and radial tires on the dynamometer and the test track permits a comparison of the effect of tire type on fuel economy. The ratio of the meter measured fuel economy of a vehicle with radial tires to the meter measured fuel economy of the same vehicle with bias belted tires is computed and presented in Tables 14 and 15 for track and dynamometer runs, respectively.

Before the combined ratios in Tables 14 and 15 were computed, they were computed separately for the conditions of air conditioning on and off. Since no significant air conditioning effect was detected in Section 8.4 and since there is no apparent basis for considering a tire type air conditioning interaction effect, the ratios (air on and off) were combined. Also note in Tables 14 and 15 that since the same fuel meter was often used to test the vehicle with radial and with bias tires, more ratio calculations are possible than were possible for dynamometer-to-track ratio calculations.

In general, we note that the radial-to-bias ratio is dependent on the driving cycle and can be less than or greater than one. Ratios computed from track tests are generally greater than one and tend to support the contention that radial tires achieve somewhat better fuel economy (0 to 4% better for highway cycle) than bias tires. For comparisons on the dynamometer, ratios are generally lower than one, implying that dynamometer testing-- instead of simulating the on-road fuel efficiency of radial tires in comparison to bias belted tires, generally shows radial tires at a relative disadvantage.

Table 14

RATIO ± 1 STANDARD ERROR OF FUEL ECONOMY MEASURED WITH RADIAL TIRES TO FUEL ECONOMY MEASURED WITH BIAS TIRES FOR DYNAMOMETER TESTS

	PINTO	HONDA	DATSUN	ASPEN*	IMPALA
BAG1	0.975 ± 0.027	0.997 ± 0.024	0.967 ± 0.024	0.999 ± 0.021	0.961 ± 0.027
BAG2	0.964 ± 0.016	1.029 ± 0.013	0.985 ± 0.014	0.977 ± 0.013	1.014 ± 0.016
BAG3	0.965 ± 0.022	1.030 ± 0.017	0.994 ± 0.019	0.989 ± 0.018	0.988 ± 0.023
FTP	0.967 ± 0.012	1.022 ± 0.010	0.984 ± 0.010	0.992 ± 0.009	0.996 ± 0.012
HH	0.964 ± 0.014	1.034 ± 0.011	0.990 ± 0.012	0.983 ± 0.010	1.001 ± 0.014
HST	0.980 ± 0.015	0.985 ± 0.017	0.975 ± 0.014	1.038 ± 0.012	0.982 ± 0.014
CST		0.984 ± 0.019	0.969 ± 0.023	1.002 ± 0.027	
HNO			1.008 ± 0.017	0.989 ± 0.016	
HRE			1.116 ± 0.017	1.002 ± 0.016	
HSM					
10	0.952 ± 0.023	0.987 ± 0.023	0.962 ± 0.019	1.198 ± 0.027	
20	0.961 ± 0.023	0.989 ± 0.023	0.958 ± 0.019	0.997 ± 0.017	
30	0.917 ± 0.023	0.990 ± 0.023	0.953 ± 0.019	0.997 ± 0.027	
40	0.990 ± 0.023	0.986 ± 0.023	0.958 ± 0.019	0.977 ± 0.027	
50	0.980 ± 0.023	0.988 ± 0.023	1.000 ± 0.019	0.988 ± 0.027	
60	0.967 ± 0.023	0.987 ± 0.023	0.968 ± 0.019	0.983 ± 0.027	

* Combined ratios for air on and air off.

Table 15

RATIO ± 1 STANDARD ERROR OF FUEL ECONOMY MEASURED WITH RADIAL TIRES TO FUEL ECONOMY MEASURED WITH BIAS TIRES FOR TRACK TESTS

	PINTO	HONDA	DATSUN	CHEVETTE	PACER*	ASPEN**	IMPALA**	GRANADA
BAG1	1.032 ± 0.047	1.057 ± 0.035	1.093 ± 0.042	1.028 ± 0.038	---	1.107 ± 0.044	1.100 ± 0.025	0.930 ± 0.038
BAG2	1.017 ± 0.020	0.997 ± 0.019	1.040 ± 0.016	1.016 ± 0.022	1.051 ± 0.033	1.029 ± 0.013	1.075 ± 0.011	0.986 ± 0.016
BAG3	1.008 ± 0.035	0.982 ± 0.028	1.053 ± 0.028	1.060 ± 0.030	0.970 ± 0.047	1.066 ± 0.023	1.071 ± 0.022	0.977 ± 0.023
FTP	1.018 ± 0.017	1.006 ± 0.014	1.055 ± 0.014	1.030 ± 0.016	---	1.057 ± 0.015	1.080 ± 0.010	0.970 ± 0.013
HH	1.013 ± 0.019	0.994 ± 0.017	1.046 ± 0.016	1.037 ± 0.018	1.015 ± 0.028	1.048 ± 0.013	1.075 ± 0.012	0.980 ± 0.013
HC	---	---	---	---	1.009 ± 0.028	---	---	---
HST	1.039 ± 0.027	1.012 ± 0.018	1.034 ± 0.019	1.022 ± 0.029	0.999 ± 0.038	1.044 ± 0.015	1.030 ± 0.018	1.030 ± 0.019
CST	0.978 ± 0.033	---	---	---	1.025 ± 0.033	---	---	---
HNO	---	0.992 ± 0.027	---	0.995 ± 0.027	---	---	---	---
HRE	---	1.009 ± 0.027	---	1.019 ± 0.027	---	---	---	---
HSM	---	1.029 ± 0.033	---	1.012 ± 0.027	---	---	---	---
10	---	---	0.998 ± 0.027	---	---	1.053 ± 0.021	0.892 ± 0.028	1.103 ± 0.038
20	---	1.070 ± 0.027	1.009 ± 0.027	1.073 ± 0.027	---	1.068 ± 0.021	1.038 ± 0.023	1.036 ± 0.033
30	---	0.955 ± 0.027	1.030 ± 0.027	1.108 ± 0.027	---	1.075 ± 0.021	1.040 ± 0.023	1.009 ± 0.033
40	---	1.088 ± 0.027	1.033 ± 0.027	1.054 ± 0.027	---	1.058 ± 0.021	1.014 ± 0.023	1.017 ± 0.036
50	---	1.064 ± 0.027	1.035 ± 0.027	1.013 ± 0.033	---	1.073 ± 0.021	1.030 ± 0.023	1.014 ± 0.036
60	---	1.028 ± 0.027	1.020 ± 0.027	0.988 ± 0.027	---	1.058 ± 0.021	1.007 ± 0.023	1.018 ± 0.036
70	---	---	1.011 ± 0.027	1.064 ± 0.027	---	---	1.027 ± 0.023	1.025 ± 0.036
80	---	---	1.027 ± 0.027	---	---	---	1.032 ± 0.023	0.999 ± 0.036

* Meter 1358 data for radial only not used; ** Combined ratios with air on and off

8.6 Cold Tire Warm-Up Effects

In order to assess the potential influence of tire warm-up on fuel economy, comparable hot start LA-4 cycles were run using hot stabilized tires (HH) and cold tires (HC). These tests were conducted on the Aspen, Datsun, and Granada. Both the HC and HH fuel economies are computed by harmonically combining the fuel economies measured from BAGS2 and 3. In all cases tested, there were no significant differences either between HC and HH tests or between BAG3 tests run with hot tires and BAG3 tests run with cold tires. BAG3 fuel economies were compared because these were the first segments of the HC and HH cycles and any fuel economy differences due to tire temperature should be greatest over the BAG3 segment.

Table 16 presents the ratios of HC to HH BAG3 fuel economies as measured on the test track and dynamometer with either bias belted or radial ply tires. Comparisons between hot and cold tire fuel economies were made only where the same meter was used for measurement. In none of the individual cases, or combined groups, are the ratios significantly different from 1.00.

Table 16. RATIOS OF BAG3 FUEL ECONOMY WITH COLD TIRES TO BAG3 FUEL ECONOMY WITH HOT STABILIZED TIRES AS MEASURED VS. USING BIAS OR RADIAL TIRES IN TRACK OR DYNAMOMETER TESTS

TEST LOCATION / TIRE TYPE	TRACK				DYNAMOMETER			
	BIAS		RADIAL		BIAS		RADIAL	
	N*	Ratio ± 1 S.E.**	N*	Ratio ± 1 S.E.**	N*	Ratio ± 1 S.E.**	N*	Ratio ± 1 S.E.**
VEHICLE								
Aspen	2/2	1.033 ± 0.038	1/2	0.951 ± 0.047		---		---
Datsun	1/2	0.992 ± 0.047	1/4	0.995 ± 0.042		---	2/2	0.977 ± 0.027
Granada	2/3	1.003 ± 0.035	1/1	1.072 ± 0.054		---		---
Honda		---		---	3/1	0.953 ± 0.031		---
WEIGHTED MEAN (By Facility & Tire Type)		1.011 ± 0.023		1.000 ± 0.027		0.953 ± 0.031		0.977 ± 0.027
WEIGHTED MEAN (By Facility)	1.006 ± 0.018				0.967 ± 0.020			

* Number of HC BAG3 runs/number of HH BAG3 runs.

** Standard errors based on COV estimated for test-to-test variability of BAG1/BAG3 runs on track and dynamometer derived in Section 8.3

8.7 Air Conditioning Effects

Ratios of the meter-measured fuel economy with air conditioning off to the meter-measured fuel economy with air conditioning on have been computed for both dynamometer and track measurements separately. The results are presented in Tables 17 through 20 for the four groups: radials on track, radials on dynamometer, bias on track and bias on dynamometer.

A subjective analysis of variance may be conducted by inspection of the ratios as recompiled in Table 21 for the four groups of conditions described. Notice that for each of the driving cycles presented, the four ratios for each vehicle do not appear to have any systematic pattern and may be collapsed into one ratio by weighted averaging (proportional to the inverse square of the standard error of each of the four group ratios).

The recomputed ratios of fuel economy measured with air conditioning off to fuel economy measured with air conditioning on over all dynamometer, track, radial and bias tire configurations are presented in Table 22. It may be noted in Table 22 that a reduction is achieved in standard error for the weighted ratios as compared to the standard error for the individual configuration unweighted ratios, and that an apparently significant vehicle-to-vehicle difference in ratios remains. These ratios indicate decreases in fuel economy due to air conditioning ranging from 8 to 17% over the urban cycle and 5 to 12% over the highway cycle.

The air conditioning effect in Table 22 appears to be inversely related to vehicle speed for the steady-state runs. That is, the ratios (converted to percent differences) calculated for each of the steady-state speeds indicated in the table decrease from about 16% at 10 mph to about 5% at 80 mph.

Table 17. RATIO ± 1 STANDARD ERROR OF FUEL ECONOMY MEASUREMENT WITH AIR CONDITIONING OFF TO FUEL ECONOMY MEASURED WITH AIR CONDITIONING ON FOR TRACK MEASUREMENTS OF VEHICLES WITH RADIAL TIRES

	GRANADA*	CHEVETTE**	PACER***	ASPEN****	IMPALA**
BAG1	1.150 ± 0.038	1.081 ± 0.038	1.044 ± 0.047	1.080 ± 0.035	1.056 ± 0.038
BAG2	1.181 ± 0.016	1.098 ± 0.022	1.034 ± 0.020	1.108 ± 0.018	1.110 ± 0.017
BAG3	1.192 ± 0.025	1.129 ± 0.030	1.103 ± 0.038	1.040 ± 0.035	1.083 ± 0.032
FTP	1.176 ± 0.013	1.101 ± 0.016	1.055 ± 0.018	1.084 ± 0.015	1.091 ± 0.015
HH	1.186 ± 0.014	1.113 ± 0.018	1.064 ± 0.021	1.074 ± 0.019	1.097 ± 0.018
HST	1.112 ± 0.015	1.050 ± 0.022	1.091 ± 0.038	1.062 ± 0.021	1.043 ± 0.025
CST	---	---	---	---	---
HNO	---	---	1.070 ± 0.027	---	---
HRE	---	---	1.049 ± 0.027	---	---
HSM	---	---	1.086 ± 0.033	---	---
10	1.164 ± 0.033	---	---	1.031 ± 0.033	---
20	1.187 ± 0.033	1.139 ± 0.027	1.180 ± 0.027	1.163 ± 0.033	1.206 ± 0.027
30	1.131 ± 0.033	1.119 ± 0.027	1.095 ± 0.027	1.123 ± 0.033	1.153 ± 0.027
40	1.131 ± 0.033	1.081 ± 0.027	1.051 ± 0.027	1.063 ± 0.033	1.111 ± 0.027
50	1.102 ± 0.033	1.033 ± 0.033	1.058 ± 0.027	1.082 ± 0.033	1.069 ± 0.027
60	1.090 ± 0.033	0.995 ± 0.027	1.042 ± 0.027	1.052 ± 0.033	1.100 ± 0.027
70	1.111 ± 0.033	1.029 ± 0.027	1.001 ± 0.027	---	1.063 ± 0.027
80	1.014 ± 0.033	---	1.055 ± 0.027	---	1.056 ± 0.027

* Meter 1514 + Unknown

** Meter 1472

*** Meter 1358

**** Meter 1514

Table 18.

