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Evaluation of the Representativeness of EPA Fuel Economy Estimates

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I INTRODUCTION

Energy conservation has become a major national commitment. An important element of this commitment is a national strategy to improve the fuel economy of the new car fleet through a regulatory program involving stringent fuel economy standards that each manufacturer must meet for its corporate sales-weighted fleet. The basis for this regulatory program is contained in the Energy Policy and Conservation Act. To insure consumer cognizance of the fuel economy implications of the consumer's purchase decision, the Act established a fuel economy labeling program whereby each new vehicle is posted with its expected fuel economy. The results of the fuel economy labeling program are also published as an annual Mileage Guide.

The keystone to both of these programs is the Federal Test Procedure developed by EPA to quantify and regulate emissions reductions for environmental purposes. These same procedures are also utilized as the yardstick of fuel economy measurement. The fuel economy of cars is measured on pre-production prototype vehicles on a test apparatus that simulates on-road operation over a driving cycle that has been determined to yield representative emissions for urban driving conditions.

Recent suggestions that EPA fuel economy estimates significantly overpredict actual vehicle fuel economy prompted EPA to conduct a number of studies designed to explore the representativeness of the EPA methodology. The objective of this report is to summarize the results and conclusions of these studies.

The key issues addressed by this report are:

- Representativeness of the Mileage Guide fuel economy value obtained from EPA certification prototype vehicles compared to the owner's reported fuel economy for the comparable vehicle.

- Sensitivity of the EPA measurements to test procedure parameters, and to limitations imposed by the laboratory environment.

- Improvements that can be made in the EPA test procedures.

Historical Perspective - The EPA first published mileage information for model year 1973, at the direction of the President. Beginning with model year 1974, manufacturers were encouraged by EPA to label new cars with fuel economy information. The label data were also compiled in a Mileage Guide published by EPA. The mileage information was intended to provide potential new car buyers with information on the relative fuel economy performance of new models so that they could more effectively consider fuel economy in purchasing new vehicles. EPA cautioned vehicle owners on the label and in the Mileage Guide against expecting to achieve the absolute mpg estimate indicated for each vehicle in view of the wide range of driving conditions in the country that can affect vehicle fuel economy.

With the passage of the Energy Policy and Conservation Act (EPCA) in December 1975, fuel economy labeling and publication of the Mileage Guide became required by law, effective in mid-model year 1976. EPCA also established average fuel economy standards that must be met by each manufacturer on a fleetwide, sales weighted basis, and required EPA to conduct a fuel economy testing program. EPCA requires the fuel economy testing to be performed, to the maximum extent possible, in conjunction with EPA's emission certification testing. The fuel economy test procedure is required by EPCA to be comparable to that used in the voluntary program in model year 1975. While there is no express EPCA requirement that fuel economy testing for developing consumer mileage information and for compliance with EPCA standards be conducted in the same way, doing so results in large savings in terms of costs to the taxpayer, as well as in savings to the industry which are reflected in the cost of new cars.

The Fuel Economy Test - EPA fuel economy values are obtained by driving the vehicle, on a chassis dynamometer, over two prescribed driving cycles. Fuel economy results are calculated from the measured concentrations of tailpipe emissions of carbon-bearing exhaust constituents (hydrocarbons (HC), carbon monoxide (CO), and carbon dioxide (CO_2)) and a knowledge of certain characteristics of the fuel (fuel density and fuel hydrogen to carbon atomic ratio). A direct measurement of the mass of fuel used is not made in the EPA test.

A chassis dynamometer, a treadmill-like device, simulates the forces the vehicle would actually experience on the road. Although the vehicle remains still, the vehicle's engine turns its drive shaft and rear wheels (front wheels on front wheel drive vehicles), which in turn drive the dynamometer rolls. Attached to the rolls are steel disks which simulate the vehicle's inertia (resistance to acceleration) and a pump which simulates the aerodynamic drag that normally acts on a moving vehicle. Thus the vehicle's engine must provide power to overcome driveline and tire frictions (as it would on the road) in addition to the forces provided by the dynamometer.[1/] A schematic of the dynamometer is shown in Figure 1.

1/ An assumption in the design of the test is that the power dissipated by the two rear tires driven on the dynamometer simulates the power dissipated by all four tires driven on the flat road. EPA is reevaluating this assumption for various tire types in a current test program.

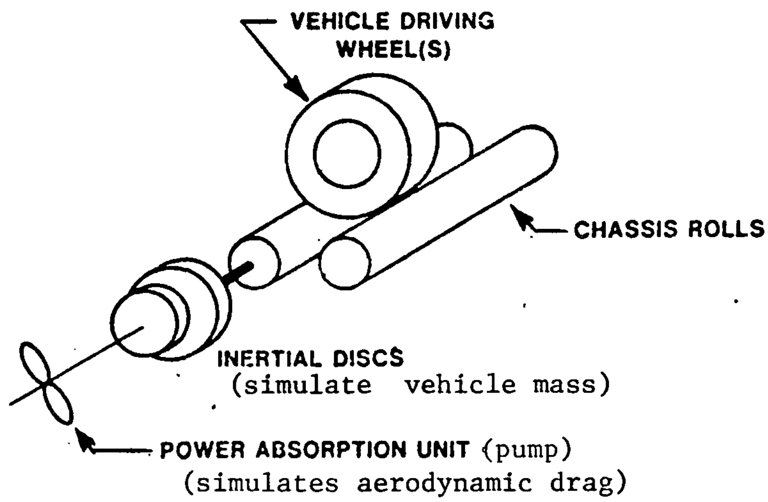

Figure 1 - Chassis Dynamometer

The city driving cycle consists of a 7.5 mile trip with an average speed of 20 miles per hour, 4.3 minutes (18%) of idling, 18 stops, and a short freeway section with a top speed of 56 mph. The test vehicle, after sitting at an ambient temperature of 68 to 86° Fahrenheit for at least 12 hours, is driven over the city cycle on the dynamometer. The engine is then stopped for ten minutes and the 7.5 mile test is repeated.[2/] The results of each part of the test, referred to respectively as the cold and hot start tests, are weighted by the national average of hot and cold start trips (53 percent cold start and 47 percent hot start) to yield an overall city fuel economy estimate.

After completion of the city test, the vehicle, in a warmed-up condition, is driven on the dynamometer over the highway cycle. This 10.2 mile trip has an average speed of 48 mph, with no stops between the beginning and end of the test. Speed variations during the trip are small, with most of the trip occurring between 40 and 60 mph. The speed versus time history of each trip is shown in Figure 2.

2/ In practice, the second portion of the hot start test following the first 505 second point is not performed. Data indicate that this portion of the cold start test, which is measured separately, also represents warmed-up vehicle operation, and repeating this portion of the test would yield the same results.

