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The IM240 Transient I/M Dynamometer Driving Schedule and The Composite I/M Test Procedure

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Table of Contents

1.0 Introduction

The United States Environmental Protection Agency (EPA) is evaluating new test procedures for use as Inspection/Maintenance (I/M) tests. Two tests under consideration are the IM240, a new driving schedule developed by the U.S. EPA, and the CDH-226, a driving schedule developed earlier by the Colorado Department of Health. EPA's focus on these procedures as possible alternatives to current I/M tests has aroused interest. The purpose of this document is to provide descriptive information about these tests to the I/M community. Statistical results from the first year of testing on the IM240 and the CDH-226 will be published later.

This document also provides information on EPA's Composite I/M Test Procedure (CITP), a lengthy testing sequence designed to evaluate the effectiveness of a large number of potential alternative I/M tests, including the IM240 and the CDH-226.

The IM240 and CDH-226 driving schedules are both based on EPA's Federal Test Procedure (FTP), which certifies compliance with federal vehicle emission standards for carbon monoxide (CO), unburned hydrocarbons (HC), and nitrogen oxides (NOx). Since a significant portion of the I/M community is relatively unfamiliar with certification procedures, the following section provides the basic background needed to understand the foundations of the IM240 and the CDH-226.

2.0 Background

In order for vehicle emissions to be controlled effectively, they must be evaluated under real world conditions. With this in mind, the United States has designed its vehicle emission control strategy around tests that measure emissions while replicating actual driving conditions. These tests stem from the development in 1965 of the LA-4 road route, which was designed to approximate a typical morning trip to work in rush-hour traffic in Los Angeles.[1] In 1972, the EPA shortened the LA-4 from 12 to 7.5 miles and adapted it for use in the laboratory on a chassis dynamometer, a device that simulates vehicle load and inertia weight.[2] Since known as the Urban Dynamometer Driving Schedule (UDDS), it is the driving schedule used to conduct the FTP.

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[1] Hass, G. C., Sweeney, M. P., and Pattison, J. N., "Laboratory Simulation of Driving Conditions in the Los Angeles Area," SAE Paper No. 660546, August 1966.

[2] Kruse, R. E. and Huls, T. A., "Development of the Federal Urban Driving Schedule," SAE Paper No. 730553, May 1973.

The FTP is the "golden standard" for determining vehicle emission levels, but it is expensive and time consuming. The EPA has approved six shorter tests for use by I/M programs in their evaluation of in-use vehicle emissions. All six currently approved I/M tests are steady-state (one-speed) tests. Five are unloaded, and one is loaded. These tests are described in the Code of Federal Regulations, Title 40, Part 81, Sections 2209 - 2214. Considerably less resource intensive than the FTP, short tests were designed to provide a more easily used but still reliable method of identifying vehicles that exceed FTP standards.

3.0 The Problem

The short I/M tests do not always correlate well to the FTP, however. Limitations in the tests themselves and, perhaps more importantly, changes in vehicle design have undermined the ability of current short tests to identify a vehicle's excess emissions (i.e., emissions above the federal standards). I/M tests originally were designed for a vehicle fleet that is rapidly being displaced by new technology, computer-controlled vehicles. New technology vehicles are equipped with improved emission control components, such as three-way catalysts, closed-loop fuel control, and fuel injection, which have changed the way vehicles respond to emission tests.[3]

These changes have implications for the future effectiveness of I/M programs. The effectiveness of short emission tests can be expressed in terms of overall failure rate, excess emissions identified (identification rate), errors of commission, and errors of omission. Errors of commission (Ec), or false failures, occur when vehicles fail an I/M test but pass the FTP. Errors of omission (Eo), or false passes, occur when vehicles pass the I/M test but fail the FTP. Based on these measures, EPA studies indicate that current short tests have become less effective in identifying excess emissions since the introduction of new technology vehicles in 1981. The challenge now is to ensure that I/M tests keep pace with changing technology so that they remain an effective tool for vehicle emission control.

4.0 Old Technology versus New Technology

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[3] Armstrong, J., Brzezinski, D. J., Landman, L., and Glover, E. L., "Inspection/Maintenance in the 1990's," SAE Paper No. 870621, February 1987.