RATIO ± 1 STANDARD ERROR OF FUEL ECONOMY MEASURED WITH AIR CONDITIONING OFF TO FUEL ECONOMY MEASURED WITH AIR CONDITIONING ON FOR TRACK MEASUREMENTS OF VEHICLES WITH BIAS TIRES

	GRANADA*	PACER*	ASPEN**	IMPALA***
BAG1	1.103 ± 0.038	---	---	1.028 ± 0.031
BAG2	1.187 ± 0.016	1.154 ± 0.028	1.100 ± 0.022	1.080 ± 0.016
BAG3	1.148 ± 0.023	1.154 ± 0.044	1.045 ± 0.033	1.068 ± 0.035
FTP	1.157 ± 0.013	---	---	1.066 ± 0.015
HH	1.169 ± 0.013	1.154 ± 0.025	1.075 ± 0.020	1.074 ± 0.019
HST	1.117 ± 0.022	1.154 ± 0.031	1.062 ± 0.022	1.059 ± 0.031
CST	---	---	---	---
HNO	---	---	---	---
HRE	---	---	---	---
HSM	---	---	---	---
10	---	---	1.172 ± 0.027	1.199 ± 0.038
20	---	---	1.142 ± 0.027	1.301 ± 0.038
30	---	---	1.125 ± 0.027	1.134 ± 0.038
40	1.134 ± 0.033	---	1.073 ± 0.027	1.064 ± 0.038
50	1.157 ± 0.033	---	1.059 ± 0.027	1.075 ± 0.038
60	1.119 ± 0.033	---	1.058 ± 0.027	1.062 ± 0.038
70	1.140 ± 0.033	---	---	1.056 ± 0.038
80	1.019 ± 0.033	---	---	1.025 ± 0.038

* Meter 1514

** Meter--Unknown

*** Meter 1472

Table 19.

RATIO ± 1 STANDARD ERROR OF FUEL ECONOMY MEASURED WITH AIR CONDITIONING OFF TO FUEL ECONOMY MEASURED WITH AIR CONDITIONING ON FOR DYNAMOMETER MEASUREMENTS OF VEHICLES WITH RADIAL TIRES

	ASPEN*	IMPALA*
BAG1	1.069 ± 0.027	1.102 ± 0.027
BAG2	1.119 ± 0.017	1.109 ± 0.016
BAG3	1.093 ± 0.025	1.089 ± 0.023
FTP	1.100 ± 0.012	1.103 ± 0.012
HH	1.106 ± 0.015	1.099 ± 0.014
HST	1.084 ± 0.014	1.111 ± 0.017
CST	---	---
HNO	---	---
HRE	---	---
HSM	---	---
10	1.202 ± 0.027	---
20	1.160 ± 0.027	---
30	1.118 ± 0.027	---
40	1.066 ± 0.027	---
50	1.070 ± 0.027	---
60	1.119 ± 0.027	

* Meter--Unknown

Table 20.

RATIO ± 1 STANDARD ERROR OF FUEL ECONOMY MEASURED WITH AIR CONDITIONING OFF TO FUEL ECONOMY MEASURED WITH AIR CONDITIONING ON FOR DYNAMOMETER MEASUREMENTS OF VEHICLES WITH BIAS TIRES

	PACER *	ASPEN*
BAG1	1.099 ± 0.027	1.081 ± 0.033
BAG2	1.135 ± 0.019	1.023 ± 0.022
BAG3	1.117 ± 0.027	1.005 ± 0.031
FTP	1.121 ± 0.013	1.032 ± 0.016
HH	1.126 ± 0.016	1.015 ± 0.019
HST	1.120 ± 0.022	1.114 ± 0.019
CST	---	---
HNO	---	---
HRE	---	---
HSM	---	---
10	1.141 ± 0.027	---
20	1.134 ± 0.027	---
30	1.106 ± 0.027	---
40	1.041 ± 0.027	---
50	1.048 ± 0.027	---
60	1.019 ± 0.027	---

* Meter--Unknown

Table 21.

COMPARISON OF RATIOS OF AIR CONDITIONING/ON TO AIR CONDITIONING/OFF MPG FOR TRACK, DYNAMOMETER AND TIRE TYPE FOR SELECTED DRIVING CYCLES

		GRANADA		CHEVETTE		PACER		ASPEN		IMPALA	
		Radial	Bias	Radial	Bias	Radial	Bias	Radial	Bias	Radial	Bias
FTP	Track	1.18	1.16	1.10	--	1.06	--	1.08	--	1.09	1.07
	Dyno	--	--	--	--	--	1.12	1.10	1.03	1.10	--
HH	Track	1.19	1.17	1.11	--	1.06	1.15	1.07	1.08	1.10	1.07
	Dyno	--	--	--	--	--	1.13	1.11	1.02	1.10	--
HST	Track	1.11	1.12	1.05	--	1.09	1.15	1.06	1.06	1.04	1.06
	Dyno	--	--	--	--	--	1.20	1.08	1.11	1.11	--
30	Track	1.13	--	1.12	--	1.10	--	1.12	1.13	1.15	1.06
	Dyno	--	--	--	--	--	1.11	1.12	--	--	--
40	Track	1.13	1.13	1.08	--	1.05	--	1.06	1.07	1.11	1.08
	Dyno	--	--	--	--	--	1.04	1.07	--	--	--
50	Track	1.10	1.16	1.03	--	1.06	--	1.08	1.06	1.07	1.06
	Dyno	--	--	--	--	--	1.05	1.07	--	--	--
60	Track	1.09	1.12	1.00	--	1.04	--	1.05	1.06	1.10	1.06
	Dyno	--	--	--	--	--	1.02	1.12	--	--	--

KEY:

	Radial	Bias
Track		
Dyno		

Table 22. RATIO ± 1 STANDARD ERROR OF FUEL ECONOMY MEASURED WITH AIR CONDITIONING OFF TO FUEL ECONOMY MEASURED WITH AIR CONDITIONING ON

(Weighted Mean of Dynamometer, Track, Radial and Bias Tire Results)

	GRANADA	CHEVETTE	PACER	ASPEN	IMPALA
BAG1	1.127 ± 0.027	1.081 ± 0.038	1.085 ± 0.023	1.075 ± 0.018	1.067 ± 0.018
BAG2	1.184 ± 0.011	1.098 ± 0.022	1.101 ± 0.012	1.093 ± 0.010	1.099 ± 0.010
BAG3	1.168 ± 0.017	1.129 ± 0.030	1.121 ± 0.020	1.053 ± 0.015	1.083 ± 0.016
FTP	1.167 ± 0.010	1.101 ± 0.016	1.097 ± 0.011	1.077 ± 0.008	1.088 ± 0.008
HH	1.177 ± 0.010	1.113 ± 0.013	1.114 ± 0.011	1.073 ± 0.009	1.092 ± 0.010
HST	1.114 ± 0.013	1.050 ± 0.022	1.124 ± 0.016	1.089 ± 0.009	1.083 ± 0.013
CST	---	---	---	---	---
HNO	---	---	1.070 ± 0.027	---	---
HRE	---	---	1.049 ± 0.027	---	---
HSM	---	---	1.086 ± 0.033	---	---
10	1.164 ± 0.033	---	1.141 ± 0.027	1.136 ± 0.016	1.199 ± 0.038
20	1.187 ± 0.033	1.139 ± 0.027	1.157 ± 0.019	1.154 ± 0.016	1.238 ± 0.022
30	1.131 ± 0.033	1.119 ± 0.027	1.101 ± 0.019	1.115 ± 0.016	1.147 ± 0.022
40	1.133 ± 0.023	1.081 ± 0.027	1.046 ± 0.019	1.056 ± 0.016	1.095 ± 0.022
50	1.130 ± 0.023	1.033 ± 0.033	1.053 ± 0.019	1.065 ± 0.016	1.071 ± 0.022
60	1.105 ± 0.023	0.995 ± 0.027	1.031 ± 0.019	1.065 ± 0.016	1.087 ± 0.022
70	1.126 ± 0.023	1.029 ± 0.027	1.001 ± 0.027	---	1.087 ± 0.022
80	1.017 ± 0.023	---	1.055 ± 0.027	---	1.046 ± 0.022

8.8 Air Conditioning Simulation Effect

Air conditioners are not normally operated during vehicle testing on dynamometers. To simulate the effect of air conditioning on fuel economy as measured on a dynamometer, the dynamometer road load at 50 mph is instead increased 10%. The ratios of fuel economy measured with air conditioning off (i.e., proper road load) to fuel economy measured with simulated air conditioning (i.e., road load increased 10%) are presented in Table 23 for both radial and bias tires. More appropriately, this analysis may be considered to be the effect on fuel economy due to a 10% increase in dynamometer power absorption unit setting.

A two-way analysis of variance of the ratios among vehicles and driving sequences yields a mean ratio of 1.0087. Thus, a 10% increase in road load produces on average less than a 1% decrease in fuel economy. This may be compared to an approximately 10% decrease in fuel economy in Table 22. The analysis of variance indicated no significant vehicle-to-vehicle ratio difference. However, a marginally significant test cycle effect was noted; however, this effect does not appear to be correlated with average test speed.

Table 23

RATIO ± 1 STANDARD ERROR OF FUEL ECONOMY MEASURED WITH AIR CONDITIONING OFF TO FUEL ECONOMY MEASURED WITH SIMULATED AIR CONDITIONING FOR DYNAMOMETER MEASUREMENTS

	DATSUN*	PACER*	ASPEN**	IMPALA**
BAG1	0.996 ± 0.027	0.963 ± 0.033	1.020 ± 0.027	0.971 ± 0.027
BAG2	1.030 ± 0.017	0.983 ± 0.023	1.030 ± 0.017	1.023 ± 0.016
BAG3	0.996 ± 0.025	1.018 ± 0.033	1.018 ± 0.025	1.021 ± 0.023
FTP	1.014 ± 0.012	0.998 ± 0.016	1.025 ± 0.012	1.010 ± 0.012
HH	1.013 ± 0.015	0.996 ± 0.020	1.024 ± 0.015	1.022 ± 0.014
HST	0.947 ± 0.017	1.016 ± 0.017	0.998 ± 1.250	1.044 ± 0.017
CST				
HNO				
HRE				
HSM				
10		0.950 ± 0.027	1.208 ± 0.027	
20		0.986 ± 0.027	1.000 ± 0.027	
30		0.954 ± 0.027	1.021 ± 0.027	
40		0.992 ± 0.027	1.027 ± 0.027	
50		1.024 ± 0.027	1.051 ± 0.027	
60		0.993 ± 0.027	1.052 ± 0.027	

* Bias Tires

** Radial Tires

8.9 Effects of Modified Cycles

Tables 24 and 25 present the computed ratios of the fuel economy for each modified highway test to the fuel economy of the standard highway test for dynamometer and track tests, respectively. Note from the tables that the cold start highway dynamometer and track tests represent a degradation in fuel economy of about 10% compared to the standard test. The noisy and redistributed cycle tests impose a 3%-5% fuel economy penalty on both the dynamometer and the track. The smooth and 50 mph cruise cycles result in a 4% to 8% fuel economy improvement over the standard cycle.

In some instances, vehicle to vehicle differences among the ratios can be statistically inferred both from the dynamometer and track tests. Even so, we present the mean ratios over all vehicles for each modified test and note that the mean ratios from dynamometer tests are statistically undistinguishable from the mean ratios from the track tests. A comparison of the modified test cycles with the standard highway cycle is presented in Appendix A.

Table 24. RATIO OF MODIFIED HIGHWAY TEST MPG TO STANDARD HIGHWAY TEST MPG FOR DYNAMOMETER TESTS

(Air Conditioner Off)

		COLD START (CST)	NOISY CYCLE	REDISTRIBUTED CYCLE	SMOOTH CYCLE	50 MPH CRUISE
Datsun	Radial	0.885 ± 0.021	1.015 ± 0.014	1.000 ± 0.014	1.072 ± 0.014	1.083 ± 0.016
	Bias	0.890 ± 0.017	0.981 ± 0.017	0.873 ± 0.017	---	1.055 ± 0.017
Pinto	Radial	---	---	---	---	1.067 ± 0.017
	Bias	---	0.962 ± 0.016	0.964 ± 0.016	1.034 ± 0.016	1.067 ± 0.022
Honda	Radial	0.892 ± 0.019	1.000 ± 0.017	1.003 ± 0.017	1.028 ± 0.016	1.066 ± 0.019
	Bias	0.893 ± 0.017	---	---	---	---
Chevette	Radial	---	---	---	---	---
	Bias	---	---	---	---	---
Pacer	Radial	---	---	---	---	---
	Bias	---	0.952 ± 0.015	0.930 ± 0.016	1.046 ± 0.016	1.063 ± 0.022
Aspen	Radial	0.920 ± 0.021	0.933 ± 0.014	0.926 ± 0.013	1.036 ± 0.014	1.103 ± 0.021
	Bias	0.940 ± 0.023	0.966 ± 0.017	0.947 ± 0.019	1.062 ± 0.017	1.143 ± 0.023
Impala	Radial	0.933 ± 0.022	0.969 ± 0.015	0.988 ± 0.015	1.034 ± 0.015	---
	Bias	---	---	---	---	1.091 ± 0.022
Mean		0.908 ± 0.008	0.972 ± 0.005	0.954 ± 0.006	1.045 ± 0.006	1.082 ± 0.007

Table 25. RATIO OF MODIFIED HIGHWAY TEST MPG TO STANDARD HIGHWAY TEST MPG FOR TRACK TESTS

(Air Conditioner Off)

		COLD START (CST)	NOISY CYCLE	REDISTRIBUTED CYCLE	SMOOTH CYCLE	50 MPH CRUISE
Datsun	Radial	---	0.963 ± 0.017	0.935 ± 0.019	1.047 ± 0.019	1.093 ± 0.022
	Bias	---	---	---	---	---
Pinto	Radial	---	---	---	---	---
	Bias	0.876 ± 0.027	0.981 ± 0.025	0.975 ± 0.025	1.100 ± 0.027	---
Honda	Radial	0.906 ± 0.029	0.965 ± 0.022	0.960 ± 0.022	1.061 ± 0.029	0.952 ± 0.022
	Bias	---	0.984 ± 0.025	0.963 ± 0.025	1.042 ± 0.025	0.906 ± 0.025
Chevette	Radial	0.804 ± 0.029	0.939 ± 0.022	0.961 ± 0.022	1.051 ± 0.022	1.081 ± 0.029
	Bias	---	0.965 ± 0.033	0.964 ± 0.033	1.061 ± 0.033	1.091 ± 0.033
Pacer	Radial	0.934 ± 0.038	0.988 ± 0.033	0.977 ± 0.033	1.121 ± 0.038	1.211 ± 0.033
	Bias	---	---	---	---	---
Aspen	Radial	0.931 ± 0.030	0.945 ± 0.020	0.972 ± 0.019	1.049 ± 0.019	1.157 ± 0.030
	Bias	---	---	---	---	---
Impala	Radial	0.937 ± 0.031	0.985 ± 0.022	0.995 ± 0.022	1.071 ± 0.022	1.126 ± 0.025
	Bias	---	---	---	---	---
Mean		0.898 ± 0.012	0.968 ± 0.008	0.967 ± 0.008	1.067 ± 0.008	1.077 ± 0.010

8.10 Computed Road Load Horsepower From Coast Downs

Coast-down tests were conducted on the track and dynamometer on vehicles equipped with bias belted and radial tires. The quantities that were measured were vehicle direction (i.e., north, south, curve for track tests), wind speed, wind direction, and time in seconds for the vehicle to coast from 55 mph to 45 mph. Coast-down tests were also conducted on the track to measure the effect of the vehicles' windows being up or down and on the dynamometer to measure the effect of air conditioning off or simulated. The coast-down results are presented in Table 26.