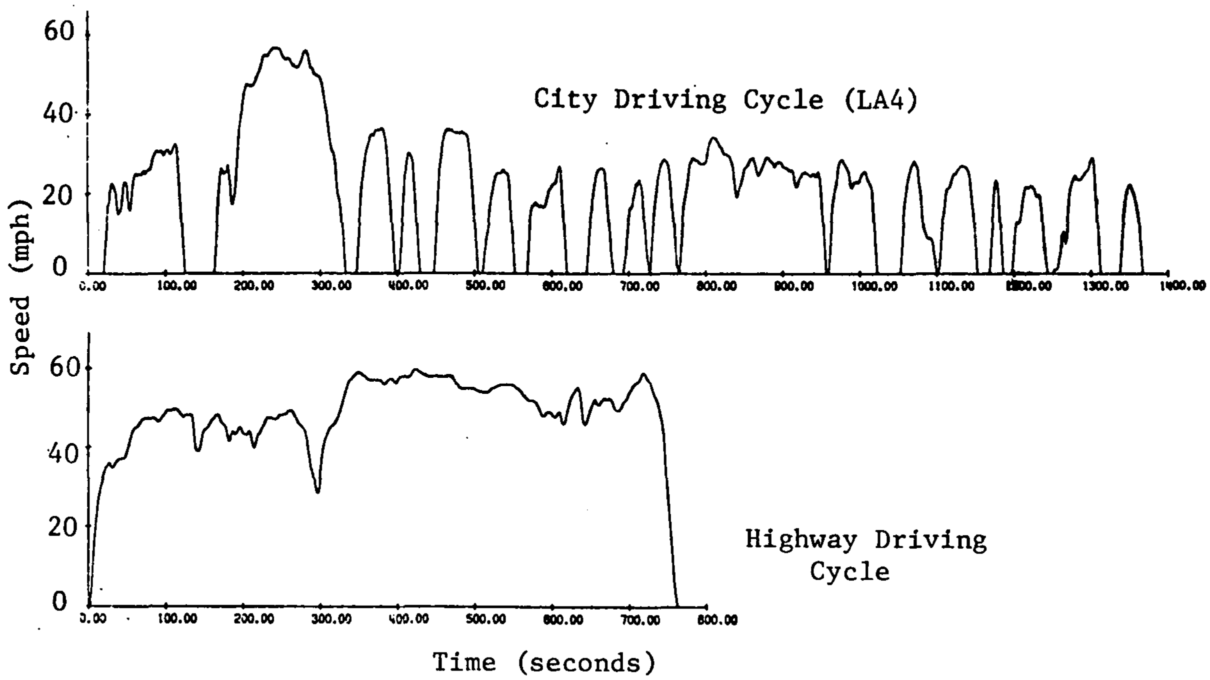

Figure 2 - Dynamometer Driving Schedules

In the Mileage Guide city, highway, and combined fuel economy estimates are presented for each model type. The combined value provides an estimate of the vehicle's overall average fuel economy. It is calculated by harmonically weighting the city value by 0.55 and the highway value by 0.45, the two factors being the nationwide fraction of city and highway trips.3/

Annually EPA tests pre-production vehicles to confirm compliance with emission standards. The test performed on these cars is identical to the procedure used to measure city fuel economy. Thus a fuel economy result is obtained as a by-product of the emission test for these cars. To fully represent all model lines, additional vehicles (about 30 percent of the total in 1977) are tested specifically for fuel economy. All vehicles are pre-production prototypes which have accumulated 4000 miles prior to testing. In 1977, approximately 750 vehicles were tested for fuel economy at EPA's laboratory.

II ANALYSIS

At issue is how well does the EPA Mileage Guide fuel economy compare to on-road fuel economy reported by owners. The data available allow this issue to be addressed in two parts. By comparing the Mileage Guide fuel economy to dynamometer fuel economy measurements on in-use cars, the effect of differing test conditions is removed. Any fuel economy differences thus identified will be the result of prototype to production vehicle differences, or of differences in maintenance,

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3/ More recent data indicate 58% city and 42% highway weighting factors would be more appropriate.

method of mileage accumulation or state-of-repair of the vehicle. These same dynamometer tests can also be compared to owner estimates of on-road fuel economy for the same vehicle. Such a comparison, to the extent that owner estimates can be relied on (few owners keep precise records), should indicate the degree to which EPA test procedures are representing the typical on-road driving and operating conditions. Together these results can identify overall differences between Mileage Guide and on-road fuel economy.

A. Comparision of Mileage Guide Fuel Economy to Dynamometer Tests of In-Use Production Cars

FY75 Emission Factor Testing - Each year EPA contracts to test approximately 2000 in-use production vehicles for emissions. The data are used for a variety of purposes, including generation of emission factors for use in air quality planning. This testing program is labelled Emission Factors (EF) and is designated by the fiscal year (FY) funding used (e.g., FY75 EF Program). Although a wide range of vehicle model years and types are tested, the emphasis is placed on the newer models. The vehicles are randomly borrowed from private owners and are tested as received, without tune-up or servicing, using the same procedures and equipment types used in EPA certification and compliance testing. Among the tests performed on the vehicles are the city and highway fuel economy tests.

The fuel economy data from this test program and the results of EPA certification and compliance tests provide a basis for comparison of prototype and production vehicles tested using the same procedures. Any discrepancy in fuel economy will be the result of inherent differences in the way the vehicles are produced or equipped (Are the prototypes typical of production vehicles?) or the condition of the vehicle (Does wear, method of mileage accumulation or improper maintenance as experienced in the real world result in lower in-use fuel economy?).

Fuel economy results from the FY75 emission factor program have been compared to the data in the Mileage Guide. Of the 1975 and 1976 model year vehicles tested, 812 matches with the city Mileage Guide fuel economy were made. Because the highway test was not performed on the 1975 model year emission factor vehicles, only 230 highway fuel economy comparisons, all on 1976 model year cars, were made.

This comparison shows that 74 percent of the vehicles tested demonstrated city fuel economy within 10 percent of the city Mileage Guide value. This translates to within two miles per gallon for a twenty mpg car. Eighteen percent of the cars demonstrated city fuel economy that was more than 10 percent low, and 8 percent were more than 10 percent better than the Mileage Guide values.[4]

The agreement was poorer for the highway fuel economy tests. Sixty-seven percent of the tests resulted in highway fuel economy within 10 percent of the Mileage Guide values. Twenty-nine percent exhibited highway fuel economy more than 10 percent poorer than the guide, and only 4 percent had fuel economy 10 percent or more above the guide. For the highway tests, the results are heavily skewed towards lower than the Mileage Guide in-use vehicle fuel economies; this is not as apparent for the city results. The above information is summarized in Table 1.

