Technical Report

"Comparison of Fuel Economy Values from the Preconditioning and Measuring Cycles of the Highway Fuel Economy Test Procedure"

by

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NOTICE

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Introduction

The Highway Fuel Economy Dynamometer Procedure consists of driving the test vehicle over two highway driving cycles with fifteen seconds of idle between them. The first cycle is for preconditioning purposes and the second cycle is used for the fuel economy determination. This procedure is designed to follow the Federal Emission Test Procedure, known as the FTP. However, in the event that it cannot be scheduled within three hours of the FTP, the vehicle will be re-driven over one cycle of the EPA Urban Dynamometer Driving Schedule, known as the LA-4, before running the two highway driving cycles (see Appendix B). 1/

Since the vehicles are driven either over a FTP or a LA-4 prior to the highway fuel economy test, the vehicles may already be in a stabilized condition during the first cycle. Therefore, a study was conducted on fifteen light-duty certification vehicles during the regular certification highway fuel economy tests to determine if it is necessary to run the second highway cycle. For this study, fuel economy values were determined during both cycles and were then compared. All fifteen vehicles had smaller fuel economy values during the preconditioning cycle than during the measuring cycle. This report presents summary statistics of the absolute and relative (percent) differences between the fuel economy determinations of the two cycles and compares these differences to the time elapsed between the end of the FTP (or LA-4) and the start of the highway test. An additonal comparison of fuel economy values determined during a three highway cycle study is presented and discussed.

Discussion/Analysis

The sampling procedure and recording during the preconditioning cycle were conducted in exactly the same manner as during the measuring highway cycle. Additional recordings were: (1) whether an FTP or LA-4 were run previous to the highway fuel economy test (HFET) and (2) the soak time between the FTP (LA-4) and the HFET. The purpose of recording these parameters was to determine if either of these two factors have an effect on the difference seen between the two fuel economy values.

For each vehicle, the fuel economy values during the preconditioning cycle were less than those determined during the measuring cycle. This supports the results of a one vehicle study conducted by Austin, Hellman and Paulsell 2/ in which they found that during the first highway cycle the vehicle was not yet stabilized. After running a vehicle over an FTP and allowing a one hour soak time, they found that the fuel economy determinations during the first cycle were 98% of the highway fuel economy values from a fully warmed-up vehicle. If we assume that the vehicle is fully warmed-up during the second cycle, then the 98% compares favorably with the 96% found for the average of the eight vehicles in this study that had an FTP run just prior to the highway tests with an average of one hour and 26 minutes of soak time. The decrease in the percentage may possibly be due to the increase in the average soak time.

Table 1 shows the mean values for the soak time and the mean absolute and relative differences for the fifteen vehicles differentiating by FTP and LA-4. The relative differences do not seem to be affected significantly by the procedure that was used prior to the highway test. However, a direct relationship between soak time and the percent differences was found when these two variables were plotted against each other. This plot is given in Figure 1 together with the regression line running through the points. The purpose of the regression line is to more clearly visualize the direct relation between the variables shown by the positive slope of the line. The point that is circled seems to have a percent difference too large for a small elapsed time of 52 minutes. Since this point corresponds to a manual transmission vehicle, its highway driving trace was examined to see if there was any discrepancy between the preconditioning and measuring cycles' shift patterns. The shift speeds were actually different and the preconditioning acceleration line was substantially below the trace with the vehicle being driven at wide-open throttle. All the traces for the other manual transmission vehicles in the sample were also examined and no differences were found between their two cycles' speed time traces. A description of the vehicles and their corresponding fuel economy determinations can be found in Appendix A.