Table 26 also presents the calculated Road Load Horsepower (RLHP) at 50 mph. This quantity is calculated from the coast-down times by the expression

$$\text{RLHP} = \frac{\text{inertia weight (lbs)}}{\text{coast-down time (secs)}} (0.06073)^*$$

For the track tests, the effect of track grade is eliminated by averaging the coast-down times for two different track directions (e.g., north and south). The RLHP calculated is the total horsepower required to overcome both rolling and aerodynamic resistance for a vehicle with a particular inertia weight as tested on the track or dynamometer.

One way of assessing the dynamometer-to-track effect due to improper RLHP simulation on the dynamometer is to ratio the RLHP determined from track tests to the RLHP determined from dynamometer tests. These ratios are presented in Table 27 for radial and bias tires for tests with air conditioning off and windows up. Note that the ratio for bias tires is consistently larger than the corresponding ratio for radial tires for each of the vehicles tested. This is consistent with the notion that the rolling resistance of radial tires is less than the rolling resistance of bias tires. Also note that in all but two instances, the ratios (bias and radial) are less than unity and this would seem to imply that the track road load horsepower necessary to overcome rolling and aerodynamic resistance is <u>less than</u> the dynamometer road load horsepower.

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* See Appendix F for derivation of formula.

Table 26(a)

MEASURED COAST-DOWN TIMES AND CALCULATED ROAD LOAD HORSEPOWER FOR DYNAMOMETER AND TRACK TESTS

VEHICLE	SITE	TEST WEIGHT (lbs)	DIRECTION	TIRE TYPE	WIND SPEED (mph)	WIND** DIRECTION (deg)	WINDOWS	A/C*	AVG. TIME FROM 55 TO 45 MPH (secs)	CALCULATED RLHP @ 50 MPH
PINTO	TRACK	3150	N	R	1	90	UP	OFF	13.07	13.52
			S						15.23	
			N				DOWN		12.80	14.21
			S						14.13	
			N	B	6	335	UP		11.83	14.66
			S						14.27	
			W. Curve						12.30	15.06
			E. Curve						13.10	
	DYNO #5	3000	N/A	R	N/A	N/A	N/A	OFF	12.40	14.69
				B					13.80	13.20
IMPALA	TRACK	4869	N	R	3	272	UP	OFF	15.00	16.80
			S						20.20	
	DYNO #5	5000	N/A	R	N/A	N/A	N/A	OFF	14.14	21.47
								SIM.	14.00	21.69
				B				OFF	14.60	20.80
								SIM.	13.93	21.80
ASPEN	TRACK	4318	N	R	6	328	UP	OFF	13.86	15.65
			S						19.66	
			N	B	1	323			14.00	16.67
			S						17.46	
	DYNO #5	4000	N/A	R	N/A	N/A	N/A	OFF	12.34	19.69
								SIM.	14.00	20.47
				B				OFF	12.93	18.79
								SIM.	12.23	19.86

* A/C = Airconditioning

** Relative to North.

Table 26(b)

MEASURED COAST-DOWN TIMES AND CALCULATED ROAD LOAD HORSEPOWER FOR DYNAMOMETER AND TRACK TESTS

VEHICLE	SITE	TEST WEIGHT (lbs)	DIRECTION	TIRE TYPE	WIND SPEED (mph)	WIND** DIRECTION (deg)	WINDOWS	A/C*	AVG. TIME FROM 55 TO 45 MPH (secs)	CALCULATED RLHP @ 50 MPH
GRANADA	TRACK	3978	N	R	5	157	UP	OFF	14.90	16.72
			S						14.00	
			N	B	4.5	20			11.45	18.66
			S						11.60	
			E. Curve						11.60	20.13
			W. Curve						12.40	
	DYNO #5	4000	N/A	R	N/A	N/A	N/A	OFF	13.60	17.86
				B					13.87	17.51
PACER	TRACK	3776	N	R	0	0	DOWN	OFF	14.03	15.89
			S						14.83	
			N				UP		16.03	13.75
			S						17.33	
			N	B	4	90	UP		15.30	14.08
			S						17.27	
	DYNO #5	3500	N/A	R	N/A	N/A	N/A	OFF	13.00	16.35
				B					13.50	15.74
								SIM.	12.80	16.61
DATSUN	TRACK	2497	N	B	6.5	300	UP	OFF	12.00	12.33
			S		4.5	270			12.60	
			N		6.0	300	DOWN		11.53	12.78
			S						12.20	
			N	R	7.0	270	UP		13.90	11.27
			S						13.00	
			N				DOWN		13.00	12.23
			S						11.80	
	DYNO #5	2250	N/A	R	N/A	N/A	N/A	OFF	10.77	12.69
				B					10.99	12.43

* A/C = Air Conditioning
** Relative to North

Table 27

RATIO OF RLHP DETERMINED FROM TRACK COAST-DOWN TESTS TO RLHP DETERMINED FROM DYNAMOMETER COAST-DOWN TESTS (AIR CONDITIONING OFF/WINDOWS UP)

VEHICLE	TIRE TYPE		RATIO OF TRACK TEST WEIGHT TO DYNO TEST WEIGHT
	BIAS	RADIAL	
PINTO	1.111	0.920	1.05
IMPALA	---	0.782	0.97
ASPEN	0.887	0.795	1.08
GRANADA	1.066	0.936	0.99
PACER	0.895	0.841	1.08
DATSUN	0.992	0.888	1.11

9.0 DISCUSSION

This test program and analysis attempts to identify, quantify, and statistically verify the individual parameters contributing to dynamometer to track fuel economy differences. To this end, the testing of each vehicle is carefully controlled both for dynamometer and for track tests to every extent possible.

Each vehicle was inspected and tuned to manufacturers' specifications before testing began, so that any fuel economy differences due to vehicle state-of-tune could be eliminated. Also, to the extent possible, each vehicle was tested on the track at ambient temperatures within the same range (68°F to 86°F)* as that required by the FTP for dynamometer tests. Effects of wind and grade, which are not simulated on dynamometer tests, were compensated for on track tests by conducting the test cycle in two opposing directions and averaging the resulting measurements.

Odometer mileage also can affect fuel economy and can contribute to dynamometer to track variability. The odometer readings for the vehicles tested ranged from approximately 2000 to 11000 miles. In most cases, however, there were only a few hundred miles difference between the points at which the vehicles were tested from dynamometer to track.

The above differences in testing conditions from dynamometer to track were considered to be small. That is, differences in temperature and mileage (uncontrolled parameters considered to possibly influence fuel economy) were judged to be small contributors to fuel economy variability compared to measurement variability. Thus, no attempts were made to correct fuel economy for vehicle mileage or ambient temperature.

Fuel economy measured on the dynamometer is normally calculated by the carbon balance method. In this study, it was determined that the differences between meter fuel consumption and carbon balance fuel consumption were a function of the particular meter used as well as the magnitude of fuel consumption. Therefore, comparisons between fuel economy on the track and dyno were always made using the same or equivalently adjusted meter (i.e., for purposes of presentation meter #1514 was arbitrarily chosen and fuel consumptions measured with different meters were corrected by whatever the offset was determined to be between it and meter 1514).

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* In a few instances, tests were conducted at ambient temperatures as low as 50°F, but never above 86°F.

Dynamometer measured fuel economy divided by track measured fuel economy provides a measure of the dyno/track effect. As determined in the analysis, no statistically significant differences between the ratios computed for air conditioning on and air conditioning off are detectable. However, vehicle to vehicle differences between ratios do exist. Further, there is a difference between ratios due to tire type (i.e., radial and bias belted). If we compare the FTP ratios presented in Table 28, it may be noted that fuel economy as measured on the dynamometer is greater than the fuel economy measured on the track for all cases. Except for the Honda, the ratio is larger for the vehicle tested with bias tires as compared to the same vehicle tested with radial tires. We note two factors that may be responsible for the reverse effect in the Honda. First, the Honda is the only front-wheel drive vehicle in the group, and second, the Honda was tested with 12" bias tires and 13" radial tires.

Table 28.

COMPARISON OF DYNAMOMETER TO TRACK FUEL ECONOMY RATIOS AS MEASURED OVER THE FTP

(Mean Ratio ±1 Standard Error)

TIRE TYPE	PINTO	HONDA	PACER	ASPEN
Radial	1.051±0.014	1.114±0.011	---	1.086±0.010
Bias	1.106±0.015	1.097±0.013	1.057±0.013	1.140±0.014

Table 29 presents the ratios of fuel economy as measured with radial tires to the fuel economy as measured with bias tires for both dynamometer and track FTP tests.

Note in the table, that the ratios computed for dynamometer tests are all less than unity except for the Honda. This seems to imply that fuel economy of a vehicle measured on a dynamometer is less if it is equipped with radial tires as compared to bias belted tires. Another way of saying the same thing is that the rolling resistance of radial tires is greater than the rolling resistance of bias tires when tested on the dynamometer.

Table 29

COMPARISON OF THE RATIOS OF FUEL ECONOMY MEASURED WITH RADIAL TIRES TO FUEL ECONOMY MEASURED WITH BIAS TIRES FOR DYNAMOMETER AND TRACK

(Mean Ratios ±1 Standard Error)

VEHICLE	DYNAMOMETER	TRACK
Pinto	0.967 ± 0.012	1.018 ± 0.017
Honda	1.022 ± 0.010	1.006 ± 0.014
Datsun	0.984 ± 0.010	1.005 ± 0.014
Chevette	---	1.030 ± 0.016
Pacer	---	---
Aspen	0.992 ± 0.009	1.057 ± 0.015
Impala	0.996 ± 0.012	1.080 ± 0.010
Granada	---	0.970 ± 0.013

For track tests, it may be noted from Table 29 that the ratios are greater than unity (except for the Granada). This implies that for track tests fuel economies for vehicles equipped with radial tires are greater than fuel economies for vehicles equipped with bias tires (i.e., rolling resistance is greater for bias tires than for radial tires on track tests).

Another way to assess and compare the ratios in Tables 28 and 29, is to compute the ratios of the ratios. For example, Table 28 compares the ratios of dynamometer fuel economy to track fuel economy for vehicles with radial tires (D_R/T_R) and for vehicles with bias tires (D_B/T_B). The ratio of these two ratios may be written:

$$\frac{D_R/T_R}{D_B/T_B} = \frac{D_R/D_B}{T_R/T_B}$$

Note that $(D_R/D_B)/(T_R/T_B)$ is exactly the ratio of the ratios presented in Table 29. On the other hand, it is observed in Table 30 that the two alternatively calculated ratios of the ratios are not exactly equal. This is explained by the fact that in some cases a different number of tests were available for the dynamometer to track comparisons than were available for radial to bias tire comparisons on the same vehicle.

Table 30.

COMPARISON OF THE RATIO OF RATIOS BY TWO METHODS

	$\frac{D_R/D_B}{T_R/T_B}$	$\frac{D_R/T_R}{D_B/T_B}$
Pinto	0.950 ± 0.021	0.950 ± 0.021
Honda	1.016 ± 0.017	1.015 ± 0.019
Datsun	0.979 ± 0.019	---
Aspen	0.939 ± 0.017	0.953 ± 0.017
Impala	0.922 ± 0.016	---

Because the same meter was not always used to measure both dynamometer and track fuel consumptions, fewer comparisons could be made, in general, between the fuel economies from dynamometer to track than between fuel economies from radial to bias tires.

If the relative tire/track interactions of radial and bias tires were properly simulated by the dynamometer, then the dynamometer-to-track MPG ratio for radial tires would equal the dynamometer-to-track MPG ratio for bias tires (i.e., the ratio of the ratios would be unity). From Table 30 note that this is not true. In most cases, the ratio of the ratios is less than unity, and the magnitude of deviations is as much as 8%. The implication is that the relatively higher fuel economy achieved on the average with radial tires on the track is not reproduced on the dynamometer.

A previous study of tire-surface interaction by Burgeson[6] sheds some light on reasons for the discrepancy between dynamometer and track results. Burgeson's study investigated the rolling resistive forces on 29 pairs of tires ranging in size from BR78x13 to LR78x15 and consisting of radial, bias belted, and bias ply construction. The pairs of tires were tested on a small twin-roll dynamometer ($r \approx 5''$) and on a large single-roll dynamometer ($r \approx 24''$). No aerodynamic losses were simulated (i.e., no PUA settings). The power absorbed by the dynamometers due to only rolling resistive losses were calculated from coast-down times on both the large and small roll dynamometers.

