EPA-AA-TSS-91-1

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

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January 1991

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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.

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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.

4.0 Old Technology versus New Technology

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.

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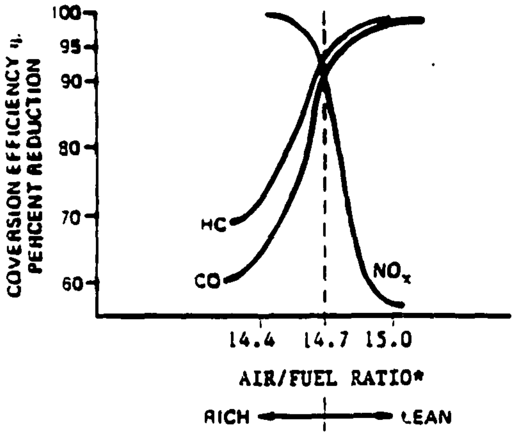
[4] Ragazzi, R. A., Stokes, J. T., and Gallagher, G. L., "An Evaluation of a Colorado Short Vehicle Emission Test (CDH-226) in Predicting Federal Test Procedure (FTP) Failures," SAE Paper No. 852111, October 1985.

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 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.

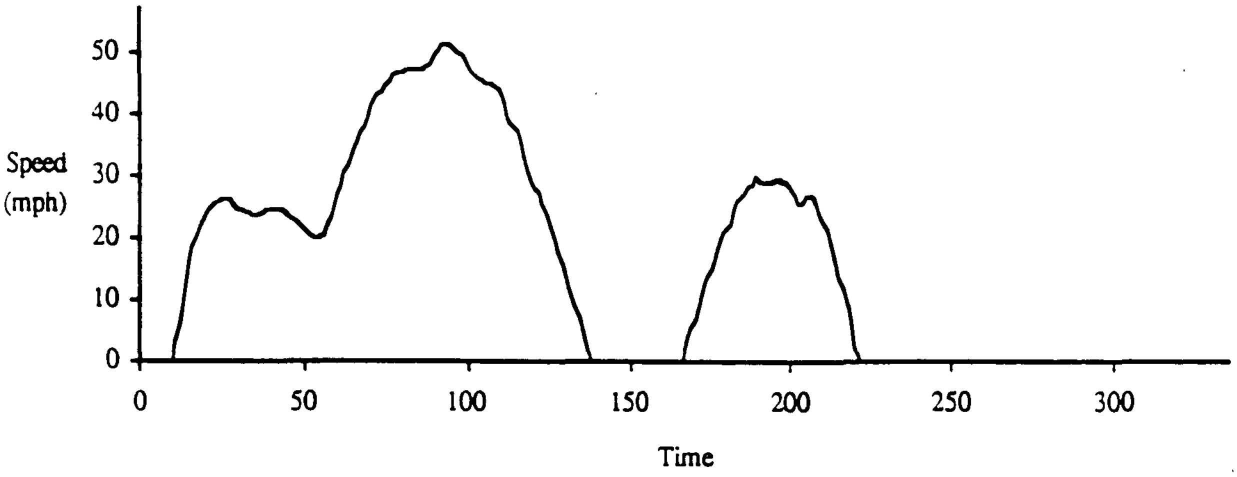
Figure 2: Air-Fuel Ratios and Conversion Efficiency

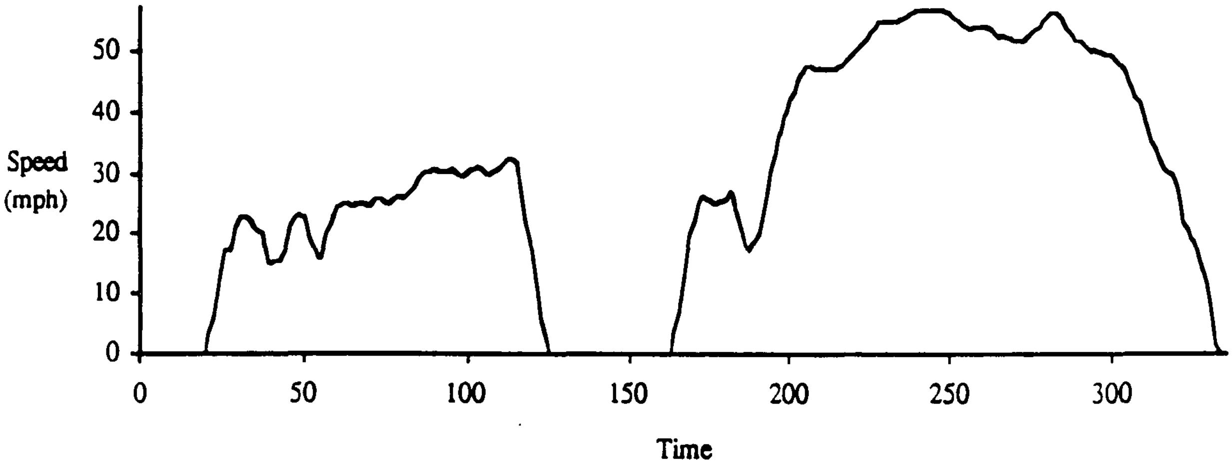


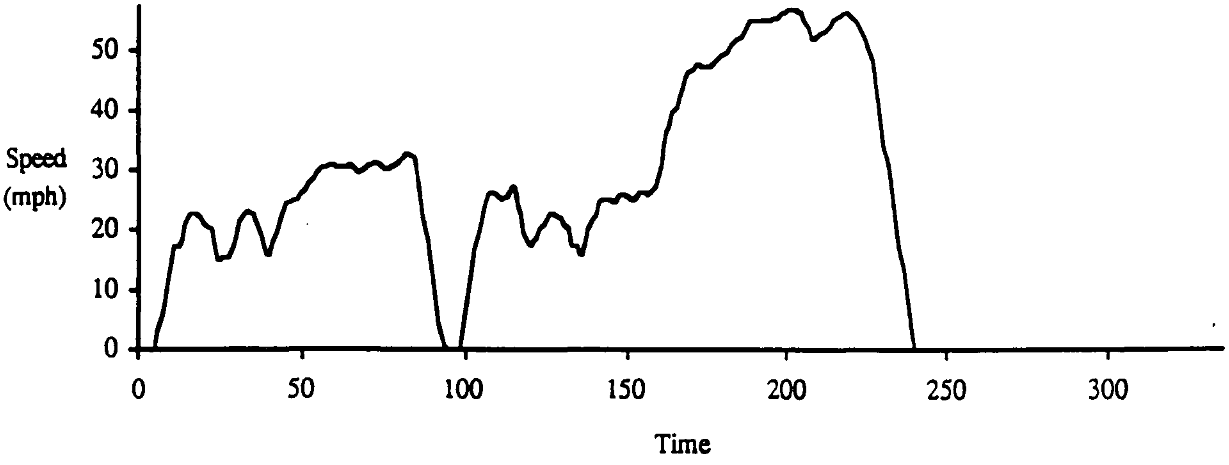
*Converted from equivalence ratios used in the original.