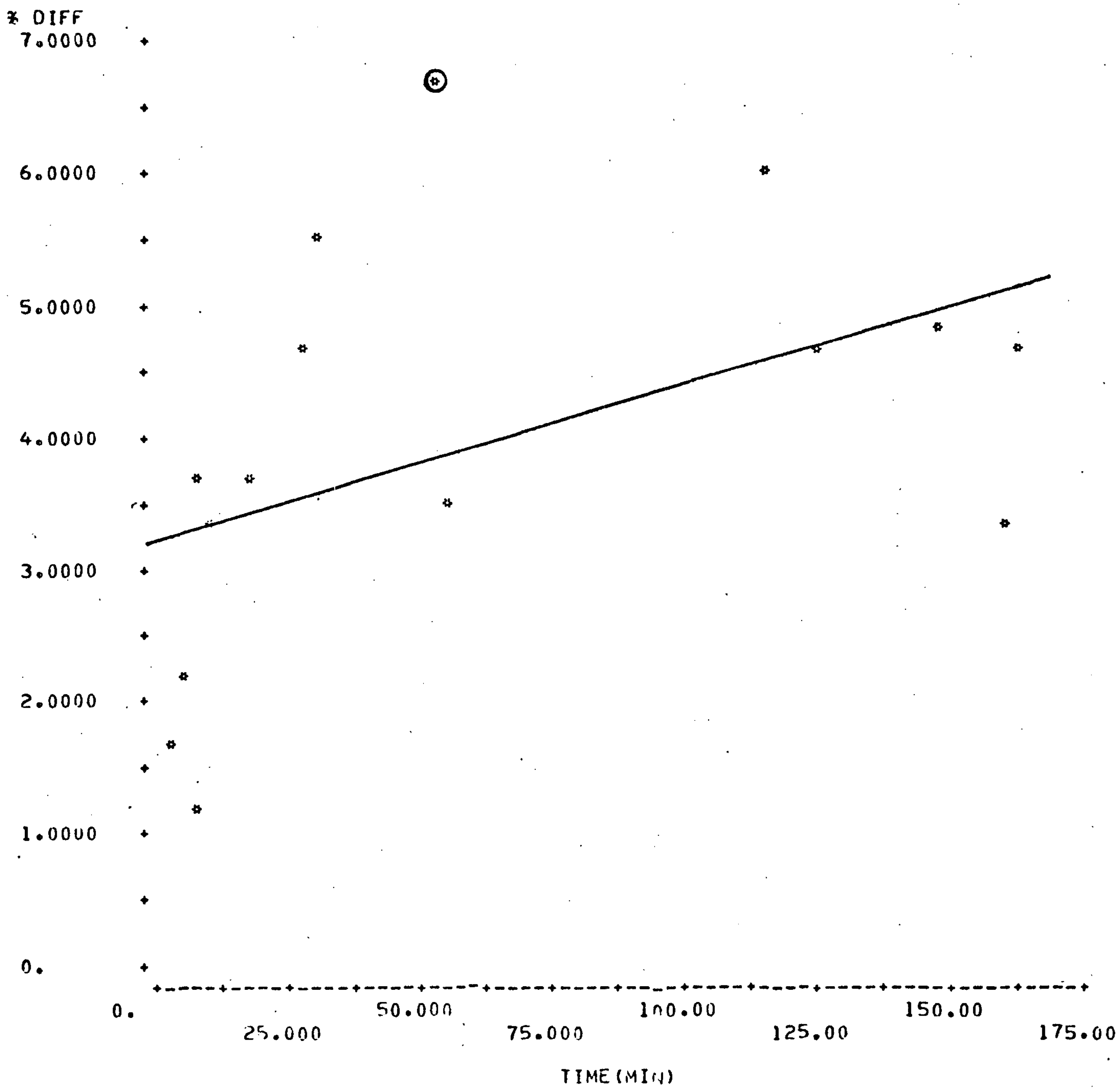

Figure 1 - Plot of percent difference between the fuel economy values versus the soak time preceding the highway fuel economy test