It is generally assumed in the dynamometer test procedure that the power absorbed by a tire (inflated to 45 psi) on the dynamometer is twice that of the tire (inflated to a typical 26 psi) on the road. That is, one might expect a rolling resistive force, F_R, measured on the dual small roll dynamometer (at 45 psi) to be twice that force measured on a flat surface (at 26 psi).

The rolling resistance determined from measurements with two tires at 45 psi on a small-roll Clayton Dynamometer was compared to the rolling resistance determined from corrected results on the large roll dynamometer. The results are reproduced in Table 31 and show that the ratio R_C of the mean rolling force on the small roll dynamometer at 45 psi to the corrected mean rolling force on a flat surface for different tire types is less than the expected factor of two and varies by tire type. From the table, note that radial tires come closest to producing a ratio of 2. In general, it may be inferred from Burgeson's results that the Clayton twin-roll dynamometer underloads vehicles (i.e., the force due to rolling resistance measured on the dynamometer is less than that actually measured on the road). Furthermore, this dynamometer underloading effect is more severe for bias belted tires than for radial, which is in qualitative agreement with Table 30.

Table 31.

RATIO (R_C) OF THE MEAN HORSEPOWER (P_R) DUE TO ROLLING RESISTANCE MEASURED ON A SMALL TWIN-ROLL DYNAMOMETER TO THE MEAN HORSEPOWER DUE TO ROLLING RESISTANCE MEASURED ON A LARGE ROLL DYNAMOMETER AND CORRECTED TO ROAD*

Tire Type	Clayton (Tires at 45 psi)	Large Roll Corrected to Road (Tires at 26 psi)	$R_C = \frac{P_R \text{ Clayton}}{P_R \text{ Road}}$
	P_R Clayton (hp)	P_R Road (hp)	
Radial	7.67	4.15	1.85
Bias	6.99	5.04	1.39
Belted Bias	7.81	5.25	1.49

* Extracted from Reference 6.

The results in Table 31 should be viewed qualitatively inasmuch as the magnitude of the ratio, R_C, obtained by Burgeson may not be correct for all tire/vehicle combinations. The reason for this is discussed by Burgeson. Radial and bias tires exhibit ranges of rolling resistance characteristics that may vary by tire manufacturer and vehicle configuration. There may be high and low rolling resistance radial and bias tires and tire-track surface interactions may be different from tire-dynamometer surface interactions.

Consistent with the above, the dynamometer to track MPG ratios computed in this study are seen to vary significantly from vehicle to vehicle. The vehicle-to-vehicle effect is more appropriately defined as a vehicle/tire configuration effect.

In addition to the contributions that rolling resistance variations make to fuel economy differences are the contributions of aerodynamic resistance. Newell[7] has investigated the extent to which manufacturer supplied PAU settings (i.e., aerodynamic resistive force) agreed with aerodynamic forces measured on ten production vehicles. In this program, vehicles were chosen for test if their manufacturer supplied PAU settings were atypically low compared to PAU settings for other similar vehicles.

Vehicle road load horsepowers (aerodynamic and rolling resistance contributions) were determined from coast-down tests on a test track. The RLHPs were corrected to an ambient air temperature of 68°F and barometric pressure of 29.00 inches Hg. The vehicle was then set up on a twin small-roll dynamometer and the PAU was set to a value that reproduced the same coast-down time that was measured on the test track. The PAU values obtained in this way were compared with the PAU values submitted by the manufacturer for that vehicle. The manufacturer and test determined PAU settings in horsepower are reproduced in Table 32.

From Table 32, note that the manufacturers' recommended PAU settings are consistently lower than those measured from the production vehicles (except for the Omni, a front-wheel drive vehicle). Also presented in Table 32 are the total RLHP calculated from coast-down times in Newell's tests. The difference between total RLHP and P_A (the PAU setting) is the implied power dissipated due to rolling resistance. The calculated values range from 4.0 to 8.0 HP and do not compare with the power dissipation results due to rolling resistance computed by Burgeson in Table 31 and which range from 8.3 to 10.5 HP.

Table 32

COMPARISON OF DYNAMOMETER POWER ABSORBER (PA) SETTINGS IN HP*

'79 VEHICLE	P_A MFR. (PAU)	P_A STUDY (PAU)	P_T TOTAL RLHP (MFR)	P_T TOTAL RLHP (STUDY)	P_R IMPLIED ROLLING RESISTANCE (TOTAL RLHP-PAU) STUDY
Fiesta	7.3	8.05	12.2	12.0	3.95
Omni	7.8	7.8	12.7	11.8	4.0
Monza	8.1	11.3	--	15.9	4.6
Granada	10.1	12.6	13.7	17.8	5.2
Firebird	8.8	10.0	14.9	14.3	4.3
Lebaron	10.8	11.6	16.3	16.9	5.3
Corvette	8.0	9.4	--	17.4	8.0
Eldorado	9.6	10.0	16.4	17.4	7.4
Trans Am	9.5	9.9	15.3	14.4	4.5
Olds '98	11.6	12.2	18.1	18.2	6.0

* Extracted, in part, from Reference 7.

There are several possible reasons for the apparent discrepancy in power dissipation measurements and calculations due to rolling resistance. The first and most obvious reason for the differences in rolling resistance has previously been discussed and refers to the wide range of rolling resistance characteristics possible for both radial and bias tires.

Second, Burgeson's estimates of track rolling resistance were made by testing tires on a large roll dynamometer ($r \approx 24''$) at 45 psi. He had to correct his results to account for roll curvature and tire pressure. Klingbeil[8] has shown that the curvature correction formula most often used (due to Clark[9] and used by Burgeson) does not correctly account for curvature due to thermal effects. If this is the case, Burgeson's absolute estimates of track rolling resistance are too high.

Third, Newell's estimates of the contribution of aerodynamic resistive forces seem to be too large a fraction of total road load horsepower (e.g., 54% to 71%). Newell's estimates of aerodynamic forces are higher than the manufacturers' estimates even though his estimates of total road load horsepower at 50 mph are consistent with manufacturer supplied total road load horsepower. Newell cites tire-surface interaction effects and possible dynamometer calibration differences as possible reasons for the observed differences between his test-determined PAU settings and those submitted by the manufacturer.

Results of coast down tests on six of the eight vehicles in this test program indicate that total road load horsepower at 50 mph (RLHP) is, in general, lower on track tests than on dynamometer tests. This is exactly opposite what would be expected on the basis of fuel economy comparisons. Nevertheless, the relative relationship of the imputed rolling resistance of radial-to-bias tires on the track as compared to that on the dynamometer is consistent with the fuel economy ratio of ratios presented in Table 30. However, since we cannot accurately resolve the contributions of rolling and aerodynamic forces for these vehicles tested, we cannot completely account for the RLHP differences from track-to-dynamometer tests.

Recent studies by Yurko[10] and Gugett[11] have shown another possible influence on vehicle fuel economy as measured on a dynamometer. Yurko and Grugett have shown that there is a velocity difference (i.e., a slip) between the front and rear rolls of a small twin-roll dynamometer due to tire deformation. The effective tire radius on the rear roll is greater than the effective tire radius on the front roll. Therefore the rotational velocity of the front roll is less relative to the rear roll.

As is presently the case for a small twin-roll dynamometer, the major tractive load imposed on the vehicle is applied at the front roll. The rear roll is presently uncoupled from the front roll and is used to determine speed. Since the fuel economy, as calculated over a specified driving sequence, is dependent on the speed of (and distance traveled by) the rear roll, fuel economy estimates are greater than they would be if speed was measured from the front roll.

Results of testing by Yurko with one 1978 Mercury Montego indicate that the velocity differences between the rolls were least when the rolls were coupled (e.g., a -0.22%* velocity difference for radial tires and a 0.40% velocity difference for bias tires). Coast-down tests with radial tires indicated that the coupling of the rolls resulted in a 2% to 6% increase in measured fuel consumption rate as compared to the case when the rolls were uncoupled.

Grugett measured the fuel consumption differences due to the coupling of the dynamometer rolls as compared to the uncoupled case over the urban and highway driving cycles. Tests were conducted with one 1979 Chevrolet Nova on a test track, on a small twin-roll dynamometer with rolls uncoupled, and on a small twin-roll dynamometer with the rolls coupled. Tests showed that the uncoupled dynamometer tests overestimated fuel economy by about 10% over track tests. Coupled dynamometer tests overestimated fuel economy by about 4%.

Additional studies are needed to verify the vehicle tire slip influence on fuel economy as measured on a dynamometer. Preliminary investigations indicate that coupling of the front and rear rolls of the dynamometer might account for as much as 6% of the approximate 10% difference in fuel economy measured between dynamometer and track. Tests need to be conducted on a test track, and on a coupled and uncoupled dynamometer using different size and technology vehicles (i.e., front and rear wheel drive), and different tire types.

Additional investigations within the present study indicate that the use of air conditioning results in an increase in fuel consumption of from 7% to 18% measured over the FTP urban cycle. The increase in fuel consumption due to the use of air conditioning is independent of track or dynamometer testing and of tire type. However, the increase in fuel consumption does vary significantly from vehicle to vehicle.

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* The rotational velocity of the front roll was 0.22% <u>larger</u> than the rear roll.

At present, the impact on fuel economy due to air conditioning is simulated on the dynamometer by increasing the dynamometer road load (PAU) at 50 mph by 10%. This study found that the dynamometer simulation of air conditioning did not produce any significant change in measured fuel economy. Dynamometer simulated air conditioning is not a good indication of the effect on fuel economy due to the use of air conditioning in actual practice.

Finally, effort was expended in this study to determine the extent to which different types of driving, similar to highway driving, affected vehicle fuel economy. Public criticism over the EPA estimated highway fuel economy of vehicles has raised doubts as to whether the highway estimate is attainable. Tests in the study over modified highway cycles demonstrate highway fuel economies that are as much as 10% lower or 8% higher than the fuel economies estimated over the standard EPA highway cycle. The tests demonstrated that highway type driving characterized by smooth steady driving resulted in a highway fuel economy approximately 6% larger than the EPA estimate. Driving at a constant 50 mph resulted in an 8% increase in fuel economy over the EPA highway cycle fuel economy. On the other hand, highway type driving characterized by a greater percentage of time either accelerating/decelerating or at speeds above 60 mph resulted in significant decreases in fuel economy of about 3-4% compared to EPA estimates. Cold start highway fuel economy was about 9%-10% lower than EPA highway cycle fuel economy. In all cases, the dynamometer produced statistically equivalent effects on fuel economy due to the modified cycles as those produced on track tests.

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APPENDIX A

COMPARISON OF MODIFIED AND STANDARD HIGHWAY CYCLES

APPENDIX A

Table A-1

COMPARISON OF MODIFIED AND STANDARD HIGHWAY CYCLES

	STANDARD CYCLE	SMOOTH CYCLE	NOISY CYCLE	REDISTRIBUTED CYCLE
Distance, Miles	10.24	10.23	10.26	10.56
Time, Seconds	765	765	765	765
Average Speed, mph	48.2	48.1	48.3	49.7
Minimum mph*	28.4	50.0	25.1	18.1
Maximum mph	59.5	50.0	63.0	72.5
Stops per Mile	0.098	0.098	0.097	0.095
PERCENT TIME IN SPEED RANGES				
Idle	0.5	0.5	0.5	0.5
0-10 mph	2	2	2	2
10-20 mph	1	1	1	1
20-30 mph	2	1	2	3
30-40 mph	8	1	9	10
40-50 mph	41	3	38	25
50-60 mph	46	92	46	40
60-70 mph	0	0	2	16
> 70 mph	0	0	0	2

* Excluding initial acceleration and final deceleration.

Table A-2

DISTRIBUTION OF TIME SPENT IN ACCELERATION AND SPEED RANGES:

Standard EPA Highway Cycle

ACCELERATION RATE (MPH/sec)	SPEED (MPH) 0-10	10-20	20-30	30-40	40-50	50-60
3.6 ... 4.2						
3.0 ... 3.6						
2.4 ... 3.0	2	3				
1.8 ... 2.4		1	2	1		
1.2 ... 1.8	1		1	4		
0.6 ... 1.2			3	1	7	1
0 ... 0.6			1	15	73	57
Zero	4		1	19	103	141
0 ... -0.6			1	6	100	151
-0.6 ... -1.2	1		2	7	21	6
-1.2 ... -1.8	3			3	4	
-1.8 ... -2.4	1	3	1		3	1
-2.4 ... -3.0	2	1	2		1	
-3.0 ... -3.6			1	3		
-3.6 ... -4.2						
-4.2 ... -4.8						
-4.8 ... -5.4						
Total % of Time in Speed Range	1.8	1.1	2.0	7.7	40.8	46.7

Table A-3

DISTRIBUTION OF TIME SPENT IN
ACCELERATION AND SPEED RANGES:

Smooth Highway Cycle

ACCELERATION RATE (MPH/sec)	SPEED (MPH) 0-10	10-20	20-30	30-40	40-50	50-60
3.6 ... 4.2						
3.0 ... 3.6						
2.4 ... 3.0	2	3	1			
1.8 ... 2.4			2			
1.2 ... 1.8	1		2	3	2	
0.6 ... 1.2				4	6	
0 ... 0.6					3	1
Zero	4					702
0 ... -0.6					6	
-0.6 ... -1.2	1				3	
-1.2 ... -1.8	3				2	
-1.8 ... -2.4	1	3	1			
-2.4 ... -3.0	2	1	2			
-3.0 ... -3.6			1	3		
-3.6 ... -4.2						
-4.2 ... -4.8						
-4.8 ... -5.4						
Total % of Time in Speed Range	1.8	0.9	1.2	1.3	2.9	91.8

Table A-4

DISTRIBUTION OF TIME SPENT IN
ACCELERATION AND SPEED RANGES:

Noisy Highway Cycle

ACCELERATION RATE (MPH/sec)	SPEED (MPH) 0-10	10-20	20-30	30-40	40-50	50-60	60-70
3.6 ... 4.2	1	2					
3.0 ... 3.6		1		1			
2.4 ... 3.0			3	2			
1.8 ... 2.4			1				
1.2 ... 1.8	1		1	1	9		
0.6 ... 1.2			2	7	24	19	1
0 ... 0.6				16	59	67	3
Zero	7			10	62	110	5
0 ... -0.6	1		1	14	93	128	6
-0.6 ... -1.2			2	6	23	24	3
-1.2 ... -1.8		2	2	4	9	5	
-1.8 ... -2.4	1	1	1	2	3	1	
-2.4 ... -3.0	2	1	1	1	2		
-3.0 ... -3.6	1		1	1	1		
-3.6 ... -4.2			1		1		
-4.2 ... -4.8				1	1		
-4.8 ... -5.4				1	2		
Total % of Time in Speed Range	1.8	0.9	2.1	8.7	37.8	46.3	2.3

Table A-5

DISTRIBUTION OF TIME SPENT IN ACCELERATION AND SPEED RANGES:

Redistributed Highway Cycle

ACCELERATION RATE (MPH/sec)	SPEED (MPH) 0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80
3.6 ... 4.2								
3.0 ... 3.6								
2.4 ... 3.0	2	3						
1.8 ... 2.4		1	2	1				
1.2 ... 1.8	1		5					
0.6 ... 1.2		1	3	8	9	1		
0 ... 0.6				16	40	83	17	7
Zero	4	1	1	19	55	95	56	
0 ... -0.6		2	1	25	64	112	49	6
-0.6 ... -1.2	1	2	4	4	18	11	3	1
-1.2 ... -1.8	3		4		5	2		
-1.8 ... -2.4	1	3	1		1	1		
-2.4 ... -3.0	2	1	2					
-3.0 ... -3.6			1	3				
-3.6 ... -4.2								
-4.2 ... -4.8								
-4.8 ... -5.4								
Total % of Time in Speed Range	1.8	1.8	3.3	9.9	25.1	39.8	16.3	1.8

APPENDIX B

TEST VEHICLE-DESCRIPTIONS

APPENDIX B

TEST VEHICLE-DESCRIPTIONS

1. CHASSIS MODEL YEAR MAKE - 1976 Honda CVCC Civic
   EMISSION CONTROL SYSTEM - Honda CVCC

Engine

Type	4-stroke prechamber, stratified charge, spark ignited, single OHC, in-line 4 cyl.
Bore x Stroke	2.91 x 3.41 in./74 x 86.5 mm
Displacement	90.8 CID/1488 cc
Compression Ratio	7.9:1
Maximum Power at rpm	60 hp kW at 5000 rpm
Fuel Metering	Single carburetor with progressive 2 bbl for combustion chamber and 1 bbl for pre-chamber
Fuel Requirement	91 RON

Drive Train

Transmission Type	4 speed manual
Final Drive Ratio	3.875:1

Chassis

Type	Unitized body, front transverse mounted engine, front wheel drive
Tire Size	OEM Goodrich 6.00Sx12 and OEM Michelin 155SRx13
Curb Weight	1795 lb/815 kg
Inertia Weight	2000 lb/910 kg
Passenger Capacity	Four

Emission Control System

Basic Type . . . . Prechamber stratified charge with thermal reactor and PCV

Mileage on Vehicle . . . . 5,460 miles

2. CHASSIS MODEL YEAR/MAKE - 1976 Datsun B-210
EMISSION CONTROL SYSTEM - EGR, Air Injection

Engine

Type	4-stroke Otto Cycle, OHV, in-line, 4 cyl.
Bore x Stroke	2.99 x 3.03 in./76 x 77 mm
Displacement	85 cu. in./1397 cc
Compression Ratio	8.5:1
Maximum Power at rpm	80 hp/60 kW at 6000 rpm
Fuel Metering	Single progressive 2 bbl carburetor
Fuel Requirement	91 RON low lead

Drive Train

Transmission Type	4 speed manual
Final Drive Ratio	3.89:1

Chassis

Type	Unitized body, front engine, rear wheel drive
Tire Size	OEM Toyo 155SRx13 and OEM Bridgestone 155x13
Curb Weight	1965 lb/890 kg
Inertia Weight	2250 lb/1020 kg
Passenger Capacity	Four

Emission Control System

Basic Type	EGR, PCV, air injection
Mileage on Vehicle	3,600 miles

3. CHASSIS MODEL YEAR/MAKE - 1976 Ford Pinto
EMISSION CONTROL SYSTEM - Catalyst, EGR, Air Injection

Engine

Type	4-stroke, Otto cycle, OHC, in-line, 4 cyl.
Bore x Stroke	3.78 x 3.13 in./96.0 x 79.5 mm
Displacement	140 cu. in./2300 cc
Compression Ratio	9.0:1
Maximum Power at rpm	92 hp/69 kW at 5000 rpm
Fuel Metering	Single 2 bbl carburetor
Fuel Requirement	91 RON unleaded

Drive Train

Transmission Type	3 speed automatic
Final Drive Ratio	3.18:1

Chassis

Type	Unitized body, front engine, rear wheel drive
Tire Size	OEM Goodyear A78x13 and OEM Goodyear BR78x13
Curb Weight	2587 lb./1175 kg
Inertia Weight	3000 lb./1360 kg
Passenger Capacity	Four

Emission Control System

Basic Type	Single monolith noble metal catalyst, EGR, PCV, air injection
Mileage on Vehicle	10,220 miles

4. CHASSIS MODEL YEAR/MAKE - 1976 AMC Pacer
EMISSION CONTROL SYSTEM - EGR

Engine

Type	4-Stroke Otto Cycle, OHV, in-line, 6 cyl.
Bore x Stroke	3.75 x 3.50 in./95 x 89 mm
Displacement	232 CID/3802 cc
Compression Ratio	8.0:1
Maximum Power at rpm	90 hp/67 kW at 3050 rpm
Fuel Metering	Single one bbl carburetor
Fuel Requirement	91 RON

Drive Train

Transmission Type	3 speed automatic
Final Drive Ratio	3.08:1

Chassis

Type	Unitized body, front engine, rear wheel drive
Tire Size	OEM Goodyear DR70x14 and OEM Goodyear 6.95x14
Curb Weight	3330 lb/1510 kg
Inertia Weight	3500 lb/1590 kg
Passenger Capacity	Five

Emission Control System

Basic Type	EGR, PCV
Mileage on Vehicle	4,940 miles

5. CHASSIS MODEL YEAR/MAKE - 1976 Ford Granada
EMISSION CONTROL SYSTEM - Catalyst, EGR, Air Injection

Engine

Type	4-stroke Otto cycle, OHV, in-line, 6 cyl.
Bore x Stroke	3.68 x 3.91 in./93 x 99 mm
Displacement	250 CID/4100 cc
Compression Ratio	8.0:1
Maximum Power at rpm	86 hp/64 kW at 3000 rpm
Fuel Metering	Single one bbl carburetor
Fuel Requirement	91 RON unleaded

Drive Train

Transmission Type	3 speed automatic
Final Drive Ratio	3.07:1

Chassis

Type	Unitized body, front engine, rear wheel drive
Tire Size	OEM Goodyear DR78x14 and OEM Goodyear C78x14
Curb Weight	3490 lb./1585 kg
Inertia Weight	4000 lb./1820 kg
Passenger Capacity	Five

Emission Control System

Basic Type	Single monolith noble metal catalyst, secondary air injection, EGR, PCV
Mileage on Vehicle	4,940 miles

6. CHASSIS MODEL YEAR/MAKE - 1976 Dodge Aspen Wagon
EMISSION CONTROL SYSTEM - Catalyst, EGR

Engine

Type . . . . 4-stroke Otto, OHV, in-line, 6 cyl.

Bore x Stroke . . . . 3.40 x 4.12 in./86 x 105 mm

Displacement . . . . 225 CID/3687 cc

Compression Ratio 8.4:1

Maximum Power at rpm . . . . 100 hp/75 kW at 3600 rpm

Fuel Metering . . . . Single one bbl carburetor

Fuel Requirement . . . . 91 RON unleaded

Drive Train

Transmission Type . . . . 3 speed automatic

Final Drive Ratio 2.94:1

Chassis

Type . . . . Unitized body, front engine, rear wheel drive

Tire Size . . . . OEM Goodyear FR78x14 and OEM Goodyear E78x14

Curb Weight . . . . 3811 lb/1730 kg

Inertia Weight . . . . 4000 lb/1820 kg

Passenger Capacity . . . . Six

Emission Control System

Basic Type . . . . Dual element monolith noble metal catalyst, EGR, PCV

Mileage on Vehicle . . . . 4,360 miles

7. CHASSIS MODEL YEAR/MAKE - 1976 Chevrolet Impala
EMISSION CONTROL SYSTEM - Catalyst, EGR

Engine

Type . . . . 4-stroke, Otto cycle, OHV, V-8

Bore x Stroke . . . . 4.00 x 3.48 in./101.6 x 88.4 mm

Displacement . . . . 350 cu. in./5735 cc

Compression Ratio 8.5:1

Maximum Power at rpm . . . .

Fuel Metering . . . . Single two bbl carburetor

Fuel Requirement . . . . 91 RON unleaded

Drive Train

Transmission Type . . . . 3 speed automatic

Final Drive Ratio 2.73:1

Chassis

Type . . . . Body/frame, front engine, rear wheel drive

Tire Size . . . . OEM Goodrich HR78x15 and OEM Goodrich H78x15

Curb Weight . . . . 4266 lb./1935 kg

Inertia Weight . . . . 5000 lb./2270 kg.

Passenger Capacity . . . . Six

Emission Control System

Basic Type . . . . Single pelletted noble metal catalyst, EGR, EFE, PCV

Mileage on Vehicle . . . . 4,190 miles

8. CHASSIS MODEL YEAR/MAKE - 1976 Chevrolet Chevette
EMISSION CONTROL SYSTEM - Catalyst, EGR, Air Injection

Engine

Type . . . . 4-stroke, Otto cycle, OHV, in-line, 4 cyl.

Bore x Stroke . . . . 3.23 x 2.61 in.

Displacement . . . . 58 cu. in./1400 cc

Compression Ratio 8.5:1

Maximum Power at rpm . . . . 52 hp at 5300 rpm

Fuel Metering . . . . 1 ME single bbl carburetor

Fuel Requirement . . . . 91 RON unleaded

Drive Train

Transmission Type . . . . 3 speed automatic

Final Drive Ratio . . . .

Chassis

Type . . . . Body/frame, front engine, rear wheel drive

Tire Size . . . . OEM Goodyear 155/80OR13

Curb Weight . . . . 1950 lb/1091 kg

Inertia Weight . . . . 2250 lb/1227 kg

Passenger Capacity . . . . Four

Emission Control System

APPENDIX C

RESULTS OF FUEL ECONOMY MEASUREMENTS FOR DYNAMOMETER AND TRACK TESTS

APPENDIX C

RESULTS OF FUEL ECONOMY MEASUREMENTS
FOR DYNAMOMETER AND TRACK TESTS

LOCATION: Dyno #5 — LOCATION: Dyno #5

VEHICLE: 76 Honda, CVCC — VEHICLE: 76 Honda, CVCC

TIRE: Radial 45 psi — TIRE: Bias 45 psi

A/C: Off — A/C: Off

METER: #1514 — METER: #1514

TEST TYPE	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*
BAG1	2	28.02	0.40	3	28.11	0.61
BAG2	4	28.22	1.13	4	27.43	2.21
BAG3	4	32.13	3.33	6	31.18	2.26
FTP (Derived)		29.13			28.50	
HH (Derived)		30.06			29.07	
HST	2	40.16	0.63	3	40.77	0.68
CST	2	35.83	0.34	2	36.40	0.87
HNO	3	40.15	1.43			
HRE	3	40.27	2.11			
HSM	4	41.30	1.57			
10 mph	2	19.00	2.87		19.26	
20 mph	2	33.11	4.74		33.47	
30 mph	2	43.39	4.27		43.82	
40 mph	2	49.05	4.61		49.77	
50 mph	2	42.82	2.92		43.33	
60 mph	2	35.68	4.52		36.14	
70 mph						
80 mph						

* Coefficient of variation of replicated measurements (standard deviation divided by mean)

LOCATION:	Dyno #5 and #207	LOCATION:	Dyno #5 and #207
VEHICLE:	76 Datsun	VEHICLE:	76 Datsun
TIRE:	Radial 45 psi	TIRE:	Bias 45 psi
A/C:	Off	A/C:	Off
METER:	2099 Corrected + 1514	METER:	2099 Corrected + 1513 Corrected

TEST TYPE	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*
BAG1	3	24.62	3.37	2	25.42	0.23
BAG2	4	25.54	1.16	3	25.92	1.80
BAG3	6	28.90	3.03	3	29.07	1.44
FTP (Derived)		26.16			26.59	
HH (Derived)		27.12			27.40	
HST	4	37.97	3.765	3	38.95	1.00
CST	1	33.61		2	34.68	2.58
HNO	3	38.53	1.60	2	38.21	0.45
HRE	3	37.96	1.87	2	34.00	1.69
HSM	3	40.69	0.95			
10 mph	2	18.94	0.40	2	19.69	1.62
20 mph	2	29.06	1.36	2	30.33	0.75
30 mph	2	38.92	1.04	2	40.86	0.29
40 mph	2	46.72	0.06	2	48.79	0.42
50 mph	2	41.13	1.67	2	41.10	0.00
60 mph	2	34.66	0.01	2	35.80	0.00
70 mph						
80 mph						

* Coefficient of variation of replicated measurements (standard deviation divided by mean)