Old technology, pre-computer-controlled vehicles have emission-related components that operate on a continuum. For example, if the air-fuel mixture at idle is too rich, then the air-fuel mixture is likely to be too rich across much of the operating range of the vehicle (i.e., cruise, acceleration, deceleration). For this reason a test performed only at idle or only at 30 mph is likely to identify pre-computer-controlled vehicles that malfunction to a sufficient degree to fail the FTP test also. This continuum characteristic is an inherent feature of many mechanically controlled systems, including other emission-control components like the ignition system’s distributor, which controls the ignition timing.

The newer, computer-controlled vehicles that are becoming an ever larger fraction of the fleet are not constrained by the continuum characteristic of mechanical devices. A computer can include discrete instructions for the air-fuel mixture at idle that have little bearing on the mixture at 30 mph or during an acceleration from 10 mph to 20 mph. For this reason, a vehicle with low emissions at idle or 2500 rpm or 30 mph can in principal have unacceptably high emissions during other modes. Furthermore, EPA studies show that some vehicles with very high FTP emissions do indeed pass a steady-state test, such as an idle test. By the same logic, a vehicle with high idle emissions may pass the FTP because the emissions are low through most of the vehicle’s other operating modes. An idle test falsely fails such vehicles. Transient tests, on the other hand, are responsive to changing emission levels during different modes of vehicle operation and thus overcome the limitations of steady-state testing on computer-controlled vehicles.

5.0 IM240 versus CDH-226

In the face of changing technology, EPA’s objective was to find a short transient test that would identify high emitting vehicles as defined by their FTP emissions, while minimizing errors of commission. Initially, the CDH-226[4] seemed to offer the best possibility for a viable I/M test. Since then, EPA has developed the IM240 as a possible improvement on the CDH-226.

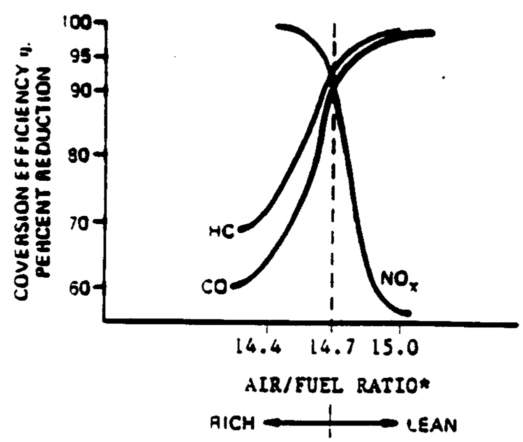
A characteristic of the CDH-226 that stands out when compared to the UDDS is that the CDH-226 is smoother (i.e., less transient), so it

[4] Ragazzi, R. A., Stokes, J. T., and Gallagher, G. L., "An Evaluation of a Colorado Short Vehicle Emission Test (CDH-226) in Predicting Federal Test Procedure (FTP) Failures," SAE Paper No. 852111, October 1985.

requires less throttle action (see Figure 1 on page 5). Throttle action is an important variable affecting vehicle emissions and could be important in identifying malfunctioning vehicles.

Take oxygen sensor operation as an example. As oxygen sensors deteriorate, their response time lags. This deteriorating response time can allow the air-fuel mixture to increasingly deviate from stoichiometric (14.7:1), the ratio at which 3-way catalysts most efficiently oxidize HC and CO and simultaneously reduce NOx (see Figure 2 below). This is important because three-way catalyst conversion efficiency rapidly deteriorates with air-fuel mixture deviations from stoichiometric. During steady-state operation, the fuel metering system adjusts to deliver a stoichiometric mixture, which should stay relatively constant. Throttle movement often causes the mixture to change, and as throttle action increases, the ability of the metering system to maintain stoichiometry becomes increasingly dependent on the response time of the oxygen sensor. A highly transient driving schedule requires more throttle action than a smooth schedule, so a deteriorated oxygen sensor is more likely to be identified on a highly transient schedule than on a smooth schedule. The same logic can also be extended to other components of emission control systems. A driving schedule can be made too transient, however. An I/M test requiring more throttle action than the UDDS might unacceptably increase test variability and thereby increase the error of commission rate.