The vehicle owner is more likely to compare an absolute mile per gallon difference than a percentage. For the city results the average in-use vehicle fuel economy was 0.5 mpg lower than the Mileage Guide. For the highway test the difference grows to 1.7 mpg lower.

Table 1 also presents the same statistics by model year. Because no highway tests were run on 1975 model year (MY) vehicles in this EF program, a comparison of city differences to highway differences can be made only for 1976 models. For 1976 model year cars, on the average, in-use vehicles were 5 percent lower than the Mileage Guide on the city test and 6 percent lower on the highway test, i.e:

$$\frac{\text{EF mpg}}{\text{Mileage Guide mpg}} = 0.95 \quad \text{city cycle, 1976 models}$$

$$= 0.94 \quad \text{highway cycle, 1976 models}$$

A criticism of using emission factor fuel economy data to compare with Mileage Guide numbers is that EF cars are tested in an as-received condition and many of the cars do not meet emission standards. However, as Table 1 shows, the results for those vehicles meeting all emission standards (47 percent) are virtually identical with the group of all vehicles. For these relatively new vehicles, the state-of-tune can not account for the lower fuel economy of the in-use vehicles. For that reason, the inclusion of vehicles not meeting emission standards in

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4/ The Mileage Guide values are a projected average of the numerous configurations in which a specific model may be built. In the 1975 Mileage Guide, multiple fuel economy results for a specific model (e.g., Pinto) were presented only if the engine size or fuel system (e.g., 2 barrel vs. 4 barrel carburetor) differed. Separate values for manual and automatic transmissions were not presented. Thus, an emission factor vehicle may have a different transmission type, axle ratio, tire type, test weight, body style, or optional equipment from the average vehicle represented by the fuel economy value in the guide. However, since the sample size in the emission factor programs is large and multiple vehicles of each model are tested, on the whole the comparison of emission factor data to the Mileage Guide values is valid. In the 1976 Mileage Guide the data are presented separately for automatic and manual transmission cars.

Table 1

Comparison of Production and Prototype Vehicle Fuel Economy
(As Measured by the Federal Test Procedure)

	All Vehicles		Vehicles Which Meet Emission Standards	
Absolute Difference (mpg)	City	Highway	City	Highway
-2 or poorer	10%[a/]	28%	12%	31%
-2 to +2	88	68	85	67
+2 or better	2	4	3	2
Percentage Difference (%)				
90 or poorer	18%	29%	19%	30%
90 to 110	74	67	72	67
110 or better	8	4	9	3

	City			Highway		
	Sample Size	Percent[b/]	Diff (mpg)[c/]	Sample Size	Percent	Diff (mpg)
All Vehicles	812	98	-0.5	231	94	-1.7
1975 models	273	103	+0.2	---	--	----
1976 models	539	95[d/]	-0.9	230	94	-1.7
Subcompacts	196	94	-1.4	49	88	-4.1
Other cars	614	98	-0.3	180	97	-0.7

a/ read as 10 percent of all EF vehicles have city fuel economy more than 2 mpg lower than shown in the guide

b/ Percent defined as EF FE/Guide FE times 100

c/ Difference defined as EF FE minus Guide FE

d/ It may be tenuous to conclude from these data that the production to prototype fuel economy difference is getting worse each model year. A trend of improving fuel economy with accumulated vehicle mileage has been identified. The 1975 and 1976 model year data agree better after correcting to a common 4,000 mile basis. Additional data, shown in Figure 3 and discussed in later sections, indicate this mileage factor accounts for most of the variation in city results from the numerous data sources.

this fuel economy comparison is deemed valid.

The FY75 EF data suggest that the agreement between in-use vehicle and prototype fuel economy is much worse for the high fuel economy of subcompacts than for larger cars. The data suggest (Table 1) a 12 percent discrepancy in highway values for subcompacts compared to a 3 percent discrepancy for the larger cars. The same comparison for city fuel economy shows a shortfall of 6 percent for subcompacts versus 2 percent for larger cars. In terms of absolute highway fuel economy, the subcompacts on the average are 4 mpg lower than the guide (1976 models).

FY74 Emission Factor Testing - In comparing FY74 EF city fuel economy to the Mileage Guide, two of the possible differences between the EF vehicles and the prototypes can be accounted for. First, the EF values are compared to the specific certification vehicle test results, thus correctly matching transmission types and vehicle weight. Second, a trend of fuel economy improving with accumulated vehicle mileage is accounted for on a model specific basis, thus correcting the emission factor results back to a common 4000 mile basis. (Mileage Guide values are determined from prototype vehicles which have accumulated an average 4000 miles, although individual vehicle mileages as high as 10,000 are allowed and occasionally occur. Since the EF vehicles had an average mileage of 9000 miles, the effect of the mileage correction is to reduce the EF fuel economy values from their measured values).

The data set chosen contains 463 cars and excludes California and high altitude vehicles. Only city fuel economy results are compared. On the average, in-use 1975 model year vehicles, when tested by the Federal Test Procedure, achieved a 6 percent lower city fuel economy than the comparable pre-production prototype vehicles used to derive the Mileage Guide values, i.e:

$$\frac{\text{EF mpg}}{\text{Cert mpg}} = 0.94 \qquad \text{city cycle, 1975 models}$$

The discrepancy is evident for virtually all manufacturers and for all inertia weight categories.

Restorative Maintenance Testing - EPA's Restorative Maintenance Program (RM) tests domestic in-use vehicles in an as-received condition and after being restored, if necessary, to manufacturer's specifications. 5/ The FY76 and FY77 programs have concentrated on equal-sized samples of the three major domestic manufacturers. The results of testing restored 1975 and 1976 model year vehicles indicate a 3 percent fuel economy discrepancy on the city cycle and 2 percent loss on the highway cycle, compared to the Mileage Guide. For the subset of vehicles achieving highway guide values of 25 mpg or better, the discrepancy grows to 5 and 4 percent respectively. The average mileage on the vehicles was 8000.

5/ Restoration includes correcting any disabled or damaged equipment, adjustments to manufacturer's specifications and, if necessary, a complete tune-up.

A preliminary look at the results of the 1977 model year RM testing (sample of 60) indicates a 6 percent shortfall from city Mileage Guide values, and a discrepancy of 5 percent for the highway results. Average vehicle mileage is approximately 2500.

$$\frac{\text{75-76 RM mpg}}{\text{Mileage Guide mpg}} = \begin{matrix} .97 & \text{city cycle} \\ .98 & \text{highway cycle} \end{matrix}$$

$$\frac{\text{77 RM mpg}}{\text{Mileage Guide mpg}} = \begin{matrix} .94 & \text{city cycle} \\ .95 & \text{highway cycle} \end{matrix}$$

Union Oil Tests - Organizations other than EPA have performed fuel economy testing on a large number of passenger cars. Union Oil Company in 1975 purchased the most popular new cars and accumulated 2000 miles on each vehicle before performing both track and dynamometer fuel economy tests. All of the cars met applicable emission standards.