LOCATION.		LOCATION:	Dyno 207
VEHICLE:		VEHICLE:	76 Datsun
TIRE:		TIRE:	Bias 45 psi
A/C:		A/C:	Simulated
METER:		METER:	Unknown

TEST TYPE	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*
BAG1				2	25.51	0.20
BAG2				2	25.16	0.37
BAG3				2	29.20	2.25
FTP (Derived)					26.21	
HH (Derived)					27.06	
HST				2	41.13	0.14
CST						
HNO						
HRE						
HSM						
10 mph						
20 mph						
30 mph						
40 mph						
50 mph						
60 mph						
70 mph						
80 mph						

* Coefficient of variation of replicated measurements (standard deviation divided by mean)

LOCATION:	Dyno 207		LOCATION:	Dyno 207
VEHICLE:	76 Chevette		VEHICLE:	76 Chevette
TIRE:	Radial 45 psi		TIRE:	Bias 45 psi
A/C:	Off		A/C:	Off
METER:	Unknown		METER:	Unknown

TEST TYPE	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*
BAG1				2	19.56	0.36
BAG2				2	24.26	0.44
BAG3				2	25.36	0.25
FTP (Derived)					23.36	
HH (Derived)					24.78	
HST				1	30.55	
CST						
HNO						
HRE						
HSM						
10 mph	1	25.94				
20 mph	1	39.45				
30 mph	1	34.80				
40 mph	1	35.11				
50 mph	1	32.55				
60 mph	1	28.24				
70 mph						
80 mph						

* Coefficient of variation of replicated measurements
(standard deviation divided by mean)

LOCATION:	Dyno #5	LOCATION:	Dyno #5
VEHICLE:	76 Pinto	VEHICLE:	76 Pinto
TIRE:	Radial 45 psi	TIRE:	Bias 45 psi
A/C:	Off	A/C:	Off
METER:	1514	METER:	1514

TEST TYPE	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*
BAG1	2	16.50	1.03	2	16.93	0.501
BAG2	2	20.10	0.46	5	20.86	1.76
BAG3	2	21.67	1.27	5	22.46	2.00
FTP (Derived)		19.59			20.26	
HH (Derived)		20.84			21.61	
HST	3	27.64	0.63	3	28.21	1.08
CST						
HNO				3	27.14	1.79
HRE				3	27.20	1.86
HSM				3	29.18	0.43
10 mph	2	17.05	0.87	1	17.91	
20 mph	2	30.65	2.31	1	31.90	
30 mph	2	33.04	0.94	1	36.04	
40 mph	2	32.32	0.33	1	32.65	
50 mph	2	29.50	0.55	1	30.09	
60 mph	2	25.31	1.90	1	26.12	
70 mph						
80 mph						

* Coefficient of variation of replicated measurements (standard deviation divided by mean)

LOCATION.		LOCATION:	Dyno #5
VEHICLE:		VEHICLE:	76 Pacer
TIRE:		TIRE:	Bias 45 psi
A/C:		A/C:	Off
METER:		METER:	1514 + Unknown

TEST TYPE	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*
BAG1				2	13.11	6.58
BAG2				2	17.26	3.44
BAG3				2	15.48	4.20
FTP (Derived)					15.73	
HH (Derived)					16.38	
HST				3	21.21	0.38
CST						
HNO				3	20.19	1.83
HRE				3	19.73	0.61
HSM				3	22.19	1.62
10 mph				1	17.00	
20 mph				1	27.07	
30 mph				1	27.24	
40 mph				1	25.22	
50 mph				1	22.54	
60 mph					16.54	
70 mph						
80 mph						

* Coefficient of variation of replicated measurements (standard deviation divided by mean)

LOCATION.		LOCATION:	Dyno #5
VEHICLE:		VEHICLE:	76 Pacer
TIRE:		TIRE:	Bias 45 psi
A/C:		A/C:	On
METER:		METER:	1514

TEST TYPE	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*
BAG1				2	11.93	5.75
BAG2				2	15.24	1.30
BAG3				2	13.86	0.15
FTP (Derived)					14.03	
HH (Derived)					14.54	
HST				1	18.94	
CST						
HNO						
HRE						
HSM						
10 mph				1	14.90	
20 mph				1	23.87	
30 mph				1	24.62	
40 mph				1	24.22	
50 mph				1	21.51	
60 mph				1	16.23	
70 mph						
80 mph						

* Coefficient of variation of replicated measurements
(standard deviation divided by mean)

LOCATION.		LOCATION:	Dyno #5
VEHICLE:		VEHICLE:	76 Pacer
TIRE:		TIRE:	Bias 45 psi
A/C:		A/C:	Simulated
METER:		METER:	Unknown

TEST TYPE	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*
BAG1				1	13.61	
BAG2				1	17.55	
BAG3				1	15.20	
FTP (Derived)					15.92	
HH (Derived)					16.45	
HST				2	20.88	0.14
CST						
HNO						
HRE						
HSM						
10 mph				1	17.90	
20 mph				1	27.45	
30 mph				1	28.56	
40 mph				1	25.43	
50 mph				1	22.01	
60 mph				1	16.65	
70 mph						
80 mph						

* Coefficient of variation of replicated measurements
(standard deviation divided by mean)

LOCATION:	Dyno #5	LOCATION:	Dyno #5
VEHICLE:	76 Aspen	VEHICLE:	76 Aspen
TIRE:	Radial 45 psi	TIRE:	Bias 45 psi
A/C:	Off	A/C:	Off
METER:	Unknown	METER:	Unknown

TEST TYPE	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*
BAG1	2	15.07	2.44	2	14.59	8.82
BAG2	3	16.69	3.03	3	16.64	5.19
BAG3	3	17.57	1.88	3	17.33	3.04
FTP (Derived)		16.54			16.33	
HH (Derived)		17.10			16.96	
HST	4	22.14	2.90	2	21.61	0.69
CST	1	20.36		1	20.31	
HNO	3	20.66	1.23	2	20.88	2.18
HRE	4	20.51	1.42	2	20.46	1.83
HSM	3	22.94	4.48	3	22.94	0.64
10 mph	1	22.11		1	18.54	
20 mph	1	29.12		1	30.44	
30 mph	1	27.29		1	27.92	
40 mph	1	26.19		1	26.81	
50 mph	1	24.41		1	24.71	
60 mph	1	20.83		1	21.20	
70 mph						
80 mph						

* Coefficient of variation of replicated measurements
(standard deviation divided by mean)

LOCATION:	Dyno #5	LOCATION:	Dyno #5
VEHICLE:	76 Aspen	VEHICLE:	76 Aspen
TIRE:	Radial 45 psi	TIRE:	Bias 45 psi
A/C:	On	A/C:	On
METER:	Unknown	METER:	Unknown

TEST TYPE	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*
BAG1	2	14.1	1.60	1	13.50	
BAG2	2	14.92	1.23	1	16.26	
BAG3	2	16.07	0.31	1	17.24	
FTP (Derived)		15.03		1	15.82	
HH (Derived)		15.46			16.71	
HST	3	20.42	2.50	2	19.40	4.01
CST						
HNO						
HRE						
HSM						
10 mph	1	18.40				
20 mph	1	25.10				
30 mph	1	24.40				
40 mph	1	24.58				
50 mph	1	22.82				
60 mph	1	18.61				
70 mph						
80 mph						

* Coefficient of variation of replicated measurements
(standard deviation divided by mean)

LOCATION:	Dyno #5	LOCATION:	
VEHICLE:	76 Aspen	VEHICLE:	
TIRE:	Radial 26 psi	TIRE:	
A/C:	Off	A/C:	
METER:	Unknown	METER:	

TEST TYPE	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*
BAG1						
BAG2						
BAG3						
FTP (Derived)						
HH (Derived)						
HST						
CST						
HNO						
HRE						
HSM						
10 mph	1	18.55				
20 mph	1	29.57				
30 mph	1	29.06				
40 mph	1	26.42				
50 mph	1	24.10				
60 mph	1	20.45				
70 mph						
80 mph						

* Coefficient of variation of replicated measurements
(standard deviation divided by mean)

LOCATION:	Dyno #5
VEHICLE:	76 Aspen
TIRE:	Radial 45 psi
A/C:	Simulated
METER:	Unknown

LOCATION:	Dyno #5
VEHICLE:	76 Aspen
TIRE:	Bias 45 psi
A/C:	Simulated
METER:	Unknown

TEST TYPE	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*
BAG1	2	14.78	1.10			
BAG2	2	16.20	0.79			
BAG3	2	17.26	0.70			
FTP (Derived)		16.14				
HH (Derived)		16.70				
HST	1	22.18		4	20.32	9.22
CST						
HNO						
HRE						
HSM						
10 mph	1	18.30				
20 mph	1	29.11				
30 mph	1	26.74				
40 mph	1	25.49				
50 mph	1	23.23				
60 mph	1	19.80				
70 mph						
80 mph						

* Coefficient of variation of replicated measurements (standard deviation divided by mean)

LOCATION:	Dyno #5
VEHICLE:	76 Impala
TIRE:	Radial 45 psi
A/C:	Off
METER:	Unknown

LOCATION:	Dyno #5
VEHICLE:	76 Impala
TIRE:	Bias 45 psi
A/C:	Off
METER:	Unknown

TEST TYPE	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*
BAG1	2	10.62	1.93	2	11.05	1.02
BAG2	4	11.55	0.34	2	11.39	0.43
BAG3	4	13.38	0.47	2	13.54	0.57
FTP (Derived)		11.77			11.82	
HH (Derived)		12.41			12.40	
HST	3	18.45	0.46	3	18.78	1.66
CST	1	17.22				
HNO	3	17.87	2.22			
HRE	3	18.23	3.33			
HSM	3	19.07	1.50			
10 mph				1	10.09	
20 mph				1	18.97	
30 mph				1	22.87	
40 mph				1	20.80	
50 mph				1	20.48	
60 mph				1	18.40	
70 mph						
80 mph						

* Coefficient of variation of replicated measurements (standard deviation divided by mean)

LOCATION:	Dyno #5	LOCATION:	Dyno #5
VEHICLE:	76 Impala	VEHICLE:	76 Impala
TIRE:	Radial 45 psi	TIRE:	Radial 45 psi
A/C:	Simulated	A/C:	On
METER:	Unknown	METER:	1514 + Unknown

TEST TYPE	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*
BAG1	2	10.94	0.45	2	9.64	6.16
BAG2	2	11.29	1.19	2	10.41	0.68
BAG3	2	13.10	0.70	2	12.29	0.46
FTP (Derived)		11.65			10.67	
HH (Derived)		12.14			11.29	
HST	2	17.68	0.60	2	16.61	0.21
CST						
HNO						
HRE						
HSM						
10 mph	1	10.24				
20 mph	1	19.08				
30 mph	1	19.69		1	17.61	
40 mph	1	20.47		1	18.59	
50 mph	1	19.54		1	17.98	
60 mph	1	17.54		1	16.15	
70 mph						
80 mph						

* Coefficient of variation of replicated measurements (standard deviation divided by mean)

LOCATION. Track
VEHICLE: 76 Honda CVCC
TIRE: Radial (24/24 psi)
A/C: Off/Windows Up
METER: Unknown + 2099 Corrected

LOCATION: Track
VEHICLE: 76 Honda CVCC
TIRE: Bias (24/24 psi)
A/C: Off/Windows Up
METER: 2099 Corrected

TEST TYPE	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*
BAG1	3	24.96	1.75	2	23.61	5.93
BAG2	6	25.41	1.76	3	25.49	0.60
BAG3	5	28.81	0.78	3	29.35	3.55
FTP (Derived)		26.14		2	25.98	
HH (Derived)		27.01			27.17	
HST	8	35.92	2.77	3	35.51	1.29
CST	1	32.56				
HNO	2	34.65	1.08	2	34.93	
HRE	2	34.48	0.86	2	34.18	
HSM	1	38.10		2	37.02	
10 mph	2	50.01	0.65			
20 mph	2	50.29	2.97	2	47.01	
30 mph	2	45.55	2.00	2	47.68	
40 mph	2	40.17	0.65	2	36.91	
50 mph	2	34.21	0.76	2	32.16	
60 mph	2	28.05	1.16	2	27.28	
70 mph				2	21.12	
80 mph						

* Coefficient of variation of replicated measurements
(standard deviation divided by mean)

LOCATION.	Track	LOCATION:	
VEHICLE:	76 Honda CVCC	VEHICLE:	
TIRE:	Radial (24/24 psi)	TIRE:	
A/C:	Off/Windows Down	A/C:	
METER:	Unknown	METER:	

TEST TYPE	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*
BAG1						
BAG2						
BAG3						
FTP (Derived)						
HH (Derived)						
HST						
CST						
HNO						
HRE						
HSM						
10 mph						
20 mph	2	52.01	2.35			
30 mph	2	50.90	3.10			
40 mph	2	46.65	2.90			
50 mph	2	41.86	1.37			
60 mph	2	35.72	0.48			
70 mph	2	29.47	0.17			
80 mph						

* Coefficient of variation of replicated measurements (standard deviation divided by mean)

LOCATION.	Track	LOCATION:	Track
VEHICLE:	Datsun	VEHICLE:	Datsun
TIRE:	Radial (24/24 psi)	TIRE:	Bias (24/24 psi)
A/C:	Off/Windows Up	A/C:	Off/Windows Up
METER:	#1472	METER:	#1472