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.

Modes of the Composite I/M Test Procedure
for use with Emission Factors Vehicles

	SEGMENT								MODE	CUM	
	NO	NAME	MODE	TYPE		DYNO	PAU	SAMP	DUR	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	
A			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	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	
B		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

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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

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

EPA-AA-TSS-91-1

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

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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.

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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.

4.0 Old Technology versus New Technology

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.

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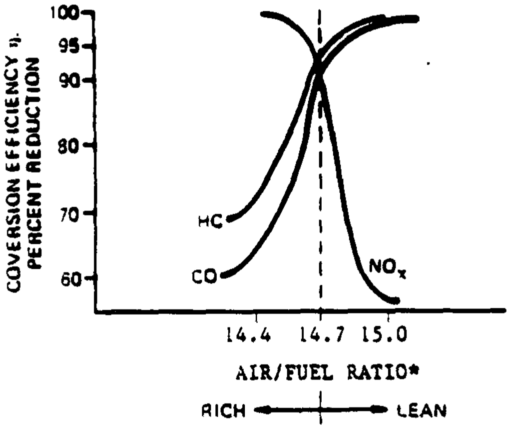
[4] Ragazzi, R. A., Stokes, J. T., and Gallagher, G. L., "An Evaluation of a Colorado Short Vehicle Emission Test (CDH-226) in Predicting Federal Test Procedure (FTP) Failures," SAE Paper No. 852111, October 1985.

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 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

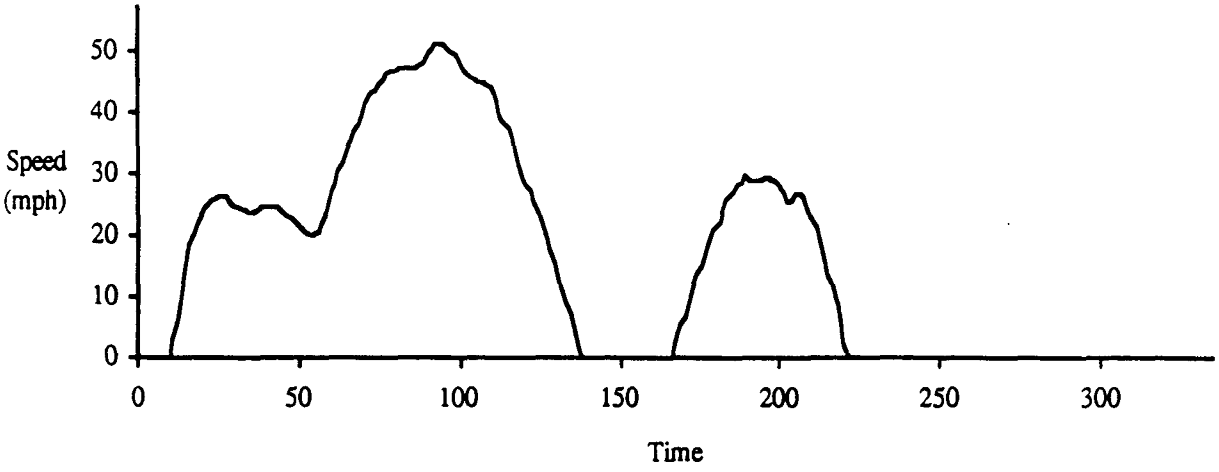


*Converted from equivalence ratios used in the original.

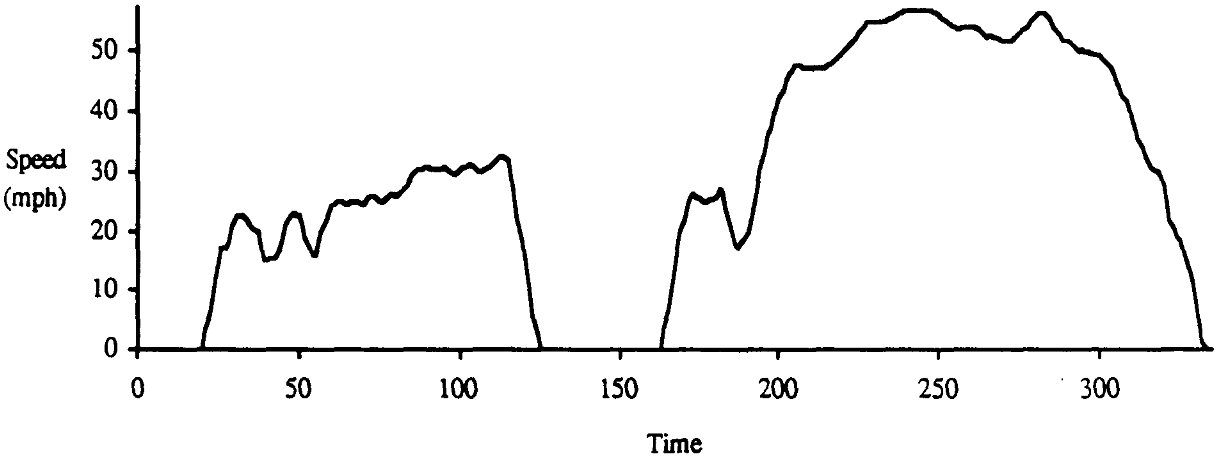
Source: Rivard, J. G., "Closed-Loop Electronic Fuel Injection Control of the Internal Combustion Engine," SAE Paper No. 730005, January 1973, p. 4.

Figure 1: Comparison of Dynamometer Driving Schedules

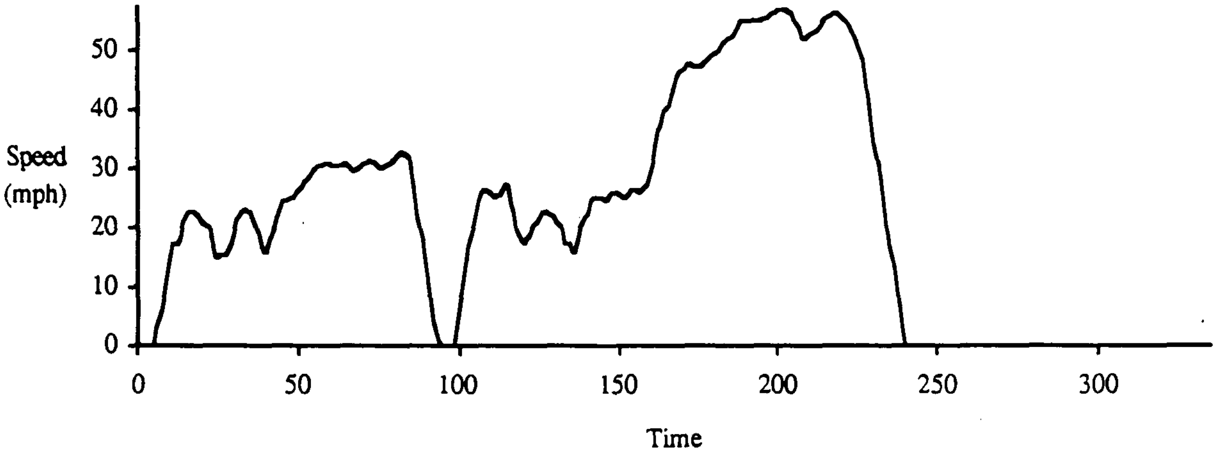
CDH-226 Driving Schedule



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.