The Union Oil city dynamometer test results, using the Federal Test Procedure, have been compared to the EPA testing of similar prototype cars. The average of two Union Oil tests on each vehicle was compared to the results of the EPA certification counterpart; 93 matches were made. The Union Oil vehicles exhibited an 8 percent lower fuel economy than the prototypes used to derive the Mileage Guide values, i.e:

$$\frac{\text{Union mpg}}{\text{Cert mpg}} = 0.92 \quad \text{city cycle, 1975 MY}$$

Lower Union Oil measured fuel economies are evident for virtually all manufacturers and all inertia weight categories.

California Assembly Line Testing - Another source of fuel economy data using the Federal Test Procedure is the California assembly line test program (CALT). The California Air Resources Board tests vehicles taken from the assembly line. Approximately 100 miles are accumulated on the vehicle before the test is performed. The selection of vehicles is primarily based on those models that come close to failing the EPA certification tests and is not a sales weighted sample.

Matches to the EPA certification data were obtained for 106 of the CALT tests on 1975 model year vehicles. The CALT vehicles showed a 14 percent lower city fuel economy than the EPA certification tests used to develop the California Mileage Guide values.[6/]

$$\frac{\text{CALT mpg}}{\text{Calif Cert mpg}} = 0.86 \quad \text{city cycle, 1975 models}$$

6/ California has different emission standards than are applicable to vehicles sold in the other 49 states. A separate Mileage Guide has been published since 1975 for California cars.

No manufacturer or inertia weight class showed less than a 10 percent discrepancy. This relatively large discrepancy is partially attributed to the fact that the engines are not fully broken-in due to the low mileage on the vehicles (100 miles or less).

Subcompact Testing - In response to complaints from the public that EPA fuel economy values are higher than can be achieved in-use, and because the subcompact class showed the highest slippage between prototype and production vehicles in other programs, EPA obtained and tested three 1977 model year production vehicles of each of the fuel economy leaders in the subcompact class. On the average these cars had accumulated 5500 miles. Each car was a near identical match to a certification counterpart. Each car was tuned to the manufacturer's specifications, usually with a manufacturer's representative present. Of the thirty-one cars, representing 11 models tested, all but four met all emission standards after being tuned to manufacturer specification. Test conditions such as road load, inertia weight and manual transmission shift patterns were identical to those used for testing the certification counterpart. Three repeat tests on each car were run.

Compared to certification fuel economy, the fuel economy for this group of 1977 model year production subcompact cars was 6 percent low for the city cycle and 7 percent low for the highway cycle. For vehicles with a combined Mileage Guide fuel economy of at least 30 mpg, the discrepancy increased to 9 percent city and 11 percent highway, i.e:

$\frac{\text{Prod FE}}{\text{Cert FE}}$	=	0.91	city	1977 models with combined Mileage Guide FE greater than 30 mpg
	=	0.89	highway	

The shortfall tended to get larger as the vehicle's Mileage Guide fuel economy increased.

These results are similar to those from the 1975 and 1976 subcompacts tested in the FY75 EF program in which a 6 and 12 percent discrepancy in city and highway fuel economy respectively was found.

Notable is that three of the 1977 production models, all with less than 30 mpg combined fuel economy, exceeded the EPA certification fuel economy values by 3 percent city and highway. These vehicles are the VW Rabbit, the 2.8 litre Pinto, and the 2.0 litre Gremlin. None of the other 23 units tested exceeded their certification fuel economy. A common denominator of these three vehicles is their engines are wholly or partially built in Germany.

A possible explanation for this result may be the varying build practices of the different manufacturers. VW, for example, claims to utilize engines removed directly from the assembly line. Other manufacturers disassemble and inspect the engine to assure all components meet nominal tolerances. More analysis of the build practices for test vehicles among the various manufacturers, and quantification of the effects of such practices, is needed before definite conclusions can be drawn on the degree to which the shortfall can be attributed to this phenomenon.

Mileage Effect on Fuel Economy - A trend of improving city fuel economy with vehicle accumulated mileage can be identified using the FY75 emission factor data. The FY74 emission factor data show the same trend. Figure 3 shows an estimate of this effect. The solid line was derived from the FY74 emission factor data on 1975 model year cars. The other data are the results of the test programs previously discussed. These data support the trend that city fuel economy improves with higher accumulated vehicle mileage.

This relationship may explain why the city fuel economy discrepancy determined from the numerous data sources varies from 14 percent at 100 miles (CALT) to -3 percent for 1975 model year cars in the FY75 EF program (22,400 average odometer mileage). From Figure 3, the city fuel economy discrepancy at the 4000 mile point is 5 to 6 percent.

The small sample of highway fuel economy results currently available does not indicate a trend with accumulated mileage.

State-of-Tune and Maintenance - Tests on older, pre-catalyst cars have shown an average 8 percent benefit in fuel economy due to regular tune-ups. However, more recent studies on relatively new, low mileage catalyst cars have shown that the fuel economy benefit for such cars is smaller. The distinction for the newer low mileage cars is that the primary cause of failure to meet emission standards is disabled parts and maladjustments, as opposed to worn out parts. On the average, correction of maladjustment (except idle mixture and speed) or disablements resulted in a one percent improvement in fuel economy. For those vehicles requiring an adjustment to idle mixture and/or speed, fuel economy improved another 3 percent. A full tune-up, performed after the disablement and maladjustment repairs, had a negligible effect.

The conclusion reached for the low mileage car data included in this report is that the state-of-tune, on the average, does not explain the differences between the prototype and production vehicle fuel economy. As previously discussed, the FY75 emission factor data also support this conclusion (see Table 1).

The above discussion should not be construed to conclude that vehicle maintenance is not needed. The data indicate that for maladjusted low mileage cars a 3 to 4 percent improvement in fuel economy is possible.