Table 1

Procedure Preceding Highway Test	Sample Size	Mean Soak Time (min)	Mean F.E. Difference (mpg)	Mean % Difference*
FTP	8	86	.9	4.1
LA-4	7	31	1.1	3.9
Overall	15	60	1.0	4.0

$$* \ \frac{\text{CERT F.E.} - \text{PREC F.E.}}{\text{CERT F.E.}} \times 100$$

The results of one of the tests were not included in the analysis because of a change in the test procedure. During the second cycle run, it was discovered that the sampling pump was off. Lab personnel then decided to complete the cycle and sample during a third cycle to obtain the certification fuel economy values. This procedure was considered to be in agreement with the Highway Fuel Economy Test Procedure since the second cycle could serve the purpose of preconditioning the vehicle followed by a cycle driven for the fuel economy measurement. Furthermore, the underlying assumption was that the vehicle is already in a stabilized condition during the second cycle and, therefore, the fuel economy values determined during a third cycle should not increase significantly. Any change seen is assumed to be purely by chance so that at times a small increase can be seen and at other times a small decrease. This assumption was based on the study conducted by Austin, Hellman, and Paulsell that was mentioned earlier. However, their results were based on testing only one vehicle under two different testing conditions.

The results for the certification vehicle that was run over three cycles were 20.5 mpg during the first cycle and 22.0 during the third, a 6.8% difference. Since this difference was the largest for all the tested vehicles, it was considered a possibility that if the second cycle were sampled, it's fuel economy value would be less than 22.0 mpg. Since valid three cycle tests have been run in the past, it was considered important to verify if the fuel economy values do continue to increase after the second cycle. Therefore, a small test program was conducted on three light-duty non-certification vehicles during which the vehicles were soaked for at least 12 hours, were run over an FTP and allowed to soak for one hour before running three highway cycles and sampling from all three. The results for the three vehicles are in the following table:

Table 2

Fuel Economy Determination from Three Highway Cycles

Manufacturer	Model	Cycle 1 FE (mpg)	Cycle 2 FE (mpg)	Cycle 3 FE (mpg)	% Diff 1 to 2*	% Diff 2 to 3**
GM	1975 Nova	15.8	16.1	16.3	1.9	1.2
GM	1976 Chevette	27.5	27.6	27.7	.4	.4
Chrysler	1976 Aspen	20.8	21.2	21.4	1.9	.9
Mean					1.4	.8

$$* \frac{\text{CYCLE 2 F.E.} - \text{CYCLE 1 F.E.}}{\text{CYCLE 2 F.E.}} \times 100 \qquad ** \frac{\text{CYCLE 3 F.E.} - \text{CYCLE 2 F.E.}}{\text{CYCLE 3 F.E.}} \times 100$$

It is clear from the table that vehicles are not yet stabilized and will therefore obtain slightly higher fuel economy values during the third highway cycle. It is to the manufacturers' advantage when the fuel economy values published for their vehicles were determined during the third cycle. In addition, note that the percent difference between the first and second cycle fuel economy values for these vehicles are much smaller than for the fifteen vehicles tested during regular certification testing. The reason for this discrepancy is not known but may result from different warm-up characteristics and emission control devices.

From the table we can see a tendency for the percent difference between the second and third cycles to increase as the difference between the first and second cycles increases (see Figure 2). If we assume that this increase will be linear we can then extrapolate the line that goes through the means of the Y-axis values in Figure 2. Therefore, 2.0% is an estimate of the difference between the second and third cycle for the average case of a 4.0% difference between the first and second cycle for certification vehicles. The difference between the first and third cycle for this average certification case would be less than the sum of 2.0% and 4.0%, that is, less than 6.0% (this is mathematically proven in Appendix C). Since the certification vehicle eliminated from the analysis had a difference of 6.8%, it seems to be an above average vehicle, and therefore, the estimate of 2.0% appears to be not only reasonable but may be conservative.

Summary/Recommendations

1. Fuel economy values determined during the preconditioning cycle of the Highway Fuel Economy Test will be lower than those determined during the measuring cycle.