ATTACHMENTS

<u>*ATTACHMENT A*</u>

Specifications for Electric Chassis Dynamometers

U.S. Environmental Protection Agency

Motor Vehicle Emission Laboratory
2565 Plymouth Road
Ann Arbor, MI 48105

ATTACHMENT A
RFP C100081T1
37 Pages

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Appendices:

1.0 General Features

Federal regulations for exhaust emissions and fuel economy of motor vehicles specify tests using chassis dynamometers. The purpose of the chassis dynamometer is to duplicate the forces encountered by a vehicle moving on a road by modeling those characteristics with a stationary vehicle on a rotating surface. EPA envisions a variety of testing needs to address future regulations. A key feature of the recent Clean Air Act Amendments is that the test conditions appropriately simulate "real-world" conditions.

The optimal dynamometer utilizes the latest technology through a digitally-controlled, electrically-activated, motor-absorber that supplements mechanical inertia, optional flywheels, and frictional forces with electrical load forces based on specific equations and coefficients. The test cell, dynamometer, and vehicle operate as a system under various ambient conditions to provide maximum flexibility and ease of operation. In all cases, the loading capabilities, control algorithms and other operating characteristics of these dynamometers must be able to accurately and precisely simulate the forces encountered by a vehicle on the road.

While twin roll dynamometers have traditionally been used at MVEL for most testing, this acquisition allows vehicle loading by means of either a twin roll or single roll configuration if the performance specifications contained herein are met. The twin roll configuration shall have synchronous roll speeds and shall apply the total load force through a symmetrically balanced design so that the forces at the roll/tire contact points contribute uniformly to the total simulation of the road forces. The single roll dynamometer shall have a 48" diameter roll and shall be the system configuration installed in the Cold Test Facility (CTF) at a minimum.

The chassis dynamometer shall conform to the requirements specified herein.

1.1 Equipment

The dynamometer shall be designed and constructed to be capable of operating on a continuous basis (24 hours per day, 7 days per week). It shall withstand all static and dynamic loads which are encountered during vehicle testing, and shall not produce any vibrations which may impair the operation of the vehicle or dynamometer.

The dynamometer components shall be capable of withstanding shock loading from maximum acceleration/deceleration forces, such as locked vehicle brake at 60 mph, wide open throttle (WOT), emergency shutdown, or any system malfunction(s) that induces abrupt forces, without damage to any component(s).

The dynamometer system shall consist of the following components, at a minimum, arranged in a configuration that optimizes the physical dimensions, system response characteristics, and flexibility to simulate various loading schemes:

- the roll(s) in a structure or frame suitable for this application
- a vehicle inertia simulation system
- an electric motor-absorber system
- all pneumatic and/or hydraulic components
- all operator and driver interface panels, displays, controls, and interface wiring for the computer system
- all calibration devices
- a means to ensure safe and efficient installation and removal of the vehicle
- a vehicle restraint system to limit the dynamic lateral and fore/aft travel of the vehicle

- safety equipment, including noise and EFI suppression
- all electrical cabling, piping, tubing, and cabinets
- installation, checkout, and warranty
- complete documentation including construction, installation, operation, service, parts, etc.

Additional details of these requirements are contained in other paragraphs throughout this document.

The dynamometers shall be installed in the test cells as specified by Delivery Order, which shall include a test cell configuration plan.

Repair service and spare parts shall be available within one working day of request during the one year warranty period.

1.2 Component Preparation

All surfaces of the dynamometer system shall be treated with protective coatings (such as plating, primers, epoxy, etc.) or made from materials that will prevent rust, scaling, flaking, or chalking under all the operating conditions of the test cell environment.

Rotating parts such as roll(s), flywheels or shafts, and other non-paintable parts, shall be protected from corrosion by applying suitable treatments.

1.3 Documentation

Five (5) copies of the documentation of the dynamometer system shall be provided to the Project Officer upon delivery of each dynamometer. The documentation shall be in English and shall include, at a minimum, the following:

- the dynamometer mechanical layout
- schematics of all pneumatic and hydraulic components
- color coded and/or numbered schematics and wiring lists of all electric components
- technical and operational manual(s), including a complete description of the system control algorithms, performance measures, calibration procedures, system hardware and software operation, response characteristics and system source code.
- parts list(s)
- recommended, on-hand, spare parts list
- maintenance and calibration instructions

The operation manual(s) shall include complete information on the dynamometer's functions, capabilities and user interface procedures.

The parts list shall include, at a minimum, the following:

- All subcontractors' parts, to enable the government to obtain precise information, including addresses and phone numbers
- The model and/or part number designations of all component parts

One set of recommended on-hand spare parts shall be supplied, at time of installation, for each dynamometer provided. As an option, the contractor may guarantee delivery of these parts per the one working day time period specified in Section 1.1.

1.4 Ambient Operating Conditions

The dynamometer shall be used to test vehicles exposed to the following ambient conditions: (See Note)

test cell temperature:	0 to +110 °F
relative humidity:	0 to 90%
altitude:	up to 3,300 feet for all units except the Denver location

Note: The dynamometer performance shall not be affected by the conditions applied to the vehicle test environment. The vehicle test environment and dynamometer operating environment may be separately controlled spaces. The objective is to maintain frictional stability and to minimize component exposure to adverse conditions. Air for the temperature control of the dynamometer shall be taken from a dry air source so that condensation in the dynamometer system is prevented.

1.5 Electrical Specifications

The system shall operate with the following electrical voltages:

120 V (± 10%)	60 Hz	instrumentation only
480 V (± 10%)	60 Hz	(three phase, four wire)

The motor-absorber electrical interface shall be regenerative (i.e., generated power shall be fed back to the grid.)
The equipment shall be grouped into the following sections:

1. electronic and display
2. power

The electronic and display section shall be installed in a standard 19" rack, which may be in a separate cabinet from the power section. The operator interface cabinet shall be located in the dynamometer control room for operator access.

The controls at the electronic and display section shall include, at a minimum:

- emergency stop switch
- operator interface and displays

Two switches shall also be accessible from the vehicle driver's seat door. If these switches are operable from the control room, a safety interlock or alert to the driver shall be installed.

- vehicle alignment switch
- lift platform switch
- roll brake switch

The minimum requirements for instrumentation at the power section are as follows:

- emergency stop switch
- main power switch
- armature-current display (may be installed inside the cabinet)
- armature-voltage display (may be installed inside the cabinet)
- running-time (hour) meter
- fault protection circuit(s)

Installation shall conform to the latest editions of the National Electric Code (NEC) and Building Officials Code Administrators International (BOCA).