TEST TYPE	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*
BAG1	4	23.78	3.46	1	21.76	
BAG2	9	24.60	1.48	4	23.65	4.82
BAG3	5	27.54	1.21	3	26.15	2.88
FTP (Derived)		25.14			23.83	
HH (Derived)		25.98			24.83	
HST	6	36.76	1.41	3	35.56	3.04
CST						
HNO	4	35.40	1.98			
HRE	3	34.38	1.36			
HSM	3	38.48	2.68			
10 mph	2	18.48	1.11	2	18.51	1.64
20 mph	2	28.94	0.54	2	28.68	1.65
30 mph	2	39.50	0.52	2	38.35	1.00
40 mph	2	45.58	0.34	2	44.12	1.70
50 mph	2	40.18	0.67	2	38.83	1.51
60 mph	2	34.81	0.02	2	38.14	0.06
70 mph	2	29.69	0.29	2	29.36	0.02
80 mph	2	24.96	4.08	2	24.31	0.26

* Coefficient of variation of replicated measurements (standard deviation divided by mean)

LOCATION.	Track	LOCATION:	Track
VEHICLE:	76 Chevette	VEHICLE:	76 Chevette
TIRE:	Radial (24/24 psi)	TIRE:	Bias (24/24 psi)
A/C:	Off/Windows Up	A/C:	Off/Windows Up
METER:	#1472	METER:	#1472

TEST TYPE	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*
BAG1	2	17.68	0.32	2	17.20	1.69
BAG2	7	22.09	4.20	2	21.74	1.30
BAG3	7	23.51	6.71	2	22.18	2.55
FTP (Derived)		21.32			20.70	
HH (Derived)		22.76			21.95	
HST	7	26.69	0.64	1	26.11	
CST	1	21.47				
HNO	2	25.07	1.86	2	25.20	0.36
HRE	2	25.66	0.03	2	25.18	0.81
HSM	2	28.05	0.30	2	27.71	0.77
10 mph						
20 mph	2	35.88	2.35	2	33.44	3.98
30 mph	2	34.33	5.48	2	30.98	3.72
40 mph	2	32.16	0.88	2	30.52	2.76
50 mph	1	28.85		2	28.49	1.91
60 mph	2	23.59	5.10	2	23.87	1.78
70 mph	2	20.09	2.92	2	18.88	9.62
80 mph						

* Coefficient of variation of replicated measurements (standard deviation divided by mean)

LOCATION.	Track	LOCATION:	
VEHICLE:	76 Chevette	VEHICLE:	
TIRE:	Radial (24/24 psi)	TIRE:	
A/C:	Off/Windows Down	A/C:	
METER:	#1472	METER:	

TEST TYPE	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*
BAG1						
BAG2						
BAG3						
FTP (Derived)						
HH (Derived)						
HST	2	27.20	1.14			
CST						
HNO						
HRE						
HSM						
10 mph						
20 mph	2	35.05	5.61			
30 mph	2	30.63	2.26			
40 mph	1	30.46				
50 mph	1	28.55				
60 mph	2	24.29	1.51			
70 mph	2	20.05	0.21			
80 mph						

* Coefficient of variation of replicated measurements (standard deviation divided by mean)

LOCATION.	Track	LOCATION:
VEHICLE:	76 Chevette	VEHICLE:
TIRE:	Radial (24/24 psi)	TIRE:
A/C:	On/Windows Up	A/C:
METER:	#1472	METER:

TEST TYPE	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*
BAG1	2	16.35	0.16			
BAG2	2	20.12	1.09			
BAG3	2	20.82	1.05			
FTP (Derived)		19.36				
HH (Derived)		20.45				
HST	2	25.42	0.36			
CST						
HNO						
HRE						
HSM						
10 mph						
20 mph	2	31.51	4.76			
30 mph	2	30.69	2.79			
40 mph	2	29.74	3.45			
50 mph	2	27.94	1.59			
60 mph	2	23.72	2.71			
70 mph	2	19.52	1.09			
80 mph						

* Coefficient of variation of replicated measurements
(standard deviation divided by mean)

LOCATION. Track
VEHICLE: 76 Pinto
TIRE: Radial (24/24 psi)
A/C: Off/Windows Up
METER: 1513 Corrected + Unknown

LOCATION: Track
VEHICLE: 76 Pinto
TIRE: Bias (26/26 psi)
A/C: Off/Windows Up
METER: 1514 + Unknown

TEST TYPE	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*
BAG1	2	16.63	11.95	1	16.11	
BAG2	5	19.06	1.58	3	18.75	3.10
BAG3	3	19.64	0.10	2	19.49	6.31
FTP (Derived)		18.64		1	18.31	
HH (Derived)		19.33			19.09	
HST	2	26.01	2.47	2	25.03	3.08
CST	1	21.43		2	21.92	4.46
HNO				3	24.55	2.23
HRE				3	24.41	2.22
HSM				2	27.53	2.13
10 mph	1	18.72				
20 mph	1	29.97				
30 mph	1	31.78				
40 mph	1	30.08				
50 mph	1	28.23				
60 mph	1	24.64				
70 mph	1	20.99				
80 mph	1	16.26				

* Coefficient of variation of replicated measurements (standard deviation divided by mean)

LOCATION.	Track	LOCATION:	Track
VEHICLE:	76 Pacer	VEHICLE:	76 Pacer
TIRE:	Radial (24/24 psi)	TIRE:	Bias (26/24 psi)
A/C:	Off/Windows Up	A/C:	Off/Windows Up
METER:	1514	METER:	1514

TEST TYPE	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*
BAG1						
BAG2	2	17.04	3.82	1	16.21	
BAG3	2	14.78	1.20	1	15.24	
FTP (Derived)						
HH (Derived)		15.98			15.74	
HST	1	18.99		1	19.00	
CST	1	16.62		2	16.22	1.66
HNO	1	17.62				
HRE	1	17.12				
HSM	1	18.14				
10 mph						
20 mph						
30 mph						
40 mph						
50 mph						
60 mph						
70 mph						
80 mph						

* Coefficient of variation of replicated measurements (standard deviation divided by mean)

LOCATION.	Track	LOCATION:	
VEHICLE:	76 Pacer	VEHICLE:	
TIRE:	Radial (24/24 psi)	TIRE:	
A/C:	Off/Windows Up	A/C:	
METER:	1358	METER:	

TEST TYPE	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*
BAG1	2	12.69	0.28			
BAG2	4	15.10	3.72			
BAG3	2	15.00	2.26			
FTP (Derived)		14.50				
HH (Derived)		15.05				
HST	1	17.88				
CST	1	16.70				
HNO	2	17.67	1.40			
HRE	2	17.47	0.36			
HSM	1	20.04				
10 mph	2					
20 mph	2	33.16	4.50			
30 mph	2	29.87	3.53			
40 mph	2	25.43	4.73			
50 mph	2	21.66	3.46			
60 mph	2	16.29	6.64			
70 mph	2	14.11	0.25			
80 mph	2	12.45	0.17			

* Coefficient of variation of replicated measurements
(standard deviation divided by mean)

LOCATION.		LOCATION:	Track
VEHICLE:		VEHICLE:	76 Pacer
TIRE:		TIRE:	Bias (26/24 psi)
A/C:		A/C:	On/Windows Up
METER:		METER:	1513 Corrected + 1514

TEST TYPE	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*
BAG1				2	11.71	2.85
BAG2				5	14.05	0.89
BAG3				3	13.21	6.16
FTP (Derived)					13.27	
HH (Derived)					13.64	
HST				3	16.47	5.49
CST						
HNO				1	16.20	
HRE				1	15.39	
HSM				1	16.70	
10 mph				1	19.53	
20 mph				1	27.00	
30 mph				1	25.49	
40 mph				1	23.51	
50 mph				1	20.72	
60 mph				1	15.77	
70 mph				1	13.88	
80 mph				1	11.62	

* Coefficient of variation of replicated measurements (standard deviation divided by mean)

LOCATION.	Track	LOCATION:	
VEHICLE:	76 Pacer	VEHICLE:	
TIRE:	Radial (24/24 psi)	TIRE:	
A/C:	On/Windows Up	A/C:	
METER:	1358	METER:	

TEST TYPE	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*
BAG1	1	12.15				
BAG2	3	14.60	2.18			
BAG3	2	13.60	4.78			
FTP (Derived)		13.75				
HH (Derived)		14.14				
HST	1	16.39				
CST						
HNO	2	16.51	0.21			
HRE	2	16.66	0.04			
HSM	2	18.46	0.50			
10 mph						
20 mph	2	28.10	1.38			
30 mph	2	27.27	0.16			
40 mph	2	24.20	0.26			
50 mph	2	20.48	0.66			
60 mph	2	15.63	0.32			
70 mph	2	14.09	0.35			
80 mph	2	11.80	2.70			

* Coefficient of variation of replicated measurements (standard deviation divided by mean)

LOCATION.	Track	LOCATION:	Track
VEHICLE:	76 Aspen	VEHICLE:	76 Aspen
TIRE:	Radial (26/32 psi)	TIRE:	Bias (26/32 psi)
A/C:	Off/Windows Up	A/C:	Off/Windows Up
METER:	1514	METER:	1514

TEST TYPE	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*
BAG1	3	13.70	3.59	1	12.38	
BAG2	6	15.17	1.41	5	14.71	0.98
BAG3	3	16.48	2.88	4	15.47	2.80
FTP (Derived)		15.15			14.33	
HH (Derived)		15.79			15.06	
HST	4	20.77	2.79	3	19.90	2.71
CST	1	19.33				
HNO	3	19.62	1.38			
HRE	4	20.19	1.16			
HSM	4	21.78	3.73			
10 mph		21.88		2	22.48	1.48
20 mph		29.39		2	27.24	2.05
30 mph		28.97		2	26.97	0.60
40 mph		25.66		2	24.39	0.20
50 mph		24.03		2	22.10	1.31
60 mph		20.97		2	19.89	1.03
70 mph						
80 mph						

* Coefficient of variation of replicated measurements (standard deviation divided by mean)

LOCATION.	Track	LOCATION:	Track
VEHICLE:	76 Aspen	VEHICLE:	76 Aspen
TIRE:	Radial (26psi/32psi)	TIRE:	Bias (26psi/32psi)
A/C:	On/Windows Up	A/C:	On/Windows Up
METER:	1514	METER:	1514

TEST TYPE	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*
BAG1	2	12.69	0.72			
BAG2	4	13.69	6.32	2	13.37	2.75
BAG3	2	15.84	0.312	2	14.80	3.87
FTP (Derived)		13.97				
HH (Derived)		14.70		2	14.01	
HST	3	19.56	4.25	3	18.74	2.44
CST						
HNO						
HRE						
HSM						
10 mph	2	21.22		2	19.18	4.76
20 mph	2	25.28		2	23.86	1.72
30 mph	2	25.79		2	23.98	1.15
40 mph	2	24.15		2	22.74	0.44
50 mph	2	22.20		2	20.86	0.44
60 mph	2	19.93		2	18.80	1.73
70 mph				2	15.91	0.89
80 mph				2	13.63	1.40

* Coefficient of variation of replicated measurements
(standard deviation divided by mean)

LOCATION.	Track	LOCATION:	Track
VEHICLE:	76 Ford Granada	VEHICLE:	76 Ford Granada
TIRE:	Radial (25/25 psi)	TIRE:	Bias (25/25 psi)
A/C:	Off/Windows Up	A/C:	Off/Windows Up
METER:	1514 + Unknown	METER:	1514

TEST TYPE	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*
BAG1	2	11.66	4.49	2		
BAG2	6	14.34	4.82	7	14.58	1.93
BAG3	4	14.77	3.95	5	14.79	1.69
FTP (Derived)		13.78			14.08	
HH (Derived)		14.54			14.68	
HST	3	18.33		3	17.81	0.59
CST	3	16.99		2	15.89	5.43
HNO						
HRE						
HSM						
10 mph	1	19.98		1	18.11	
20 mph	1	26.40		2	25.49	
30 mph	1	25.63		2	25.39	
40 mph	1	23.14		2	22.78	
50 mph	1	20.88		2	20.95	
60 mph	1	18.03		2	17.73	
70 mph	1	14.49		2	14.11	
80 mph	1	10.91		2	11.00	

* Coefficient of variation of replicated measurements (standard deviation divided by mean)

LOCATION.	Track		LOCATION:	Track	
VEHICLE:	76 Ford Granada		VEHICLE:	76 Ford Granada	
TIRE:	Radial (25/25 psi)		TIRE:	Bias (25/25 psi)	
A/C:	On/Windows Up		A/C:	On/Windows Up	
METER:	1514 + Unknown		METER:	1514	

TEST TYPE	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*
BAG1	2	10.14	0.56	2	11.14	2.66
BAG2	5	12.14	1.94	5	12.28	8.04
BAG3	3	12.39	2.33	3	12.88	3.52
FTP (Derived)		11.72			12.17	
HH (Derived)		12.26			12.56	
HST	3	16.49		2	15.94	
CST						
HNO						
HRE						
HSM						
10 mph	1	18.99				
20 mph	1	21.75				
30 mph	1	22.21				
40 mph	1	20.48		1	20.09	
50 mph	1	18.59		1	18.10	
60 mph	1	16.12		1	15.84	
70 mph	1	12.68		1	12.38	
80 mph	1	10.78		1	10.79	

* Coefficient of variation of replicated measurements (standard deviation divided by mean)

	Radial	Bias
LOCATION:	Track	Track
VEHICLE:	76 Impala	76 Impala
TIRE:	Radial (26/28 psi)	Bias (26/28 psi)
A/C:	Off/Windows Up	Off/Windows Up
METER:	1472	1472

TEST TYPE	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*
BAG1	2	10.75	5.20	3	9.65	1.71
BAG2	7	11.70	3.89	6	10.76	1.09
BAG3	5	13.29	4.09	3	12.35	1.68
FTP (Derived)		11.86			10.88	
HH (Derived)		12.45		3	11.50	
HST	3	17.59	7.18	3	17.16	2.19
CST	1	16.48				
HNO	3	17.32	1.07			
HRE	3	17.50	0.16			
HSM	3	18.84	0.88			
10 mph	1	8.83		1	11.81	
20 mph	2	17.63	2.41	1	17.65	
30 mph	2	20.15	3.68	1	19.22	
40 mph	2	20.14	0.91	1	19.45	
50 mph	2	19.81	0.96	1	19.29	
60 mph	2	18.12	0.98	1	17.69	
70 mph	2	15.94	0.93	1	15.48	
80 mph	2	13.93	0.25	1	13.30	