Figure 2: Air-Fuel Ratios and Conversion Efficiency

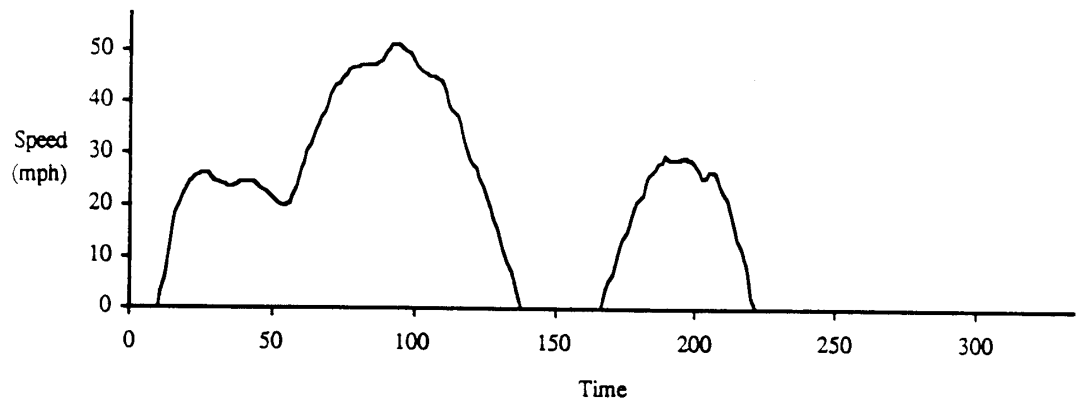


*Converted from equivalence ratios used in the original.

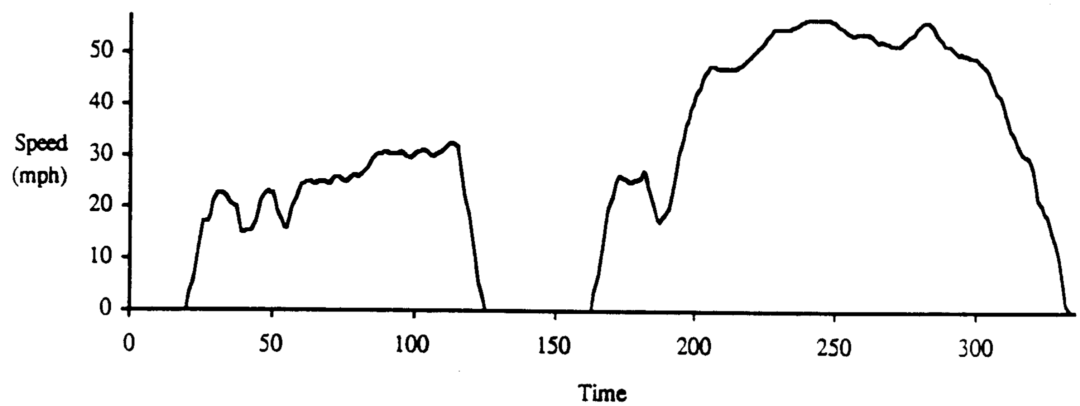
Source: Rivard, J. G., "Closed-Loop Electronic Fuel Injection Control of the Internal Combustion Engine," SAE Paper No. 730005, January 1973, p. 4.