1.6 Electronic Control

The speed and load control circuitry shall be based on digital microcomputers or microprocessors. Low current or power conversion circuitry may be excluded from this requirement.

The electrical power driving all electrically actuated relays, solenoids, valves, and motors shall be electrically isolated from the power source for the dynamometer control circuitry, computer, and interfaces.

All electrically actuated relays, solenoids, and valves shall be protected by zero switching or diode clamping so that no back EMF electrical noise is generated.

The electrical power driving the dynamometer control circuits shall be immune to all electrical noise. The system shall not feed damaging or detrimental electrical noise into the power grid. Electromagnetic fields caused by the dynamometer shall be controlled or suppressed to prevent any interference in the test vehicle or dynamometer electrical/electronic control systems. The contractor shall provide and install any isolation devices required for operation.

The dynamometer shall be protected from uncontrolled acceleration of the motor-absorber. The motor-absorber shall also have current limit protection to prevent system damage from power grid faults of short duration (<20 ms).

1.7 Roll(s)

A roll shall be defined as a cylindrical contact surface that applies the load forces to the tires on the test vehicle's drive axle(s). A roll may be a single cylinder or mechanically linked multiple cylinders. A twin roll dynamometer cradle consists of two rolls per vehicle drive axle which operate at synchronous speeds and impose forces at each tire contact point that are similar in magnitude. A single roll dynamometer consists of one roll per vehicle drive axle. The rolls, bearings, and power transfer loading devices shall be sized and configured to withstand the road load forces and axle loads of the specific test vehicles. These forces and loads shall include those values typically encountered from on-road vehicle performance tests conducted at wide open throttle from zero up to a maximum of 100 mph.

The requirements shall be the following:

nominal roll diameter (twin roll)	20 inches
tire contact angle (twin roll center spacing)	66° on a 24" contact circle
twin roll center spacing	= 2 (roll diam/2 + 24/2)(sin 33°)
nominal roll diameter (single roll)	48 inches
roll diameter determination tolerance	± 0.02% of nominal diameter
difference in cylinder diameters per roll set	± 0.02% of nominal diameter

roll width spacing shall accommodate:	
vehicle inside track width (LDV) *	36 inches
vehicle outside track width (LDV)	86 inches
vehicle inside track width (MDV) *	36 inches
vehicle outside track width (MDV)	108 inches
roll surface roughness	(See Note)
roll surface minimum hardness	Rockwell B90
roll dynamic balance quality (twin roll)	ANSI STD G2.5
roll dynamic balance quality (single roll)	ANSI STD G6.3
roll axis parallelism (twin roll)	0.020 inches TIR *
roll concentricity (twin roll)	0.004 inches TIR
roll concentricity (single roll)	0.010 inches TIR

* LDV = Light Duty Vehicle
MDV = Medium Duty Vehicle
TIR = Total Indicated Runout

Note: Roll surface finish shall provide minimum tire slippage and a tractive effort that is comparable to a vehicle operating on a typical dry, road surface. Roll surface roughness shall also not produce abnormal tire tread wear.

The speed of twin rolls shall be synchronized to within ± 0.1 mph at all operating conditions. Synchronization shall be accomplished by mechanical or electrical coupling. The total force applied by the roll(s) to the vehicle shall be the sum of the forces (including inertia) from each tire/roll contact point. The parasitic loss of the coupling device shall be stable and compensated for during all modes of vehicle or dynamometer operation.

For the 4WD system, the dynamometer rolls shall be nominally installed flush with the level, finished floor. When testing on a 2WD system, the contractor shall provide a method for maintaining the vehicle in a horizontal (± 1% grade) attitude when the drive tires are supported by the roll(s). The overall width of the LDV dynamometer shall be minimized to fit within the test cell, which will have an interior width of 16 feet. The overall width of the MDV dynamometer shall be less than 20 feet. The dynamometer frames shall be supported above the subfloor space in a manner that allows air recirculation in the subfloor area. The test vehicle is to be approximately located at the geometric center of the air flow stream of the test chamber, and in a consistent relation to the exhaust sampling system connectors which shall be in fixed locations in the subfloor space. The dynamometer(s) and the vehicle restraint system(s) shall be capable of testing both rear wheel drive vehicles and front wheel drive vehicles.

1.8 Inertia Simulation

The total inertia (mechanical plus electrical) to be simulated shall be selectable to within at least ± 10 pounds. This value shall be used to calculate the total road force required. The accuracy of the total road force imposed, including the inertia force, shall be within ± 1% of this calculated formula value under all operating conditions within acceleration rates of ± 8 mph/sec. The electrical inertia simulation shall provide response characteristics that result in total torque wheel loading that is comparable to a mechanical inertia system. For LDV dynamometers, the range of total inertia simulation shall be from 1,000 lbs. to 6,000 lbs. For MDV vehicles, the range of total inertia simulation shall be from 1,000 lbs. to 12,000 lbs.

The contractor shall measure and verify the value of the base inertia and all incremental mechanical inertia values of the dynamometers. Results of these tests shall be included in the documentation.

Any mechanical flywheels used as part of the inertia shall be dynamically balanced to the same quality standard, or better, as used for the roll(s). The control panel shall provide an indication and verification of the positive engagement and disengagement for each flywheel. The contractor shall provide, during any continuous closed throttle deceleration to zero, a means of reducing the braking force required from the drive axle. This force reduction shall be sufficient to prevent drive axle brake damage or failure.

1.9 Vehicle Restraint System

A vehicle restraint system shall be provided and installed with each dynamometer in a manner that enables unobstructed vehicle ingress and egress from any perimeter wall of the test cell.

The vehicle restraint system shall safely restrain all vehicles at all operating conditions. The vehicle restraint system shall center the drive wheel(s) of the vehicle on the roll(s).

The vehicle restraint system shall limit lateral and fore/aft motion of the vehicle to ± 0.5" without imparting any adverse vertical or horizontal forces on the vehicle or vehicle tires, and shall be easily installed, or engaged by the operator in less than ten minutes. Vehicle removal from the restraint system and the test cell shall be possible in less than two minutes.

1.10 Lift Platform and Roll Brakes

A lift platform situated between the rolls (on a twin roll configuration) shall be installed.

A roll brake which securely locks the roll(s) shall be installed.

When the lift platform is raised and the roll brake is actuated, the vehicle shall enter and leave the dynamometer without causing roll spin.

Operation of the roll brake shall be independent of the lift platform.

The lift platform shall be capable of being activated by a driver seated in the vehicle.

The lift platform shall be operable only when the roll(s) are not rotating. A roll speed interlock system shall prevent raising of the lift platform and non-emergency engagement of the roll brakes while the roll(s) are rotating.

The lift platform shall be capable of holding a vehicle in the raised position for a minimum of 24 hours.

The roll brake and lift platform shall be replaceable within four hours and without removing any system components which may change the dynamometer calibration.