* Coefficient of variation of replicated measurements (standard deviation divided by mean)

LOCATION. Track

VEHICLE: 76 Impala

TIRE: Radial (26/28 psi)

A/C: On/Windows Up

METER: 1472

LOCATION: Track

VEHICLE: 76 Impala

TIRE: Bias (26/28 psi)

A/C: On/Windows Up

METER: 1472

TEST TYPE	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*	NUMBER OF REPLICATIONS	MEAN FUEL ECONOMY	COV PERCENT*
BAG1	2	10.18	3.06	3	9.39	1.35
BAG2	4	10.54	2.16	5	9.96	1.37
BAG3	2	12.27	3.63	2	11.56	2.26
FTP (Derived)		10.87			10.21	
HH (Derived)		11.35			10.71	
HST	2	16.86	0.34	1	16.20	
CST						
HNO						
HRE						
HSM						
10 mph	2	9.85	0.72	1	9.85	
20 mph	2	14.62	6.92	1	13.57	
30 mph	2	17.48	0.53	1	16.95	
40 mph	2	18.13	1.68	1	18.28	
50 mph	2	18.53	0.50	1	17.94	
60 mph	2	16.47	3.13	1	16.66	
70 mph	2	14.99	2.08	1	14.66	
80 mph	2	13.19	0.96	1	12.97	

* Coefficient of variation of replicated measurements
(standard deviation divided by mean)

APPENDIX D

WEIGHTED LEAST SQUARES LINEAR REGRESSION OF VOLUMETRIC AND CARBON BALANCE DIFFERENCES

Let x_i, y_i be volumetric and carbon balance measures, respectively for the i^{th} group of replicated runs, and let η_i be the number of replications. Two different types of measures may be considered, namely, mean fuel consumption (in gpm) or mean fuel economy (in mpg) of the replicated runs, but the regression technique is the same in either case. Define $\Delta_i = y_i - x_i$, the difference between volumetric and carbon balance measures, and assume a linear model for the dependence of Δ on x. That is,

$$\Delta_i = a + bx_i + \varepsilon_i$$

where a and b are unknown constants to be estimated and ε_i is an error of zero mean and variance given by

$$\sigma_{\varepsilon_i}{}^2 = \frac{x_i^2 (COV)_0^2}{\eta_i}$$

It is assumed here that the variabilities of a single carbon balance measurement and of a single volumetric measurement are expressed by constant coefficients of variation, $(COV)_C$ and $(COV)_M$, respectively, and that $(COV)_0^2 = (COV)_C^2 + (COV)_M^2$ is the (squared) coefficient of variation of an unreplicated difference Δ relative to the mean of either measure.

From this, it follows that as shown above, the variance of ε_i (the error in Δ_i) is $(COV)_0^2$ multiplied by the squared mean (approximately x_i^2) to convert to variance, and then divided by η_i to reflect the variance reduction derived from replication.

Because the $\sigma_{\varepsilon_i}{}^2$ are not uniform over the data set, those points with smaller variance should receive relatively higher weight in estimation of a regression line. The appropriate weighting is proportional to the inverse of the variance. Thus, define normalized weights as follows:

$$\upsilon_i = \frac{\eta_i/x_i^2}{\sum_j \eta_j/x_j^2} = \frac{\eta_i}{x_i^2 U}$$

The estimation of a and b by least (sum of weighted) squares regression is based on the following statistics:

$$\overline{\Delta} = \sum_i \upsilon_i \Delta_i$$

$$\overline{\Delta^2} = \sum_i \upsilon_i \Delta_i^2$$

$$\overline{x} = \sum_i \upsilon_i x_i$$

$$\overline{x^2} = \sum_i \upsilon_i x_i^2$$

$$\overline{\Delta \cdot x} = \sum_i \upsilon_i \Delta_i x_i$$

Weighted least squares estimates for a and b may then be expressed as

$$\hat{b} = \frac{\overline{\Delta \cdot x} - \overline{\Delta}\,\overline{x}}{\overline{x^2} - (\overline{x})^2}$$

$$\hat{a} = \overline{\Delta} - \hat{b}\,\overline{x}$$

In order to assess the significance of the coefficient values so derived, their variance also needs to be estimated. To do this we need an estimate for $(COV)_0$, which is given by

$$(COV)_0^2 = \frac{\left[\overline{\Delta^2} - (\overline{\Delta})^2 - (\hat{b})^2\,(\overline{x^2} - (\overline{x})^2)\right]\,U}{N - 2}$$

where N is the number of data points (i.e., replication groups). The variance of $\hat{a}$ and $\hat{b}$ are then

$$\sigma_{\hat{a}}^2 = \frac{(COV)_0^2}{U}$$

$$\sigma_{\hat{b}}^2 = \frac{(COV)_0^2}{U\,(\overline{x^2} - (\overline{x})^2)}$$

APPENDIX E

TWO-WAY ANALYSIS OF VARIANCE WITH UNEQUAL VARIANCE ESTIMATES

Let us suppose we have sample means $\overline{y_{ij}}$ and estimated variances s_{ij}^2 of a response variable for various combinations of blocks $(i = 1, 2, \ldots, I)$ and treatments $(j = 1, 2, \ldots, J)$. We desire to know if there are significant effects due to blocks and/or treatments. This situation is different from a conventional Analysis of Variance (ANOVA) situation in that we do not have available individual responses within each (i,j) cell, but rather a cell mean and an associated variance. However, there is a very strong similarity with the 2-way ANOVA model with unequal numbers* and the formulas derived will be seen to be analogs of that model.

For applications made in this report, the $\overline{y_{ij}}$ are mean fuel economy ratios, the s_{ij}^2 are squared standard error estimates, and the blocks and treatment groups may cover such factors as different test cars, air conditioning status, and different test driving sequences.

Responses are generally available for only a subset of all (i,j). However, there must be at least one response for each block and for each treatment and, if N is the total number of cells for which responses are available,

$$N \geq I + J - 1.$$

The model assumed is a two-way effects model with no interaction:

$$\overline{y_{ij}} = \mu + b_i + t_j + e_{ij}$$

where e_{ij} are independent normal errors with zero mean and variance, s_{ij}^2. The quantity μ is the (weighted) grand mean over all available responses and the b_i (and t_j) are systematic effects due to particular blocks (and particular treatments). We desire to test certain hypothesis, notably

$H_b : b_i \equiv b$, i.e., there are no differential effects among blocks

and

$H_t : t_j \equiv t$, i.e., there are no differential effects among treatments

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* See, for example, O. Kempthorne, The Design and Analysis of Experiments, John Wiley, New York, 1952, p. 79.

Define weighting coefficients

$$n_{ij} = \frac{N}{s_{ij}^{2}} \Big/ \sum_{k,l} \frac{1}{s_{kl}^{2}}$$

utilizing the convention that $1/s_{ij} = 0$ for all non-response (i,j) cells. Note, therefore that

$$n_{ij} = 0 \quad \text{for all non-response (ij)}$$

and

$$\Sigma n_{ij} = N$$

Define

$$N_{i\bullet} = \sum_{j} n_{ij} \qquad N_{\bullet j} = \sum_{i} n_{ij}$$

$$Y_{i\bullet} = \sum_{j} n_{ij} \overline{y_{ij}} \qquad Y_{\bullet j} = \sum_{i} n_{ij} \overline{y_{ij}}$$

$$Y_{\bullet\bullet} = \sum_{i,j} n_{ij} \overline{y_{ij}}$$

Impose the two conditions

$$\Sigma N_{i\bullet} \hat{b}_i = \Sigma N_{\bullet j} \hat{t}_j = 0$$

on the model because of linear dependences of the coefficients. This says that the weighted average block effect over all blocks is constrained to zero and the weighted average treatment effect over all treatments is constrainted to zero, therby defining an unambiguous grand mean effect μ.

Weighted least squares estimates of the coefficients, $\hat{\mu}$, $\hat{b}_i$, $\hat{t}_j$, are next obtained. The grand mean estimate is computed first

$$\hat{\mu} = \frac{Y_{\bullet\bullet}}{N}$$

Define the column vectors

$$X = (b_1, b_2, \ldots, b_{I-1}, t_1, t_2, \ldots, t_{J-1})^T$$

$$C = (Y_{1.} - N_{1.}\hat{\mu}, \ldots, Y_{I-1,.} - N_{I-1.}\hat{\mu}, Y_{.1} - N_{.1}\hat{\mu}, \ldots, Y_{.J-1} - N_{.J-1}\hat{\mu})^T$$

and the I+J-2 order square matrix

$$\Lambda = \left(\begin{array}{ccc|ccc} N_{1.} & & 0 & & & \\ & \ddots & & & \lambda_{ij} & \\ 0 & & N_{I-1.} & & & \\ \hline & & & N_{.1} & & 0 \\ & \nu_{ij} & & & \ddots & \\ & & & 0 & & N_{J-1.} \end{array}\right)$$

$$\lambda_{ij} = n_{i,j-I+1} - \left(\frac{N_{.j-I+1}}{N_{.J}}\right) n_{iJ} \quad ; \quad \begin{cases} i = 1, \ldots, I-1 \\ j = I, \ldots, I+J-1 \end{cases}$$

$$\nu_{ij} = n_{j,i-I+1} - \left(\frac{N_{j.}}{N_{I.}}\right) n_{I,i-I+1} \quad ; \quad \begin{cases} i = I, \ldots, I+J-1 \\ j = 1, \ldots, I-1 \end{cases}$$

Solve the matrix equation $\Lambda X = C$ for X, i.e.,

$$X = \Lambda^{-1} C$$

This provides all the $\hat{b}_i$ except $\hat{b}_I$ and all the $\hat{t}_j$ except $\hat{t}_J$. Solve for $\hat{b}_I$ and $\hat{t}_J$ from the previously imposed constraints.

The reduction in Sum of Squares (S.S.) due to fitting μ, b_i is

$$R(\mu, b) = \sum_{i=1}^{I} \frac{(Y_{i.})^2}{N_{i.}} \quad ; \quad \text{I degrees of freedom (d.f.)}$$

Similarly, the reduction in S.S. due to fitting μ, t_j is

$$R(\mu,t) = \sum_{j=1}^{J} \frac{(Y_{\cdot j})^2}{N_{\cdot j}} \quad ; \text{ J degrees of freedom (d.f.)}$$

Finally, the reduction in S.S. due to fitting all parameters, μ, b_i, t_j is

$$R(\mu,b,t) = \hat{\mu}\, Y_{\cdot\cdot} + \sum_i \hat{b}_i\, Y_{i\cdot} + \sum_j \hat{t}_j\, Y_{\cdot j} \quad ; \quad (I+J-1) \text{ d.f.}$$

<u>For testing hypothesis $H_b : b_i \equiv b$</u>

Mean square due to fitting b_i : $S = \dfrac{R(\mu,b,t) - R(\mu,t)}{I-1}$

Mean square error: $E = \dfrac{1}{\frac{1}{N} \sum_{ij} 1 / s_{ij}^2}$; d.f. > > 1*

Under H_b, S/E has approximately F-distribution with $(I-1,\infty)$ degrees of freedom. Therefore, for tests at a level of significance α, reject H_b if $S/E > f_{I-1,\infty,\alpha}$.

<u>For testing hypothesis $H_t : t_j \equiv t$</u>

Mean square due to fitting t_j : $T = \dfrac{R(\mu,b,t) - R(\mu,b)}{J-1}$

Mean square error: $E = \dfrac{1}{\frac{1}{N} \sum_{ij} 1 / s_{ij}^2}$; d.f. > > 1*

Under H_t, T/E has approximately F-distribution with $(J-1,\infty)$ degrees of freedom. Therefore, for tests at a level of significance α, reject H_t if $T/E > f_{J-1,\infty,\alpha}$.

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* Note, in contradistinction to conventional ANOVA, the mean square error is estimated (externally) from the S_{ij}^2, rather than from the variations of y_{ij} among the block/treatment cells, because of the considerably greater degrees of freedom in the external estimate.

APPENDIX F

CALCULATION OF HORSEPOWER FROM COAST-DOWN TIMES

If the time, Δt, it takes a vehicle of mass, M, to decelerate from 55 mph to 45 mph is measured in seconds, then the force acting on the vehicle at 50 mph is estimated to be

$$F = M \frac{\Delta v}{\Delta t}$$

F is in units of pounds if M is in units of slugs, Δv in units of feet per second and Δt in units of seconds. The power dissipated by the vehicle at speed V_T is

$$P = FV_T$$

where P is in units of ft-lbs/min if V_T is in units of ft/min.

$$V_T = 50 \text{ mph} = 4400 \text{ ft/min}$$

$$\Delta v = 10 \text{ mph} = 14.667 \text{ ft/sec}$$

Thus,

$$P \text{ (ft-lb/min)} = \frac{\frac{M \text{ (lb)}}{32.16 \text{ lb/slug}} (14.667 \text{ ft/sec}) (4400 \text{ ft/min})}{\Delta t \text{ (sec)}}$$

and

$$P \text{ (ft-lb/min)} = \frac{\text{Mass of vehicle in lb}}{\text{Coast-down time in seconds}} (2006.7 \text{ ft sec/min})$$

$$P \text{ (Horsepower)} = \frac{\text{Mass of vehicle in lb}}{\text{Coast-down time in seconds}} (0.06081)$$

since

$$\frac{1 \text{ ft-lb}}{\text{min}} = \frac{1 \text{ horsepower}}{33{,}000}$$