Figure 1: Comparison of Dynamometer Driving Schedules

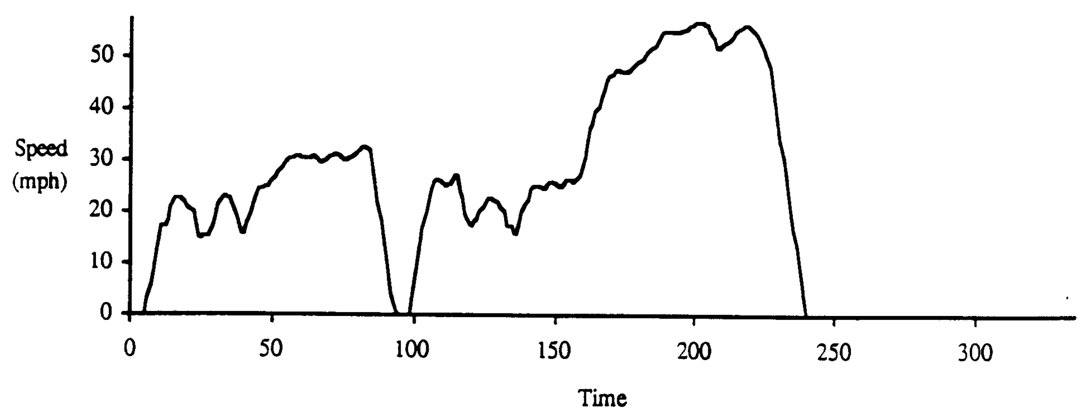
CDH-226 Driving Schedule



Hills 1 & 2 of the Urban Dynamometer Driving Schedule



IM240 Driving Schedule



For these reasons, EPA decided to develop a more transient alternative to the CDH-226, to make the new test similar to the UDDS, and to evaluate both procedures to determine which is better for I/M testing. EPA’s alternative was dubbed the IM240 since it was designed for I/M testing with a duration of 240 seconds.

6.0 IM240 Description

The IM240 driving schedule is depicted graphically in Figure 1. Appendix 1 provides a speed-versus-time table in one-second increments. The table also lists the UDDS segments that were used to create the IM240.

The IM240 was patterned closely on the first two "hills" of the UDDS. It uses actual segments of the UDDS and incorporates the UDDS's peak speed of 56.7 miles per hour. Testing over the entire range of speeds was considered important to detect malfunctioning vehicles given the discontinuous operating characteristics of computer-controlled vehicles. Using actual segments of the UDDS was considered important to help improve correlation and minimize errors of commission and errors of omission.

The two large decelerations from hills 1 and 2 are the only segments that were not taken directly from the UDDS. The deceleration rate for both hills was set at 3.5 mph/sec, whereas the maximum deceleration rate from the UDDS is 3.3 mph/sec. The higher deceleration rate prevents the IM240 from exceeding four minutes, which was taken somewhat arbitrarily to be a measurable upper limit for a test time that would allow an adequate rate of vehicle processing, or throughput. The 3.5 mph/sec rate, which has been used successfully in the CDH-226, also allows time for an idle and an additional transient portion on hill 2 (between 140 seconds and 158 seconds).

As seen in Appendix 2, the IM240 differs statistically from the CDH-226. Because of differences in design, it was speculated that one of the tests might correlate better than the other to the FTP.

The IM240 test is run in two segments. The shorter segment is 94 seconds in duration, which was an informed guess as to the minimum amount of time needed to realize significant improvements in FTP correlation. For comparison, EPA has divided the CDH-226 into two segments as well, the shorter segment being 86 seconds. By dividing each test into two parts, EPA can evaluate the effectiveness of the entire test as well as the effectiveness of each of the shorter segments.

The test procedure stipulates that the engine is running with the transmission in gear before the driving schedule begins. Exhaust sampling begins simultaneously with the start of the driving schedule.

IM240 testing is being performed separately and in conjunction with other short tests, including the CDH-226, in the Composite I/M Test Procedure, which is described below.

7.0 Composite I/M Test Procedure

The EPA has devised the multi-purpose Composite I/M Test Procedure (CITP) to evaluate the effectiveness of the IM240, the CDH-226, and potential steady-state alternatives to current I/M tests. The goal of the program is to identify emission tests which balance the need for high FTP correlation and high identification rates against cost, equipment, and time requirements. Acceptable alternative tests would be sophisticated enough to measure the emissions of new technology vehicles adequately while conforming to the constraints of an I/M program.

CITP testing is being performed at EPA's Motor Vehicle Emission Laboratory (MVEL) in Ann Arbor, Michigan and under contract at the Automotive Testing Laboratories (ATL) facility in New Carlisle, Indiana, just outside of South Bend. All Emission Factor Program[5] test vehicles receive the CITP after the as-received FTP test on Indolene test fuel.

7.1 Dynamometer Settings

The CITP sequence consists of 11 test modes run over 77 minutes. At EPA's lab, the CITP is divided into two parts, A and B, which differ by the dynamometer settings used (see Table 1). (Because of different equipment configurations, testing at the ATL facility is done in four parts.) Part A is performed using the certification dynamometer settings, which require an expensive multiple curve dynamometer and a complicated process for determining the proper road load and inertia weight settings for each vehicle. In Part B, the dynamometer settings are limited in order to evaluate the tradeoff between cost and FTP correlation that is associated with less sophisticated dynamometers.