1.11 Safety Devices

All safety devices for protection of the equipment shall be as independent of the processor as practical.

Warning lights on the dynamometer, indicating the status of the lift platform and roll brakes, shall be visible from the driver of the vehicle.

The dynamometer shall have the following personnel safety devices:

A safety barrier shall be installed to prevent personnel contact with the roll(s) during vehicle testing and during dynamometer roll operation without a vehicle. If a single roll dynamometer consists of two roller cylinders, or a twin roll cradle consists of four roller cylinders, the area between the rolls/cylinders shall be covered to provide a surface that facilitates personnel safety and allows vehicle movement.

An emergency stop switch shall be installed in the dynamometer test cell, at the vehicle, and at the electronic and display cabinet, and also at the power cabinet if it is separate. The emergency stop function shall cause shutdown (braking) of the dynamometer using the electric motor-absorber working at the maximum current limits. In the event the electric motor-absorber is unable to decelerate the roll(s) to zero, the roll brake may be used. In all cases, the roll(s) shall be decelerated to zero mph in less than 5 seconds and shall not damage the dynamometer system.

An emergency shutdown function shall be triggered automatically by the processor when any of the following limits are exceeded:

- dynamometer's maximum speed (fixed value)
- vehicle's maximum speed (value input during calibration)
- vehicular movement (>0.5 inches)

An emergency warning function shall be triggered automatically by the processor when any of the following limits are exceeded:

- excessive armature or field current of the motor-absorber
- overheating of the motor-absorber
- malfunction of the dynamometer cooling system
- malfunction of the power transfer system
- power failure
- other conditions needed to protect the dynamometer or personnel

These conditions do not warrant an immediate shutdown of the dynamometer system but rather a warning of a condition that requires immediate attention.

An indicator of activation of the emergency stop function, shutdown, or warning shall be installed in the dynamometer test cell (visible from the vehicle driver's seat) and in the dynamometer control room. The indicator shall be operational at all times, including during power failures.

1.12 Instrumentation

Display meters shall be installed to provide for speed, force, and horsepower readings for both the vehicle driver and the operator console.

The roll revolution and associated speed measurements shall be monitored by digital or optical sensors. A speed measurement method on each roll, and one for the vehicle wheel shall be installed to monitor roll(s) speed, to determine the angular velocity of the drive tire, and to verify roll speed synchronization under all test conditions. Measured speed shall have an accuracy and a resolution of a minimum of ± 0.05 mph at any speed. The speed measurement system shall be drift-free and shall require no analog calibration. Test distance driven shall be determined to a resolution of one part in 2000.

The acceleration and deceleration rates (mph/sec) of the roll(s) shall be determined by electrical or numerical methods. All acceleration rates shall be accurate to within ± 0.01 mph/sec or ± 1% of the acceleration rate, whichever is greater, and shall be determined within 100 ms of true occurrence.

The dynamometer shall have a torque measurement system to indicate the forces being applied to the dynamometer roll(s). This system shall be capable of indicating torque readings to a resolution of 0.05% of rated output or ± 0.2 ft-lbs, and shall be capable of sampling data at a rate of 1 KHz or higher.

The performance specifications of the torque transducer shall be the following:

hysteresis: less than ± 0.1% of rated output
zero/shunt drift: less than ± 0.1% of rated output in a 24 hour period
repeatability: less than ± 0.05% of rated output
nonlinearity: less than ± 0.1% of rated output (See Note)
accuracy: less than ± 0.1% of rated output at all values between ± 10-100% of rated output based on the best fit calibration regression

Note: Nonlinearity is defined as the deviation at mid-scale from a straight line connecting the zero and ± full-scale values, expressed as a percent of the rated output.

Calibration of the torque transducer for both positive and negative torque by the dead weight lever arm technique shall be provided. An electronic shunt calibration value shall be correlated to this dead weight technique. Torque transducer verification procedures under dynamic operation shall also be provided.

Elapsed time measurements shall have an accuracy and resolution of at least ± 0.01 seconds.

The design of the road load control system shall measure the force and determine the horsepower delivered at the roll surface(s) based on the applied torques, accelerations, and speeds of the roll(s). This system shall compensate for the mass and parasitic friction both inside and outside the control loop of the dynamometer.

Separate digital displays, easily seen by the driver, shall be provided for the following parameters, at a minimum:

Roll speed (mph)
Tractive force (lbs)
Tractive horsepower (hp)

1.13 Bearings and Lubrication Intervals

All bearings, gears, or coupling devices shall be designed to have minimum and stabilized frictional losses.

All bearings shall have a service life of at least 30,000 hours. All parts requiring lubrication shall be lubricated before delivery. All lubrication points shall be easily accessible and well documented. The lubricants, lubrication system, or the dynamometer system configuration shall not generate, into the test cell enclosure, hydrocarbon emissions that would adversely affect a vehicle running loss test at 100 °F.

The frictional losses of the dynamometer at all environmental conditions shall be thoroughly characterized for all modes of operation. Steady speed (50 mph) frictional losses shall remain within ± 0.1 hp of the final stabilized value following a ten minute warm-up period.

1.14 Covering of the Dynamometer Pit

The area around the roll(s) shall be covered by slip-resistant plates capable of supporting test vehicles.

All floor plates shall be secure, and if moveable during dynamometer wheelbase adjustments, shall not cause any opening in the floor surface following the adjustment.

The weight of a single plate shall not exceed 115 lbs.

2.0 4 Wheel-Drive Chassis Dynamometer Requirements

The basic requirements for a 2WD chassis dynamometer shall also apply to the 4WD version. Additional 4WD requirements are described in this section, and are to be applied as appropriate to single or twin roll configurations.

2.1 Set-up

The dynamometer chassis frames shall be installed on a support base and shall provide torsional stiffness and alignment performance.

The front and rear roll, or sets of rolls, shall be parallel to within 0.08 inches as measured by the centerline differential across the maximum roll width.

The front and rear roll, or sets of rolls, shall be electrically or electrohydraulically adjustable to the vehicle wheelbase. This adjustment process shall indicate the final wheelbase distance and shall utilize adjustment methods to assure the vehicle tire contact points are uniformly loaded. After adjustment, the roll chassis positions shall remain positively fixed on the base frame, even during power or hydraulic failures.

Operation of either 4WD or 2WD shall be selectable. Operation in the 2WD mode shall be possible with either roll or set of rolls. The non-driven rolls, in a twin roll configuration, shall be locked with the lift platform down to act as a vehicle wheel chock.

On a twin roll configuration, a mechanism or method controlled by the processor shall provide speed synchronization between the front and rear roll of each drive axle cradle.

On a twin roll configuration, to ensure ease of vehicle handling when entering or leaving the dynamometer, each set of twin rolls shall have a lift platform and a roll brake. The raising and lowering of both lifts shall be synchronized in the 4WD mode.

2.2 Requirements for Roll Synchronization

The speed of all rolls shall be synchronized to within ± 0.1 mph at all operating conditions.