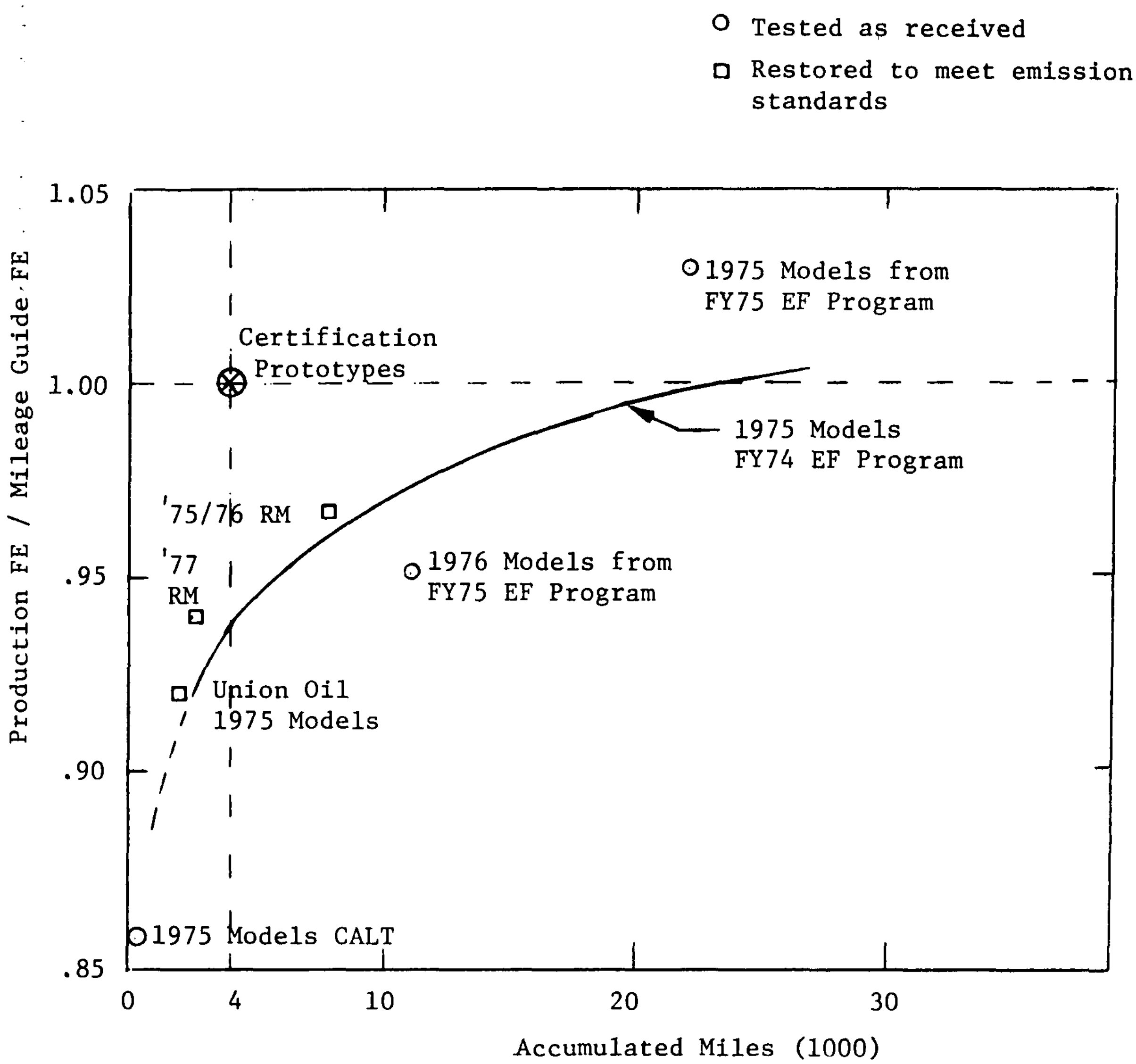

FIGURE 3

Production Fuel Economy vs. Odometer Mileage

(City cycle <u>only</u>)

For higher mileage cars with worn parts (e.g., misfiring spark plugs) a tune-up can restore substantially more lost fuel economy. In addition, EPA restorative maintenance programs have shown average reductions in tailpipe emissions of 60 percent CO, 32 percent HC, and 5 percent NOx due to corrective maintenance.

Findings: Comparison of Mileage Guide Fuel Economy to Dynamometer Tests of In-Use Cars - The large quantity of data from the numerous data sources presented above strongly support a conclusion that the prototype vehicles tested by EPA are not fully representative, from a fuel economy standpoint, of production vehicles. In-use cars, when tested on a dynamometer, achieve an average 5 percent lower city fuel economy and 6 percent lower highway fuel economy. For the high mpg subcompact class this discrepancy grows to 9 and 11 percent respectively.

Since many of the results (RM, Union Oil, EPA Subcompact Program) are based on cars that met the applicable emission standards, it is unlikely that the maintenance condition or state-of-tune of these relatively new in-use cars explains any of the observed production vs. prototype fuel economy differences. The conditions under which mileage has been accumulated has been suggested as a possible cause of this discrepancy. (Mileage is accumulated on the certification prototype vehicles in a relatively short time with few periods with the engine off). Although a small sample upon which to discount this argument, the fact that seven of the eight VW Rabbits, 2.8 litre Pintos, and 2.0 litre Gremlins exceeded the Mileage Guide fuel economy while none of the other 23 vehicles (8 models) did, would suggest that the fuel economy discrepancy is attributable to the vehicle and not the method of mileage accumulation.

The discrepancy would thus appear to be caused by physical differences in the prototype vehicle when compared to its production counterpart. These differences have not been identified, but may include such items as atypical component tolerances and fuel system calibrations, or the use on prototypes of unrepresentatively low rolling resistance tires.

B. Comparison of On-Road Fuel Economy to Dynamometer Tests of In-Use Vehicles

Section A identified a fuel economy shortfall between prototype and production vehicles when both vehicle types were tested on a dynamometer using the same test procedures. The next question is whether on-road fuel economy differs from the dynamometer test results for the same production car.

Owner Estimates - Owners who participate in the EPA emission factor programs are asked to estimate the city and highway fuel economy they obtain in-use. These owner estimates have been compared to the dynamometer test results of the owner's car. [7] The conclusion drawn is that far more people estimate poorer highway in-use fuel economy than is obtained by testing their car using the Federal Test Procedure. For the city test the results are more evenly distributed, as shown below.

Owner Estimate Minus EPA Test	Percent of Sample City	Percent of Sample Highway
-2 mpg or poorer	18%[8]	45%
-2 to +2	69%	48%
+2 mpg or better	13%	7%

On the average the owners estimated city fuel economy 2 percent lower than measured by city dynamometer tests on their car. For the highway test the average estimate was 11 percent low.

Owners of subcompacts estimated city fuel economy 3 percent better than the test result, however for highway driving the result slipped to 9 percent low. Unlike the production versus prototype test result, this highway discrepancy was typical for all car classes from subcompact to full size. [9]

7/ Data are for 1974-1976 model year vehicles in the FY75 emission factor program. Sample size is 105 for the highway test and 565 for the city test.