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[5] The Emission Factor Program tests vehicles owned by the general public. Data from these in-use vehicles are used with a computer model known as MOBILE4 to calculate the emission rates of in-use vehicles. These emission rates are then used with air quality models to estimate the contribution of mobile source emissions to ambient air pollution.

Table 1

Modes of the Composite I/M Test Procedure for use with Emission Factors Vehicles										
SEGMENT NO	NAME	MODE	TYPE		DYNO	PAU	SAMP	MODE DUR	CUM DUR	NOTES
1	IM240 (2x)	IM240	Trans	Loaded	Cert	Cert	Raw	4	4	Warmup; compare raw vs CVS sampling
		IM240	"	"	"	"	"	4	8	
2	IM240	IM240	Trans	Loaded	Cert	Cert	CVS+Raw	4	12	High throttle action transient
3	SS Series	20 mph	Stdy St	Loaded	Cert	Cert	Raw	2	14	Compare var-PAU/fixed-spd & var-PAU/var-spd
		Idle-N	"	Unloaded	"	"	"	1	15	Modes: 20/I/30/I/40/I/50/I @2 min/cruise,1 min/I
		30 mph	"	Loaded	"	"	"	2	17	
		Idle-N	"	Unloaded	"	"	"	1	18	
		40 mph	"	Loaded	"	"	"	2	20	
		Idle-N	"	Unloaded	"	"	"	1	21	
		50 mph	"	Loaded	"	"	"	2	23	
		Idle-N	"	Unloaded	"	"	"	1	24	
4	IM240	IM240	Trans	Loaded	Cert	Cert	CVS+Raw	4	28	Warmup
5	CDH226	CDH226	Trans	Loaded	Cert	Cert	CVS+Raw	4	32	Moderate throttle action transient
	TECH BREAK		N/A					10		
6	SS50	50 mph	Stdy St	Loaded	2-IW	Cert	Raw	3	3	Warmup
7	CDH226	CDH226	Trans	Loaded	2-IW	Cert	CVS+Raw	4	7	Compare cert IW to simple IW approach
8	2-Mode Idle	Idle-N	Stdy St	Unloaded	N/A	N/A	Raw	0.5	8	Conventional I/M
	Restart	2500 rpm	"	"	"	"	"	0.5	8	
		Idle-N	"	"	"	"	"	1	9	
		Eng. off	"	"	"	"	"	0.2	9	
		2500 rpm	"	"	"	"	"	0.5	10	
		Idle-N	"	"	"	"	"	1	11	
	TECH BREAK		N/A					5		
9	SS50	50 mph	Stdy St	Loaded	2-IW	Cert	Raw	3	3	Warmup
10	IM240	IM240	Trans	Loaded	2-IW	Cert	CVS+Raw	4	7	Compare cert IW to simple IW approach
11	SS Series	20 mph	Stdy St	Loaded	Trim	Clay	Raw	2	9	Compare Clayton single-curve to cert curves
		Idle-N	"	Unloaded	"	"	"	1	10	
		30 mph	"	Loaded	"	"	"	2	12	
		Idle-N	"	Unloaded	"	"	"	1	13	
		40 mph	"	Loaded	"	"	"	2	15	
		Idle-N	"	Unloaded	"	"	"	1	16	
		50 mph	"	Loaded	"	"	"	2	18	
		Idle-N	"	Unloaded	"	"	"	1	19	
			TOTAL					77		

NOTES
1. Clayton loading is 30HP @ 50mph (cubic curve)
2. 50 mph cruise at Clayton loadings may be dropped for small vehicles
3. 2-IW requires IW settings of 2500 or 3500, depending on vehicle
4. Dyno settings will need to be changed prior to steps 6 and 11

vsn 2.2b

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The dynamometer settings in Part B are limited to two possible inertia weight settings of 2500 or 3500 pounds, depending on the weight of the vehicle. Steady-state loaded modes in Part B are performed with only a single setting (30 hp @ 50 mph) for all vehicles to simulate the Clayton single-curve dynamometers. A yet-to-be-completed comparison of test results between parts A and B will help to determine whether the expense of certification-type dynamometers is justified.

7.2 Sampling Methods

The CITP also allows EPA to compare methods of measuring exhaust emissions. The entire CITP series undergoes second-by-second raw exhaust measurements. MVEL uses an Allen BAR-80 specification analyzer to gather and analyze the sample and a Macintosh running EPA’s GAS-4 program for data collection. ATL uses a Gordon-Darby analyzer to analyze the sample and an IBM-compatible computer for data collection.