The parasitic losses of any mechanical synchronization shall be independent of the selected wheelbase and shall be stable and compensated for, by the system, under all operating modes.

2.3 Operation Mode 2WD/4WD

The 4WD dynamometer shall be usable as a 2WD dynamometer as well. Either roll or set of rolls (front or back) shall be usable for 2WD operation.

The synchronization of the rolls or roll sets shall be controllable by the processor. The display shall indicate the configuration of the dynamometer at all times.

The configuration of the dynamometer (4WD or 2WD) shall be stored in the road load model or test data set.

The roll or set of rolls which is not used in the 2WD configuration shall be locked using the roll brake.

The calibration, compensation, and storage of the dynamometer losses shall be maintained in both 2WD and 4WD configurations.

2.4 Wheelbase Adjustment

The distance between the front and back roll, or sets of rolls, shall be continuously adjustable between 80 and 130 inches. The time required for adjusting the dynamometer to any wheelbase in the 80 to 130 inch range shall not exceed five minutes. A provision to extend the wheelbase to 180 inches shall be installed with setup requiring no more than one hour.

The wheelbase spacing shall be automatically adjustable to the vehicle wheelbase, this condition shall be indicated by a zero speed, null restraint force and centered axles.

The wheelbase shall be adjustable while the dynamometer is in either 2WD or 4WD configuration.

The value of the final wheelbase setting shall be read and stored to within ± 0.2% of the nominal wheelbase.

2.5 Vehicle Restraint System

A vehicle restraint system shall be installed with each dynamometer that enables unobstructed vehicle ingress and egress from any perimeter wall of the test cell.

The vehicle restraint system shall be capable of safely restraining all vehicles at all operating conditions.

The vehicle restraint system shall limit lateral and fore/aft motion of the vehicle to ± 0.5" without imparting any adverse vertical or horizontal force on the vehicle, and shall be easily installed, or engaged by the operator in less than ten minutes. Vehicle removal from the restraints and test cell shall be possible in less than two minutes.

3.0 System Processor Requirements

3.1 General Computer Requirements

The signal cabling shall not cause malfunctions due to capacitive or inductive interference.

Dynamometer operating system software, control software and parameters, and data acquisition interfaces shall be stored and accessed using commercially available standard microcomputer hardware. The contractor shall provide a complete description of the hardware and operating software. Access to all software (including source code) and operation parameters shall be provided.

All analog input and output signal converters shall have a nominal ± ten volt range with a minimum of 0.005 volts per bit resolution.

All digital input/output channels shall be 0 to 5 volt TTL (transistor-transistor-logic) and shall be optically isolated from their source.

Error messages and the operating hours counter shall function at all times.

It shall be possible for personnel without special computer experience to operate the dynamometer processor and the peripheral units, including the input of parameter changes. The dynamometer shall operate in both a local mode without interaction with a remote computer system, and in a client/server mode, while connected to a remote system that contains vehicle test parameters and data sets,and may be used to receive or send data sets of test information or calibration.

3.2 Processor Modes/Functions

The dynamometer processor shall support, at a minimum, the following operation modes and tests:

- road load simulation mode
- self-motoring mode
- dynamometer coastdown test
- quick check coastdown test
- speed control mode
- torque control mode
- acceleration mode
- deceleration mode
- calibration mode

The dynamometer processor shall check all processor functions (e.g., CPU, memory, and input/output channels) using an on-line diagnostics program.

3.2.1 Road Load Inertia Simulation Mode

The load applied by the dynamometer shall simulate the rolling resistance, aerodynamic drag, and inertia forces that occur on the road according to the following formula:

$$F_R = A + B*V + C*V^2 + D*W + M*dV/dt \quad \text{(See Note)}$$

where:

F_R = total vehicle road load force to be applied at the surfaces of the rolls
A = constant load coefficient (friction)
B = load coefficient dependent on velocity (speed boost)
C = load coefficient dependent on velocity squared (windage)
D = grade coefficient (-,+) [sin Θ]
W = weight of vehicle
M = effective vehicle mass, taking into account the rotational masses
V = velocity of the roller surfaces
dV / dt = acceleration rate of the roller surfaces

Note: The total force is the sum of the individual forces applied by each roller surface.

The simulation of the total road force, including the inertia force shall be ± 1 % of its formula value under all operating conditions and at all velocities. All dynamometer configurations, mechanical and electrical, shall produce comparable results that are not significantly different from the standpoint of accuracy, precision, or reproducibility.

The system response time shall be less than 100 milliseconds. System response time shall be defined as the time lag between a step change in demanded force at the roll surface, and the occurrence of 90% of the final demand value. Total response shall include mechanical delay, measurement lag, computational time, and power control electrical response parameters that will be combined to provide a critically damped response function. Appendices E and F provide response definitions.

In road load simulation mode, sets of coefficients containing road load curves and inertias shall be directly accessible from the system storage device within ten seconds.

All data sets shall have a sufficient number of characters in their nomenclature to provide uniquely identifiable names for retrieval.

In simulation mode, all functions shall be performed, and the error value monitored by the dynamometer processor.

Calibration for frictional losses shall be automated.

For any inertia configuration, the processor shall determine a friction curve using a steady speed, constant acceleration or deceleration, or a coastdown procedure. The user shall have the capability to manually set the frictional loss coefficients.

The frictional losses shall be compensated for over the entire speed range.

The frictional losses shall be modeled by the following equation:

$$F_o = a_o + b_o * v + c_o * v^2 + d_o * v^3 + e_o * (m * dv/dt) \qquad \text{(See Note)}$$

where:

F_o = total dynamometer frictional losses outside the force control loop
a_o = constant frictional loss coefficient
b_o = frictional loss coefficient dependent on velocity
c_o = frictional loss coefficient dependent on velocity squared
d_o = frictional loss coefficient dependent on velocity cubed (optional)
e_o = frictional loss coefficient dependent on acceleration
m = effective vehicle mass, taking the rotational masses into account
v = velocity of the roll surfaces

Note: Frictional losses shall be determined on each roll, incremental mechanical inertia, and coupler and shall be compensated for in the road load function. These losses shall also be determined as a function of the acceleration power transfer.

The system shall support polynomial fits up to 3rd order.

The dynamometer processor shall retrieve historical data sets from on-line disk storage or from a remote server.

The prevailing dynamometer rotational direction shall be part of the stored calibration data, as well as a specific date/time stamp associated with each run.

All dynamometer loss coefficients shall be part of the long-term data storage, and shall be readily available for trend analysis and quality control functions.

3.2.2 Self-motoring Mode

The motor-absorber system shall motor both the roll(s) and the inertia system. This shall allow the following procedures to be executed, at a minimum:

- vehicle alignment
- dynamometer warm-up
- coastdown and acceleration tests
- speed signal checks
- dynamometer calibration
- dynamic torque verification
- system response characterization

The desired acceleration/deceleration rate and final speed shall be specified by the operator and automatically controlled through the dynamometer processor.