2. There is a direct, but not very strong relation between the percent difference of the fuel economy values from both cycles and the soak time between the FTP (or LA-4) and the highway test.

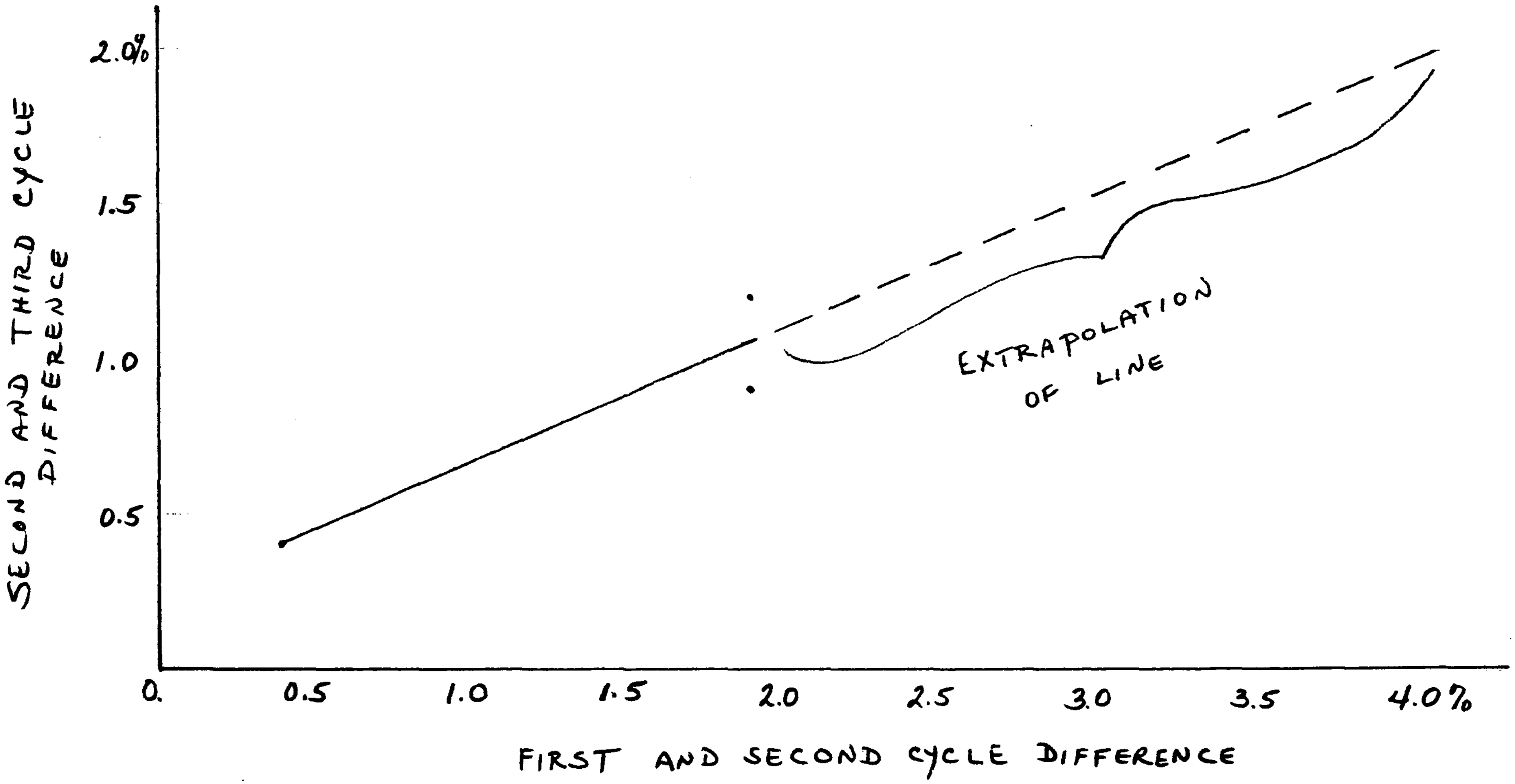

Figure 2 - Plot of percent difference between second and third cycle fuel economy values versus the difference between those from the first and second cycles.