In addition to raw exhaust measurements, which reveal the concentration of pollutants (percentage or parts per million), loaded transient modes also are analyzed using Constant Volume Sampling (CVS), which reveals mass emissions (grams per mile). Raw exhaust measurements, while less complicated and less expensive than CVS, do not account for differences in the size of the exhaust stream and so do not accurately measure the total mass of pollutants emitted.[6] Constant Volume Sampling, on the other hand, does measure the mass of pollutants but requires complicated and expensive equipment. If certain assumptions are made, mathematical formulas can be applied to raw exhaust measurements so that they can be expressed as approximate mass measurements. By comparing the results of these calculations to the actual CVS readings, the accuracy of the calculated mass results can be

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[6] CVS measurements provide a much better indication of vehicle emission levels than raw exhaust measurements. A raw exhaust reading of 200 ppm HC from a small motorcycle and the same 200 ppm reading from a large truck (which is entirely possible) suggest that the two vehicles pollute equally. However, such a conclusion is wrong. The truck will have a much higher volume of exhaust. Over a given one-mile drive, the motorcycle may only emit 50 cubic feet of exhaust gases, whereas the truck may emit 500 cubic feet. With both vehicles emitting 200 ppm HC over the mile, the total amount of HC emitted by the truck will be 10 times greater than the amount emitted by the motorcycle. A Constant Volume Sampler allows the total emissions per mile to be measured; a raw exhaust analyzer does not.

determined. If the identification rates, errors of commission, and errors of omission from the raw exhaust calculations compare favorably to the CVS readings, use of the less expensive, less complicated raw exhaust method may be justified.

7.3 CITP Steady-State Modes

In addition to the IM240 and the CDH-226, the CITP includes a loaded steady-state test at 50 mph (SS50), a two-mode idle restart test, and a steady-state series. The steady-state test at 50 mph is run for three minutes as a warm-up for the IM240 and the CDH-226. The two-mode idle segment is approximately four minutes in duration. This test consists of an engine restart inserted between sequences of idle and 2500 rpm operation. The two-mode idle was included in the CITP because it is representative of tests currently being used in many I/M programs.

The steady state series contains loaded modes at 20, 30, 40, and 50 mph separated by an idle. This series represents an intermediate step between the idle test and the loaded transient schedule. Its advantages over loaded transient cycles include the cost savings of raw gas versus CVS analyzers and of single versus multiple curve dynamometers. In addition, unlike loaded transient cycles, the steady-state series does not require the use of driving schedules or related equipment or technician skills.[7]

8.0 Summary

Changes in vehicle technology have created the need for more sophisticated I/M tests. In response to this need, the EPA has developed the IM240, a short transient test, as a possible alternative to current I/M tests. The EPA is evaluating the IM240 as well as the CDH-226 and several steady-state tests in the Composite I/M Test Procedure. CITP testing is ongoing, and the results will be published at a later date.

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[7] McCargar, J., Memorandum to Richard D. Lawrence, October 19, 1989, U.S. EPA, Emission Control Technology Division, Technical Support Staff.

Appendix 1

IM240 Speed versus Time Table

Actual Time secs.	UDDS Equiv Time secs.	IM240 Speed mph	IM240 Accel Rate mph/sec
0*	16	0	
1	17	0	0
2	18	0	0
3	19	0	0
4	20	0	0
5	21	3	3
6	22	5.9	2.9
7	23	8.6	2.7
8	24	11.5	2.9
9	25	14.3	2.8
10	26	16.9	2.6
11	27	17.3	0.4
12	28	18.1	0.8
13	29	20.7	2.6
14	30	21.7	1
15	31	22.4	0.7
16	32	22.5	0.1
17	33	22.1	-0.4
18	34	21.5	-0.6
19	35	20.9	-0.6
20	36	20.4	-0.5
21	37	19.8	-0.6
22	38	17	-2.8
23	39	14.9	-2.1
24	40	14.9	0
25	41	15.2	0.3
26	42	15.5	0.3
27	43	16	0.5
28	44	17.1	1.1
29	45	19.1	2
30	46	21.1	2
31	47	22.7	1.6
32	48	22.9	0.2
33	49	22.7	-0.2
34	50	22.6	-0.1
35	51	21.3	-1.3
36	52	19	-2.3
37	53	17.1	-1.9
38	54	15.8	-1.3
39	55	15.8	0
40	56	17.7	1.9
41	57	19.8	2.1
42	58	21.6	1.8
43	59	23.2	1.6
44	60	24.2	1
45	61	24.6	0.4
46	62	24.9	0.3
47	63	25	0.1

*Engine is running and transmission is in gear before driving schedule and exhaust sampling begin.