The roll(s) shall be motored, or "jogged", during vehicle alignment by use of a momentary contact device.

The motor-absorber shall be capable of accelerations and decelerations of the base mechanical inertia at any rate between 0 and 10 mph/sec.

3.2.3 Dynamometer and Vehicle Coastdown Test

The dynamometer shall perform continuous or incremental coastdown tests. These tests shall be performed with or without a vehicle on the roll(s). If a vehicle is used, the transmission shall be in neutral during the coastdown.

During the coastdown test, the dynamometer shall achieve a stabilized speed above the selected upper speed limit (v_{upper}) and then coast down to the selected lower speed limit (v_{lower}) under the influence of the selected road load model. Speed, torque, acceleration, time, and other pertinent data shall be digitally recorded or logged at the specific sampling rate (0.1 or 1.0s) for subsequent regression analysis.

The maximum v_{upper} shall be 80.0 mph.
The minimum v_{lower} shall be 5.0 mph.
The minimum $v_{interval}$ shall be 5.0 mph.
The coastdown range is v_{upper} to v_{lower}

The number of coastdowns to be performed shall be selectable by the operator.

At the conclusion of each coastdown the following values shall be displayed, at a minimum:

For the selected coastdown range:

- the upper and lower speeds of the range
- the elapsed range time: $t_{v_{upper}} - t_{v_{lower}}$
- calculated coefficients a_o, b_o, and c_o using the coastdown data of the entire curve

For each selected speed interval within the coastdown range:

- the upper and lower speeds of the interval
- the elapsed interval time: $t_{v_1} - t_{v_2}$
- actual absorbed horsepower
- difference between motor-absorber power and actual absorbed power.

The operator shall have the ability to automatically conduct the standard coastdown test as defined in 40CFR §86.118-78. Title 40: Chapter I - Environmental Protection Agency, Part 86, Subpart B, Section-86.118-78 - Dynamometer Calibration.

3.3 Interface with Master/Host Computer System

The dynamometer processor shall have the ability to communicate using, at a minimum, an RS-232 interface to a master/host computer system. IEEE-488, RS-422, Ethernet, and Appletalk are acceptable supplemental protocols. The specifications for the RS-232 communication to the master/host computer shall be as follows:

selectable baud rate(s):	1200, 2400, 4800, 9600, or 19200 bits per second
selectable character size:	7 bits, or 8 bits
selectable parity:	even, odd, or none
selectable parity bit:	0 bit, or 1 bit

The dynamometer processor shall exchange all necessary information, including commands, data, error messages, and reports with the master/host computer system. The dynamometer processor shall provide the remote computer system with the following values, at a minimum:

- all site and vehicle data relevant to the test setup
- operation mode
- data set name of road load model
- mechanical, electrical, and total inertia simulated on each roll
- coefficients of road load model
- coefficients of dynamometer loss curve on each roll
- the effective rolling radius of the tires, as determined under minimum load (neutral coast down or steady speed motoring) at 50 mph.

The dynamometer shall be operational in a remote mode with minimal interaction by the operator. In this mode, any test data or commands that must be entered to configure or control the dynamometer for a test may be accessed from a remote computer system instead of from the dynamometer processor's input devices, such as keyboard, keypad, or mouse.

3.4 Real-Time Data Monitoring

During dynamometer operation, the following real-time data (either as analog, digital, or computed data) shall be available for a remote computer, either directly from the dynamometer hardware or from the dynamometer processor for each roll(s):

- wheel speed and accel/decel rate	
- front/rear roll speed and accel/decel rate (twin roll dynamometer)	(actual and demand)
- roll speed and accel/decel rate (single roll dynamometer)	(actual and demand)
- torques	(actual, demand, and error)
- horsepowers	(actual, demand, and error)
- inertia simulations	(actual, demand, and error)
- distances	(roll revolutions pulses)
- status of roll brake	(on, off)
- status of vehicle lift	(up, down)
- status of local/remote control	(local, remote)

The dynamometer system shall log or store data for later batch transfer as a tab delimited text file or in a compatible format to a remote computer.

3.5 Electric Dynamometer Data Acquisition Package

Each dynamometer shall be supplied with a separate microcomputer capable of running the EPA Video Driver's Aid (VDA) application module and accessing the VDA file server via the EOD Laboratory Network System. This microcomputer system shall collect the dynamometer speed signals and monitor all other test parameters. The system (or equivalent) shall include, at a minimum:

-One Macintosh IIfx chassis with 6 NuBus slots, 8 MBytes RAM, 210MB internal disk, and extended keyboard.
-One Color monitor 19" or larger diagonal screen at 70-75 pixels per inch, including video card(s).
-One LabView 2.0 (runtime) or later software to access data from the NuBus hardware.
-Three NuBus cards from National Instruments
  NB-MIO-16XL18, NB-MIO-16XH18, and NB-DMA2800
-One NB Series RTSI Bus cable from National Instruments
-Two SSR (8 module mounting racks) with SC-2050 Adapters and 2 CB-50 Terminal Strips
-One NuBus card to enable Ethernet communications
-One NuBus card to generate the video signal for a color projector to display the VDA trace as a rear screen image from outside the vehicle test cell.

One system shall be used in the instrumented vehicle for the acceptance testing. Therefore, it shall be shipped to EPA a minimum of 60 days prior to commencement of contractor performance testing.

4.0 Acceptance Tests, Procedures, and Criteria

4.1 General Acceptance Provisions

The contractor shall complete all performance tests before shipment of the dynamometer(s) to EPA.

The contractor shall supply complete procedures for performing parasitic loss corrections for EPA review before beginning any testing.

The contractor shall supply all collected data for EPA review before shipment of the dynamometer(s). EPA shall complete all reviews within 15 days of receipt.

EPA shall reserve the right to observe the performance testing at the contractor's facility. The contractor shall give the EPA Project Officer a minimum of 15 days written notice prior to the start of any performance testing.

No authorization to ship the dynamometer(s) shall be made until acceptance of the dynamometer's performance is approved by the EPA Project Officer. The contractor shall accept full responsibility for any equipment, supplies, or materials shipped prior to Government approval.

4.2 Testing Requirements and Overview

EPA shall reserve the right to waive specific testing if other means or data are available to verify the criteria and/or performance.

Appendix A is a cross reference guide to specific dynamometer requirements and the subsequent tests which will be used to verify the requirements.

4.2.1 Reporting

The contractor shall submit a report to the EPA Project Officer for each dynamometer within 30 days of completion of the contractor's performance testing. The report shall contain, at a minimum, all information required under Sections 4.2.4 and 4.3, as well as:

A. A complete description of all parameters related to and including the raw test data collected including:

1. Test dates
2. Personnel
3. Location (test site and dynamometer serial number)
4. Ambient conditions (including time of day, barometer, temperature, and humidity)
5. Exact tire specification and configuration [tire pressure, tire radii (free-hanging, flat surface, and dynamometer roller-to-axle center)]
6 Axle loads (both drive and non-drive)
7. Total empty vehicle weight
8. Driver weight
9. Percent fuel fill and tank capacity (in gallons)
10. Vehicle drive axle brake and bearing drag

B. A summary table for the testing results (Section 4.4.3.5) indicating all speeds and torque measurements and statistics on the repetitive tests.