3. The mean absolute difference found between the fuel economy values was 1.0 mpg and the mean percent difference ($\frac{\text{CERT F.E.} - \text{PREC F.E.}}{\text{CERT F.E.}}$ x 100) found was 4.0%.

4. Vehicles are not yet stabilized during the second highway cycle since the fuel economy values continue to increase when a third cycle is run. For an average difference between the first and second cycle fuel economy values of 4.0%, the difference between the second and third cycle values is estimated to be approximately 2.0%.

It is recommended that only data collected during the second HFET cycle be used for calculation of a vehicle's fuel economy. Using data from the first cycle would penalize the manufacturer by lowering his corporate average fuel economy (CAFE). Using data from the third cycle would give the manufacturer an advantage over other manufacturers by raising his CAFE and his published fuel economy values.

References

1. "Fuel Economy Testing; Calculation and Exhaust Emissions Test Procedures for 1977-1979 Model Year Automobiles", Federal Register, Vol. 41, No. 177, Friday, September 10, 1976.

2. Austin, Thomas C., Karl H. Hellman, C. Don Paulsell, "Passenger Car Fuel Economy During Non-Urban Driving", SAE 740592, New York, New York, 1974.

APPENDIX A

Vehicle Description
and
Fuel Economy Data

Table A-1

Vehicle Description

Test No.	Manufacturer	Model	Vehicle ID	Curb Wt. (lbs)	Trans	Tire Size
79-0024	Ford	Pinto	8E2-2.3-F-24	2548	M-4	A78X13
79-0046	Ford	Thunderbird Wagon	8S1-400-F-280	4365	A-3	HR78X15
79-0044	Ford	Ford	8A1-351M-F-276	4500	A-3	HR78X15
79-0075	Ford	Ford Sedan	8A1-400-F-275	4501	A-3	HR78X15
79-0106	Checker	Marathon	8C8	4094	A-3	G78X15
79-0103	AMC	Pacer Wagon	D76-84C(D)	3625	A-3	D78X14
79-0104	Chrysler	Plymouth	A163	2210	M-4	P165/75R13
79-0148	Avanti	Avanti II	2261A	3793	A-3	195-15
79-0149	Chrysler	VW Rabbit	A005T	2218	A-3	P155/80R13
79-0203	Chrysler	Chrysler	A197	4929	L-3*	JR78X15
79-0186	Toyota	Corolla 4DR Sedan	78-FE-2	2012	M-4	6.15S13
79-0150	GM	Monza Sta Wagon	84B2-288G	3032	M-4	BR70-13
79-0284	GM	Regal Sport Coupe	84E3-48170F	3377	A-3	P205/70R14
79-0151	AMC	Pacer Wagon	D76-84C(D)	3625	A-3	E78X14
79-0348	Ferrari	Ferrari	13492	3240	M-5	205/70VR14