8/ Read as 18% of car owners estimate city fuel economy more than 2 mpg lower than the results of EPA's dynamometer test of their car.

9/ The owner estimates are usually not based on detailed records, but instead on a general perception of the vehicle's fuel economy. The only measure of fuel economy is based on refueling the vehicle's tank, and it is unlikely the entire tank would have been consumed by driving in a manner similar to the EPA city test. The estimates for the highway test, if based on long trips, may be more accurate, however they are likely to be low because of the fuel economy penalty associated with operation at highway speeds typically higher than represented by the EPA test. These limitations should be considered when interpreting these data.

C. Overall Comparison: Mileage Guide to On-Road Fuel Economy

The results presented in the previous sections each addresses a part of the shortfall of the EPA fuel economy numbers. By combining these results, a comparison of the Mileage Guide to in-use, on-road fuel economy can be made. This is schematically presented below.

	Data Source		Reason for Difference	Causes
high F.E.	Mileage Guide Fuel Economy	(A)		
			Prototype to production slippage	Prototype vehicle is different than production vehicles
	Dyno Tests of In-Use Cars	(B)		
			Test procedures not representative of how owners drive	1. Road forces not fully simulated 2. Ambient conditions different (cold, wind, rain, altitude) 3. Driving conditions different (high speed, short trips, rough road, hard driving)
low F.E.	Owner Measured or Perceived Fuel Economy	(C)		

OVERALL DIFFERENCE =(B/A) times (C/B)

The average fuel economy difference between the Mileage Guide and dynamometer tests of in-use cars was shown to be 5 percent for the city test and 6 percent for the highway test. Owners estimated fuel economy 2 percent lower for city driving and 11 percent lower for highway driving compared to dynamometer tests of their cars. Combined these results suggest an overall discrepancy between the Mileage Guide and on-road fuel economy of 7 and 16 percent for city and highway driving respectively. For combined city and highway driving the overall discrepancy is 11 percent.

Overall In-Use Fuel Economy Discrepancy
(percent)

Best Estimate	City	Highway	Combined
production vs prototype	5%	6%	
on-road vs dyno tests	2%	11%	
Total (Mileage Guide vs On-Road)	7%	16% 10/	11%

For the subcompact class the highway discrepancy increases.

Overall Subcompact In-Use Fuel Economy Discrepancy
(percent)

Best Estimate	City	Highway	Combined
production vs prototype	9%	11%	
on-road vs dyno tests	-3%	9%	
Total (Mileage Guide vs On-Road)	6%	19%	11%

In terms of absolute miles per gallon, the discrepancy for a typical vehicle in the fleet is approximately 1 mpg city and 4 mpg highway. For subcompacts the shortfalls are 1.4 and 7 mpg respectively. If this discrepancy continues the average mpg shortfall for 1985 (assuming an average fuel economy equal to EPCA's 27.5 mpg standard) would be approximately 2 and 5 mpg respectively. These results are summarized below.

Estimated Overall Fuel Economy Discrepancy, mpg

	City	Highway	Combined
1976 average vehicle	1 mpg	4 mpg	2 mpg
1976-77 subcompacts only	1+	7	3
projected 1985 vehicle	2	5	3

10/ Totals calculated from (production FE/Mileage Guide FE) times (owner-estimated on-road FE/production FE); for example, 0.94 times 0.89 equals 0.84 or a 16 % discrepancy.

GM Owner Survey - A check on the reasonableness of the above results can be made by asking owners to record mileage and fuel consumed over a period of time. General Motors asked its 1975 car owners to record odometer readings and gallons of fuel purchased for four fill-ups. The resulting data were screened to eliminate illogical data. EPA's analysis of these data concentrated on those vehicles nominally six months old for which the data recorded were obtained in the summer months. These conditions come closest to matching the EPA certification test condition. Because transmission type was not available, the data were compared to the automatic transmission certification results. (A small minority of cars has manual transmissions). In addition, no city or highway data were indicated, so the comparison to certification data was made using the 55/45 combined fuel economy values.

The results of the GM postcard survey suggest a 9 percent lower in-use fuel economy compared to the EPA Certification values. This compares well to the 11 percent combined fuel economy shortfall estimated above. The average vehicle mileage in the GM survey was 6000.

III TEST PROCEDURE INFLUENCES

In the previous section a production vehicle fuel economy shortfall was identified relative to the prototype vehicles used to establish the Mileage Guide fuel economy values. This slippage was determined by testing both prototype and production vehicles using identical test procedures and test conditions. The in-use vehicle fuel economy shortfall was attributed to a physical difference in vehicles.

To determine the overall difference between on-road fuel economy and the Mileage Guide,the difference between owner estimated fuel economy and dynamometer tests of the owner's car was also determined. These data indicated a lower on-road fuel economy. The possible causes for this part of the overall discrepancy are related to the difference between real world driving conditions and the conditions simulated by the EPA dynamometer tests.

A. Driving Factors

The test cycles cannot represent all types of driving. For example, the city cycle is not representative of heavily congested downtown driving. At an average speed of 5 mph, fuel economy will be less than one half that represented by the typical 20 mph urban trip. Trip length also has a significant effect. From a cold start, fuel economy for a 2 mile trip may be 25 percent less than the typical 7.5 mile trip. A rough road can reduce cruise fuel economy 15 percent, and underinflated tires can account for a 7 percent loss. In- use vehicles may have high brake drag or misaligned front tires (preliminary data indicate poorly aligned front tires can cause a significant fuel economy penalty). Both of these effects can increase the work required to propel the vehicle, thus reducing in-use fuel economy. These data illustrate why no cycle can represent all driving conditions.

The extent to which these driving conditions account for the lower owner perceived fuel economy has not been quantified. In several cases, however, certain EPA test conditions tend to optimize measured fuel economy. For example, the dynamometer surface simulates a smooth road. All other road qualities tend to reduce fuel economy. Another example is the average speed of the city trip (20 mph).

Average Speed (mph)	Change in F.E. Relative to a 20 mph trip
5 mph	-57%
10	-30
15	-12
20	0
25	+10
30	+16
40	+25

Clearly, a slower speed city trip extracts a larger fuel economy penalty than the benefit gained from the higher speed trip. To this unquantified extent, the EPA test driving conditions bias the Mileage Guide results to the high side.