Actual Time secs.	UDDS Equiv Time secs.	IM240 Speed mph	IM240 Accel Rate mph/sec	
48	80	25.7	0.7	
49	81	26.1	0.4	
50	82	26.7	0.6	
51	83	27.5	0.8	
52	84	28.6	1.1	
53	85	29.3	0.7	
54	86	29.8	0.5	
55	87	30.1	0.3	
56	88	30.4	0.3	
57	89	30.7	0.3	
58	90	30.7	0	
59	91	30.5	-0.2	
60	92	30.4	-0.1	
61	93	30.3	-0.1	
62	94	30.4	0.1	
63	95	30.8	0.4	
64	96	30.4	-0.4	
65	97	29.9	-0.5	
66	98	29.5	-0.4	
67	99	29.8	0.3	
68	100	30.3	0.5	
69	101	30.7	0.4	
70	102	30.9	0.2	
71	103	31	0.1	
72	104	30.9	-0.1	
73	105	30.4	-0.5	
74	106	29.8	-0.6	
75	107	29.9	0.1	
76	108	30.2	0.3	
77	109	30.7	0.5	
78	110	31.2	0.5	
79	111	31.8	0.6	
80	112	32.2	0.4	
81	113	32.4	0.2	
82	114	32.2	-0.2	
83	115	31.7	-0.5	
84	116	28.6	-3.1	
85		25.1	-3.5	
86		21.6	-3.5	
87		18.1	-3.5	
88		14.6	-3.5	
89		11.1	-3.5	
90		7.6	-3.5	
91		4.1	-3.5	
92		0.6	-3.5	
93		0	-0.6	
94		0	0	Bag 2
95		0	0	
96		0	0	
97	163	0	0	
98	164	3.3	3.3	
99	165	6.6	3.3	

Actual Time secs.	UDDS Equiv Time secs.	IM240 Speed mph	IM240 Accel Rate mph/sec
100	166	9.9	3.3
101	167	13.2	3.3
102	168	16.5	3.3
103	169	19.8	3.3
104	170	22.2	2.4
105	171	24.3	2.1
106	172	25.8	1.5
107	173	26.4	0.6
108	174	25.7	-0.7
109	175	25.1	-0.6
110	176	24.7	-0.4
111	178	25.2	0.5
112	179	25.4	0.2
113	181	27.2	1.8
114	182	26.5	-0.7
115	183	24	-2.5
116	184	22.7	-1.3
117	185	19.4	-3.3
118	186	17.7	-1.7
119	187	17.2	-0.5
120	188	18.1	0.9
121	189	18.6	0.5
122	190	20	1.4
123	29	20.7	0.7
124	30	21.7	1
125	31	22.4	0.7
126	32	22.5	0.1
127	33	22.1	-0.4
128	34	21.5	-0.6
129	35	20.9	-0.6
130	36	20.4	-0.5
131	37	19.8	-0.6
132	38	17	-2.8
133	53	17.1	0.1
134	54	15.8	-1.3
135	55	15.8	0
136	56	17.7	1.9
137	57	19.8	2.1
138	58	21.6	1.8
139	191	22.2	0.6
140	192	24.5	2.3
141	66	24.7	0.2
142	67	24.8	0.1
143	68	24.7	-0.1
144	69	24.6	-0.1
145	70	24.6	0
146	71	25.1	0.5
147	72	25.6	0.5
148	73	25.7	0.1
149	74	25.4	-0.3
150	75	24.9	-0.5
151	76	25	0.1