*L = lock up/auto

Table A-2

Fuel Economy Measurements

Test No.	Manufacturer	Test Date	Curb Wt. (Lbs)	Time (min)	CERT FE (mpg)	PREC FE (mpg)	Diff. (mpg)	% Diff $(\frac{C-P}{C})X100$	Proc.
79-0024	Ford	01-05-78	2548	8	35.2	34.8	0.4	1.1	LA-4
79-0046	Ford	01-05-78	4365	27	19.2	18.3	0.9	4.7	FTP
79-0044	Ford	01-05-78	4500	115	20.1	18.9	1.2	6.0	FTP
79-0075	Ford	01-06-78	4501	163	19.1	18.2	0.9	4.7	FTP
79-0106	Checker	01-06-78	4094	5	14.5	14.2	0.3	2.1	LA-4
79-0103	AMC	01-09-78	3625	10	17.9	17.3	0.6	3.4	LA-4
79-0104	Chrysler	01-09-78	2210	30	39.7	37.5	2.2	5.4	LA-4
79-0148	Avanti	01-11-78	3793	148	18.4	17.5	0.9	4.9	FTP
79-0149	Chrysler	01-11-78	2218	18	32.6	31.4	1.2	3.7	FTP
79-0203	Chrysler	01-16-78	4929	7	16.7	16.1	0.6	3.6	LA-4
79-0186	Toyota	01-16-78	2012	52	44.7	41.7	3.0	6.7	LA-4
79-0150	GM	01-18-78	3032	160	23.8	23.0	0.8	3.4	FTP
79-0284	GM	01-18-78	3377	55	25.8	24.9	0.9	3.5	FTP
79-0151	AMC	01-18-78	3625	125	17.5	16.7	0.8	4.6	LA-4
79-0348	Ferrari	01-19-78	3240	3	18.3	18.0	0.3	1.6	FTP

APPENDIX B

Section 600.111-78 Federal Register
Friday, September 10, 1976

Federal Register Description of Highway Fuel Economy Test

§ 600.111–78 Test procedures.

(a) The test procedures to be followed for generation of the city fuel economy data are those prescribed in §§ 86.127 through 86.138 of this chapter, as applicable. (The evaporative loss portion of the test procedure may be omitted unless specifically required by the Administrator.)

(b) The test procedures to be followed for generation of the highway fuel economy data are those specified in § 600.111–78 (b) through (h) inclusive.

(1) The Highway Fuel Economy Dynamometer Procedure consists of a preconditioning highway driving sequence and a measured highway driving sequence.

(2) The highway fuel economy test is designated to simulate non-metropolitan driving with an average speed of 48.6 mph and a maximum speed of 60 mph. The cycle is 10.2 miles long with 0.2 stops per mile and consists of warmed-up vehicle operation on a chassis dynamometer through a specified driving cycle. A proportional part of the diluted exhaust emissions is collected continuously for subsequent analysis using a constant volume (variable dilution) sampler. Diesel dilute exhaust is continuously analyzed for hydrocarbons using a heated sample line and analyzer.

(3) Except in cases of component malfunction or failure, all emission control systems installed on or incorporated in a new motor vehicle must be functioning during all procedures in this subpart. The Administrator may authorize maintenance to correct component malfunction or failure.

(c) Transmissions—The provisions of § 86.128 of this chapter apply for vehicle transmission operation during highway fuel economy testing under this subpart.

(d) Road load power and inertia weight determination—§ 86.129 of this chapter applies for determination of road load power and inertia weight for highway fuel economy testing.

(e) Vehicle preconditioning—The Highway Fuel Economy Dynamometer Procedure is designed to be performed immediately following the Federal Emission Test Procedure, §§ 86.127 through 86.138 of this chapter. When conditions allow, the tests should be scheduled in this sequence. In the event the tests cannot be scheduled within three hours of the Federal Emission Test Procedure (including one hour hot soak evaporation loss test, if applicable) the vehicle should be preconditioned as in paragraph (e) (1) or (2) of this section, as applicable.

(1) If the vehicle has experienced more than three hours of soak (68° F–86° F) since the completion of the Federal Emission Test Procedure, or has experienced periods of storage outdoors, or in environments where soak temperature is not controlled to 68° F–86° F, the vehicle must be preconditioned by operation on a dynamometer through one cycle of the EPA Urban Dynamometer Driving Schedule, § 86.115 of this chapter.

(2) In unusual circumstances where additional preconditioning is desired by the manufacturer, the provisions of paragraph (a)(3) of § 86.132 of this chapter apply.