Probably the most prevalent cause of lower in-use highway fuel economy is vehicle speeds which exceed the 55 mile per hour speed limit. Average cruise fuel economy for six cars, ranging from a Rabbit to a Continental, indicates 70 mph speeds reduce fuel economy an average of 24 percent from the fuel economy at 45 mph. These data are shown below:

Cruise Speed (mph)	Fuel Economy (mpg)	Reduction from 45 mph, %
45	25	0
60	21	16
70	19	24
80	16	36

These test results show that speeds higher than represented by the highway test cycle will result in on-road fuel economy significantly lower than estimated by EPA.11/

Shift Patterns - Another test procedure aspect which can affect fuel economy as measured by the Federal test procedure on manual transmission cars is the shift patterns and speeds. Historically EPA has recommended shift points for manual transmission cars, although allowing manufacturers

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11/ Average speed for the highway cycle is 48 mph, however since it is a transient cycle, lower fuel economy can be expected than for a 48 mph steady speed cruise. Portions of the highway cycle, however, represent cruise operation at 45 and 55 mph.

to use different values if these values are included in the owners manual. The purpose of this provision is to allow for representative shift points for cars which have unusual engine and gearing characteristics. In the past few model years, use of this provision has increased from practically nothing in model year 1975 to special shift patterns being used for testing most of the small high fuel economy cars. The trend is towards shifting gears at lower speeds and skipping gears when sufficient power is available.

A comparison of the impact on fuel economy of various shift patterns has been made for two high fuel economy cars. The baseline shift pattern was defined at 15-25-40 mph.[12/] Manufacturer recommended shift patterns, using lower speed shift points, were used during the city test and compared to the results from 15-25-40 shifting. The manufacturer's recommended shift speeds produced a 10 percent improvement in fuel economy on the city cycle.

Such an effect has several implications. If owners do not follow the lower speed shift patterns recommended in the owners manual, a significant discrepancy between city in-use and Mileage Guide results will occur. Of equal importance, the ranking ability of the guide could be affected, putting automatic transmission vehicles or vehicles not recommending lower shift points at a significant disadvantage. A procedural change which will eliminate use of unrepresentative shift patterns is being prepared for the 1979 model year.

Road Load - Similar to shift points, EPA has historically utilized a road load power test condition which is a function of only the vehicle weight. In the past most manufacturers have used these recommended values. An option to demonstrate by track coast down testing that the vehicle has a road load different than that recommended has been available, and in recent years manufacturers have used the alternate procedure when to their advantage. [13/] (Fifty-six percent of 1978 certification vehicles used an alternate road load value). The purpose of this option is to give proper credit for low air resistance (drag) cars, and by giving such credit encourage the development of cleaner aerodynamic designs to reduce in-use fuel economy.

An improved road load prediction method based on vehicle frontal area has been developed. This method of determining recommended road load will become effective with 1979 model year certification. On the average the dynamometer power setting is unchanged by the new equation; however

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12/ This is the pattern historically recommended by EPA: 1st to 2nd gear at 15 mph, 2nd to 3rd gear at 25 mph, 3rd to 4th gear at 40 mph.

13/ A coast down test involves shifting the car into neutral at a predetermined vehicle speed and allowing the car to coast. From the rate of deceleration the forces (road load) acting on the vehicle can be calculated.

the ability to predict the appropriate road load for a specific vehicle is improved. This new method will decrease the need for manufacturers to perform as many track coastdown tests, and will provide an improved tool for assessing the reasonableness of requested alternate road load settings. The effect on fuel economy will be to provide a more realistic road load test condition for higher drag cars, which previously were tested using the inertia weight based value.

The tire to dynamometer roll interface is also receiving much attention. This part of the road load is not simulated by the dynamometer power absorber since it is the vehicle that must overcome tire resistances during the test. An uncertainty lies in how well does the interface between the tire and the twin dynamometer rolls (see Figure 1) simulate the road surface. The assumption in the past has been that the two tires driving the rolls simulate the rolling resistance of all 4 tires on the road. 14/ An examination of the physical constraints of the tires pinched between two rolls suggests that simulation of a flat road surface may be imperfect. Slippage at the tire-roll surface may occur, and because the two driving tires are absorbing the forces of approximately four tires on the road, the tire warm-up characteristics differ on the dynamometer. A study of this subject, including the effects of various tire types, is currently underway.

A method of identifying if imperfect road load simulation is occuring is to test a vehicle on the dynamometer and on the test track, duplicating the test conditions as closely as possible. Test programs utilizing this approach have been performed with results indicating the dynamometer gives from 4 to 11 percent better fuel economy than operation on the track. Exact duplication of test conditions is difficult to obtain, however. Corrections for ambient condition differences between the track and lab for example, would reduce the reported difference by one half. The results still directionally suggest a dynamometer to road fuel economy difference may exist, and a carefully controlled test program to quantify any difference is planned.

Improvements identified in these road load studies could be factored into the new road load equation. As an initial step, different frontal area road load equations have been developed for bias and radial tire equipped test vehicles.

Best estimates of the effect of changes in road load on fuel economy indicate this parameter can have a substantial impact on measured fuel economy, i.e:

Approximate Change in Fuel Economy due to a 10% change in Road Load

	City	Highway
Power absorber	1%	4%
Rolling Resistance	2%	2%

14/ The tires are pressurized to 45 psig; the front tires are stationary during the dynamometer test (for rear wheel drive vehicles).

Road load settings derived by manufacturers from coast down tests have varied by as much as 40 percent from the EPA inertia weight table values, indicating the need to evaluate the representativeness of road load values obtained by the coast down method. In addition, improvements to the coast down methodology are currently being developed.

Air Conditioning - EPA's test procedures simulate air conditioner usage by increasing the dynamometer road load setting by 10 percent. A comparison of actual operation of the air conditioners during the dynamometer and track tests to the road load simulation method showed that the dynamometer simulation of the air conditioner produces no change in fuel economy. 15/ Both the track and dynamometer tests with the air conditioner actually operating showed a ten percent penalty on both the city and highway test. The conclusion is the current test procedure produces results which bear no resemblance to actual air conditioner use. A test program to develop an improved simulation based on actual air conditioner operation is planned.

B. Environmental Factors

The fuel economy test is performed at approximately 75°F. Results of limited 50 mph tests at lower temperatures indicate a 5 percent fuel economy penalty at 50°F increasing to a 11 percent penalty at 20°F. Operation on hot days does not increase fuel economy to the same extent, Thus even if a 75°F test condition is an annual daytime temperature average in some parts of the country, its use may not yield an average annual fuel economy. If average fuel economy data are to be achieved, testing at lower temperatures or development of temperature correction factors will be required. A cold weather test program on in-use vehicles will be conducted in the winter of 1977/78 to further quantify the temperature effect on fuel economy.

C. Ranking

A primary purpose of the EPA fuel economy program is to provide a ranking of vehicles by fuel economy which can be used by the consumer to select the best fuel economy car. An analysis of the ranking ability of the Mileage Guide combined fuel economy, when compared to the actual ranking based on the FY75 emission factor data (dynamometer tests of in-use cars), has been made and the results are shown below.