Actual Time secs.	UDDS Equiv Time secs.	IM240 Speed mph	IM240 Accel Rate mph/sec
152	77	25.4	0.4
153	78	26	0.6
154	79	26	0
155	80	25.7	-0.3
156	81	26.1	0.4
157	82	26.7	0.6
158	193	27.3	0.6
159	194	30.5	3.2
160	195	33.5	3
161	196	36.2	2.7
162	197	37.3	1.1
163	198	39.3	2
164	199	40.5	1.2
165	200	42.1	1.6
166	201	43.5	1.4
167	202	45.1	1.6
168	203	46	0.9
169	204	46.8	0.8
170	205	47.5	0.7
171	206	47.5	0
172	207	47.3	-0.2
173	208	47.2	-0.1
174	214	47.2	0
175	215	47.4	0.2
176	216	47.9	0.5
177	217	48.5	0.6
178	218	49.1	0.6
179	219	49.5	0.4
180	220	50	0.5
181	221	50.6	0.6
182	222	51	0.4
183	223	51.5	0.5
184	224	52.2	0.7
185	225	53.2	1
186	226	54.1	0.9
187	227	54.6	0.5
188	228	54.9	0.3
189	229	55	0.1
190	230	54.9	-0.1
191	231	54.6	-0.3
192	232	54.6	0
193	233	54.8	0.2
194	234	55.1	0.3
195	235	55.5	0.4
196	236	55.7	0.2
197	237	56.1	0.4
198	238	56.3	0.2
199	239	56.6	0.3
200	240	56.7	0.1
201	241	56.7	0
202		56.3	-0.4
203		56	-0.3

Actual Time secs.	UDDS Equiv Time secs.	IM240 Speed mph	IM240 Accel Rate mph/sec
204		55	-1
205		53.4	-1.6
206	271	51.6	-1.8
207	272	51.8	0.2
208	273	52.1	0.3
209	274	52.5	0.4
210	275	53	0.5
211	276	53.5	0.5
212	277	54	0.5
213	278	54.9	0.9
214	279	55.4	0.5
215	280	55.6	0.2
216	281	56	0.4
217	282	56	0
218	283	55.8	-0.2
219	284	55.2	-0.6
220	285	54.5	-0.7
221	286	53.6	-0.9
222	287	52.5	-1.1
223	288	51.5	-1
224		50.5	-1
225		48	-2.5
226		44.5	-3.5
227		41	-3.5
228		37.5	-3.5
229		34	-3.5
230		30.5	-3.5
231		27	-3.5
232		23.5	-3.5
233		20	-3.5
234		16.5	-3.5
235		13	-3.5
236		9.5	-3.5
237		6	-3.5
238		2.5	-3.5
239		0	-2.5

Appendix 2

Comparative Statistics
IM240, UDDS, CDH-226

Idle Modes

	Number of Idle Periods (sec)	Percent of Total Schedule	Length of First Idle (sec)	Average Idle Time (sec)	Standard Deviation Idle Time
IM240	2.0	3.8	4.0	4.5	0.7
UDDS	18.0	19.0	20.0	14.4	10.7
CDH-226	3.0	19.9	10.0	15.0	12.3

Speeds

	Average Speed (mph)	Average Speed Without Idle Modes (mph)	Maximum Speed (mph)
IM240	30.0	30.8	56.7
UDDS	19.6	24.1	56.7
CDH-226	22.3	27.9	51.3

10 mph Segments

Percent of Driving Schedule in each 10 mph Range
(without idle modes)

	0-10 mph	10-20 mph	20-30 mph	30-40 mph	40-50 mph	50-60 mph
IM240	5.2	18.3	34.3	13.9	8.7	19.1
UDDS	13.8	19.2	45.9	11.0	3.4	6.6
CDH-226	9.4	12.7	46.4	8.3	19.9	3.3

Average Rate of Acceleration (mph/sec)

	0-10 mph	10-20 mph	20-30 mph	30-40 mph	40-50 mph	50-60 mph
IM240	3.1	1.6	0.83	0.86	0.85	0.43
UDDS	2.3	1.8	0.72	0.67	0.80	0.38
CDH-226	2.3	2.0	0.74	1.4	0.53	0.57

Average Rate of Deceleration (mph/sec)

	0-10 mph	10-20 mph	20-30 mph	30-40 mph	40-50 mph	50-60 mph
IM240	3.5	2.3	1.1	1.2	2.0	0.79
UDDS	2.4	2.1	0.81	0.54	0.61	0.42
CDH-226	2.0	1.7	0.70	1.4	0.61	0.40