(f) Highway Fuel Economy Dynamometer Procedure—

(1) The dynamometer procedure consists of two cycles of the Highway Fuel Economy Driving Schedule (§ 600.109 (b)) separated by 15 seconds of idle. The first cycle of the Highway Fuel Economy Driving Schedule is driven to precondition the test vehicle and the second is driven for the fuel economy measurement.

(2) The provisions of paragraphs (b), (c), (e), (f), (g), and (h) of § 86.135 *Dynamometer procedure* of this chapter, apply for highway fuel economy testing.

(3) Only one exhaust sample and one background sample are collected and analyzed for hydrocarbons (except diesel hydrocarbons which are analyzed continuously), carbon monoxide, and carbon dioxide.

(4) The fuel economy measurement cycle of the test includes two seconds of idle indexed at the beginning of the second cycle and two seconds of idle indexed at the end of the second cycle.

(g) Engine starting and restarting—

(1) If the engine is not running at the initiation of the highway fuel economy test (preconditioning cycle), the start-up procedure must be according to the manufacturer's recommended procedures.

(2) False starts and stalls during the preconditioning cycle must be treated as in paragraphs (d) and (e) of § 86.136 of this chapter. If the vehicle stalls during the measurement cycle of the highway fuel economy test, the test is voided, corrective action may be taken according to § 86.077–25 of this chapter, and the vehicle may be rescheduled for test. The person taking the corrective action shall report the action so that the test records for the vehicle contain a record of the action.

(h) Dynamometer Test Run—The following steps must be taken for each test:

(1) Place the drive wheels of the vehicle on the dynamometer. The vehicle may be driven onto the dynamometer.

(2) Open the vehicle engine compartment cover and position the cooling fan(s) required. Manufacturers may request the use of additional cooling fans for additional engine compartment or under-vehicle cooling and for controlling high tire or brake temperatures during dynamometer operation.

(3) Preparation of the CVS must be performed before the measurement highway driving cycle.

(4) Equipment preparation—The provisions of paragraphs (b) (3) through (5) inclusive of § 86.137 of this chapter apply for highway fuel economy test except that only one exhaust sample collection bag and one dilution air sample collection bag need be connected to the sample collection systems.

(5) Operate the vehicle over one Highway Fuel Economy Driving Schedule cycle according to the dynamometer driving schedule specified in paragraph (b) of § 600.109.

(6) When the vehicle reaches zero speed at the end of the preconditioning cycle, the driver has 13 seconds to prepare for the emission measurement cycle of the test. Reset and enable the roll revolution counter.

(7) Operate the vehicle over one Highway Fuel Economy Driving Schedule cycle according to the dynamometer driving schedule specified in paragraph (b) of § 600.109 while sampling the exhaust gas.

(8) Sampling must begin two seconds before beginning the first acceleration of the fuel economy measurement cycle and must end two seconds after the end of the deceleration to zero. At the end of the deceleration to zero speed, the roll or shaft revolutions must be recorded.

Appendix C

Mathematical Computations

Mathematical Proof

Problem:

Prove that the percent difference between the first and third cycle is less than or equal to the sum of the percent difference between the first and second cycle and the percent difference between the second and third cycle.

Let X = F.E. value for first cycle
Y = F.E. value for second cycle
Z = F.E. value for third cycle

Prove that

$$\frac{Z - X}{Z} \leq \frac{Z - Y}{Z} + \frac{Y - X}{Y}$$

Proof:

$$\frac{Z - X}{Z} = \frac{Z - Y + Y - X}{Z}$$

$$= \frac{Z - Y}{Z} + \frac{Y - X}{Z}$$

Since $Z \geq Y$, then $\frac{Y - X}{Z} \leq \frac{Y - X}{Y}$

so $\frac{Z - X}{Z} = \frac{Z - Y}{Z} + \frac{Y - X}{Z} \leq \frac{Z - Y}{Z} + \frac{Y - X}{Y}$

therefore

$$\frac{Z - X}{Z} \leq \frac{Z - Y}{Z} + \frac{Y - X}{Y}$$