15/ Other EPA test results indicate a 10 percent increase in dynamometer road load setting should decrease combined fuel economy approximately 2 percent.

Size Class	Required Difference (combined mpg)	Percent of Pairs
All	4.2	58
Full	2.5	11
Intermediate	3.2	32
Compact	3.5	45
Subcompact	5.2	41
Light Truck	4.5	36

These data can be interpreted as follows. To have a 95 percent confidence that the Mileage Guide ranking for a pair of cars will be the same for the production car equivalents, the Mileage Guide combined fuel economy difference between the two cars must be at least 4.2 mpg. If the difference in mpg between the two cars being compared is less than 4.2, the probability of the Mileage Guide ranking being correct will decrease. For example, at a 2 mpg difference between two cars (not shown in the table), the probability of a correct ranking by the Mileage Guide will be 78 percent (pure chance will give a 50 percent probability). The "Percent of Pairs" column shows how many of the possible comparisons in the 1976 Mileage Guide have a difference larger than that required for 95 percent confidence. In the subcompact class, for example, 41 percent of the possible comparisons have a Mileage Guide difference of at least 5.2 mpg, and for these pairs of cars, there is at least a 95 percent chance that the equivalent production cars will rank the same way.

This ranking ability is affected by how large a range of mpg occurs in a specific class. In 1976, cars in the full size class differed at most by 7 mpg. Of the possible comparisons in this class, only 11 percent had a fuel economy difference greater than 2.5 mpg. As the range of mileages in a class increases, the number of comparisons that will be ranked correctly also increases. However, for no class will over half the cars rank correctly with 95 percent confidence.

Possible factors which can improve the ranking ability of the Mileage Guide have been discussed previously. If one manufacturer uses production engines in the prototype vehicle EPA tests while another uses a specially built engine which gives unrepresentatively high fuel economy, the relative ranking of these two vehicles may be affected. Vehicles tested with inappropriately low manual transmission shift points can achieve a higher ranking than automatic transmission cars or cars not shifted in this manner, but the associated fuel economy benefit will not be realized by the car owner. The key to good ranking ability thus lies in the equal application of the letter and spirit of the testing procedures to each vehicle tested. In the apparent absence of an acceptance of the spirit, the written rules may have to become more definitive.

IV FINDINGS AND CONCLUSIONS

1. An overall fuel economy discrepancy exists for the 1975-1976 vehicle fleet. On-road, in-use fuel economy is approximately 7 percent (1 mpg) lower than EPA city test results and 16 percent (4 mpg) lower than the EPA highway test results. If this percent discrepancy remains, by 1985 the mpg shortfall will increase because of the higher projected fleet fuel economy.

2. The 1976/77 model year highway fuel economy shortfall for the subcompact class is approximately 19 percent (7 mpg).

3. Sixty-five percent (0.8 mpg) of the city discrepancy and 35 percent (1.4 mpg) of the highway discrepancy appears to be due to undetermined differences between prototype and production vehicles. On the average, the prototypes achieve unrepresentatively higher fuel economy. For the subcompact class the discrepancy due to production-prototype slippage is greater (2 mpg city and 4 mpg highway).

4. City fuel economy improves with vehicle mileage. At 15 to 25 thousand miles, the production to prototype slippage disappears. Corrections to the data for this mileage effect bring the shortfall reported by the various studies into closer agreement when based on a common 4000 mile point. Identification of an overall trend of increasing fuel economy shortfall with each later model year, as reported by one study, is not apparent from the production and prototype dynamometer test data.

5. Planned changes to the manual transmission shift point criteria and road load prediction methods will improve the representativeness of the measured fuel economy for some vehicles. Additional planned improvements to the tire-road force simulation are needed. (See the Appendix for a list of other EPA fuel economy related projects).

6. Current air conditioner simulation test methods have little effect on fuel economy. Actual air conditioner operation results in a 10 percent fuel economy penalty.

7. Implementing test procedure changes which have a directional effect on fuel economy relative to the 1975 test procedures may impact on compliance with the EPCA standards. To be implemented, major procedural changes (such as air conditioning simulation) may require consideration of a change in the EPCA standards.

8. Proper ranking based on the Mileage Guide can be assured only if the two cars have at least a 2 to 5 mpg (combined city/highway) difference in ratings, depending on the size class. In most classes less than one half the possible vehicle comparisons have fuel economy differences larger than this. Improvement to the ranking ability can be achieved by assuring the test procedures are equally applied to all vehicles. This includes shift points, road load and methods of building the prototype vehicles.

Appendix
Current EPA Fuel Economy Related Studies

Project Title	Objective
FY77 Emission Factor Program (Passenger Cars)	Measure emissions and fuel economy of in-use cars; determine effect of cold weather operation, determine effect of different driving cycles.
FY77 Light Duty Truck Emission Factor Program	Measure emissions and fuel economy of in-use light trucks (0-8500 GVW).
Proposed Rulemaking; Fuel Economy Labeling	Evaluate, through public comment, ways of improving the presentation of EPA fuel economy information
Report on 1978 Model Year Fuel Economy Trends	Quantify 1978 model year improvements in fuel economy based on EPA certification test results
Report on 1977 Model Year Fuel Economy	Analysis of fleet fuel economy based on actual sales; quantify fuel economy/ emissions trade-offs; in-use fuel economy analysis.
Evaluation of Industry Build Practices	Analysis of industry methods used to build the prototype vehicles tested for emissions and fuel economy.
Comparison of Mileage Guide to In-Use Fuel Economy Data	Continued comparison of Mileage Guide fuel economy to newer emission factor, Union Oil, GM postcard data etc.
Non-LA4 Project	Quantification of emissions and fuel economy under various ambient and driving conditions, assess impacts on air quality and national fuel consumption.

Project Title	Objective
Evaluation of Rolling Resistance of Various Model Tires	Quantify impact on fuel economy of various tire models and constructions for road and dynamometer operation.
Improvements to the Alternate Road Load Procedure	Improvements in accuracy and reduction of variability of the alternate road load procedure; Issue Advisory Circular.
Manual Transmission Shift Points	Develop criteria for determining representativeness of shift points used in developing EPA fuel economy estimates; Issue advisory circular.
Dynamometer Evaluation	Evaluate need for improvements to the dynamometer power absorber accuracy.
Refinements to the Fuel Economy Test Procedure	Evaluate effects of various parameters (brake drag, wheel alignment, lubricants) on measured fuel economy.
Air Conditioner Simulation Procedure	Develop improved test method for simulation of on-road air conditioner fuel economy penalty.
Comparison of Dynamometer vs. Track Fuel Economy	Determine if dynamometer simulated fuel economy and track fuel economy differ for the same driving cycle.