C. All setup parameters used in the configuration of the subject dynamometer to perform the requirements of Section 4.0.

D. A complete list of all test and signal conditioning equipment, including make, model number, resolution, and measurement rates for each parameter.

4.2.2 Vehicle Torque Wheel System

A vehicle shall be instrumented with torque wheels for the tests in sections 4.4.3.2 thru 4.4.3.5. The wheel torque measurement system shall have a torque reading resolution of ± 0.05% of each dead weight data point when calibrated using certified weights (± 0.1% accurate), traceable to an international standards organization. The dead weight calibration shall have uniformly spaced calibration points from maximum to minimum and all response readings shall deviate less than 0.2% of point for each calibration point (from -100 to +100 percent of the torque transducer's full scale) for both positive and negative torque calibrations. Weights shall be applied both sequentially and in random order as shown in the table below, in percent of full scale:

Positive		**Negative**		**Random**	
Load	Unload	Load	Unload		
zero/shunt	100%	zero/shunt	-100%	20%	-40%
10%	90%	-10%	-90%	80%	-10%
20%	80%	-20%	-80%	30%	-20%
30%	70%	-30%	-70%	zero/shunt	zero/shunt
40%	60%	-40%	-60%	-80%	50%
50%	50%	-50%	-50%	-30%	40%
60%	40%	-60%	-40%	-100%	100%
70%	30%	-70%	-30%	zero/shunt	zero/shunt
80%	20%	-80%	-20%	10%	-30%
90%	10%	-90%	-10%	90%	-80%
100%	zero/shunt	-100%	zero/shunt	60%	-90%

The torque wheel system shall totalize wheel revolutions and vehicle positive and negative torque separately, as well as sampling wheel angular speed and torque at least 20 times per second.

The speed used for a driver's trace and the speed used for the dynamometer load setting control loop shall be synchronized within ± 0.1 mph for all required tests.

4.2.3 Data Acquisition (Hardware/Software)

The contractor shall provide a vehicle with a General Motors five lug bolt pattern on the wheels (4.5" center-to-center spacing between every other lug nut) to measure and record test data using R14 wheels and steel belted radial tires. Test data shall be collected using torque wheels and data acquisition equipment supplied by EPA. EPA will use a Macintosh IIx computer with National Instruments 16-bit resolution hardware and LabVIEW 2.0 software to acquire all data.

4.2.4 Data Analysis and Presentation

All testing results shall be supplied with summary tables containing the following, at a minimum:

1. Elapsed Time (seconds; xxx.xx)
2. Driver's Trace and Vehicle Speed (mph; xx.xx)
3. Wheel Encoder Frequency (Sample Period Hz and Total Counts)
4. Wheel Angular Velocity and Accelerations (mph, mph/sec ; xx.xx)
5. * Front Roll Encoder Readings (Sample Period Hz and Total Counts)
6. * Front Roll Velocities and Accelerations (mph, mph/sec ; xx.xx)
7. * Rear Roll Encoder Reading (Sample Period Hz and Total Counts)
8. * Rear Roll Velocities and Accelerations (mph, mph/sec; xx.xx)
9. Power Absorption Unit Torque (Ft-Lb; xxx.x)
10. Power Absorption Unit Horsepower (hp; xx.xx)
11. Power Absorption Unit Amperage (Amps; xx.xx)
12. Vehicle Wheel Torque (Ft-Lb; xxx.x)
13. Vehicle Wheel Horsepower (hp; xx.xx)
14. Drive Trace Roll to Vehicle Drive Wheel Angular Velocity Ratio
15. All Dynamometer Settings

* Note: On a single roll dynamometer, a single roll reading shall be supplied.

The specified data for all tests shall be supplied in tab delimited ASCII text files as a function of sample collection time, sampled at least 20 times per second. The data may be recorded in SI or English units and converted to the units specified above providing the resolution and format of the raw data complies with the required specifications.

4.3 Component Review and Calibration Tests

4.3.1 Installation and Mechanical Review

Typical installation diagrams and pit specifications shall be provided for evaluation. Final installation diagrams and pit specifications shall be provided with the requirements of the performance data.

4.3.2 Structural and Dimensional Review

4.3.2.1 Frame

Frame deflection shall not adversely affect dynamometer performance or operation. Front and rear roll parallelism and alignment shall not change over the range of test vehicles the dynamometer is capable of testing. Engineering data and/or analysis shall be provided to document this requirement.

4.3.2.2 Bearings and Lubrication

Motoring torque versus elapsed time data shall be provided to document this characteristic. Parasitic losses shall be stable to within ± 0.1 hp in ten minutes or less at an average speed of 50 mph, after the dynamometer is started from a two-hour idle period, with a dynamometer enclosure temperature of 70-80 °F. Stabilized bearing friction shall remain constant within ± 2% between the dynamometer contractor's recommended calibration periods for vehicle test environment temperatures between 0 and 100 °F. The contractor shall include the parasitic calibration frequency per 1000 miles of use needed to eliminate changes > 0.1 hp at 50 mph.

4.3.2.3 Roller Geometry

The contractor shall document physical measurements that confirm dimensional requirements such as diameter, roller set parallelism, roll spacing, and surface finish.

4.3.3 System Operation and Calibration Review

The contractor shall submit, for EPA review, the torque, speed, and acceleration calibration procedures as well as the proposed electrical and base mechanical inertia simulation verification procedure 15 days before the performance and submission of results from calibrations.

4.3.3.1 Mechanical Inertia Determination

The contractor shall supply a complete summary of all physical components of the dynamometer and their individual contribution to total calculated mechanical inertia. The description shall include diagrams of physical layout and specific definition of which components are inside or outside the dynamometer's control loop.

The contractor shall provide verification of physical measurements to document that components have been built to specification. The total system inertia for each flywheel combination shall be verified to ± 0.15% of stated value. The total system inertia shall be verified through dynamic tests using the dynamometer system.

The contractor shall submit documentation that the mechanical inertia weights are balanced to within the tolerances specified by the balance quality level specified in Section 1.7. The documentation shall contain the actual procedure and data or information generated as proof of compliance with this requirement.

4.3.3.2 Torque Cell Calibration

The contractor shall provide all measurement data including documentation of the effective fixture arm length. The dead weight calibration shall have uniformly spaced calibration points from maximum to minimum. All calibration points must be accurate to < ± 0.1% of full scale (FS) for each calibration point (from -100 to +100 percent of the torque transducer's FS) for both positive and negative torque calibration weights. Calibration weights (± 0.1% accurate) shall be directly traceable to an international standards organization. On both positive and negative torque calibrations, weights shall be applied both sequentially and in random order shown in the table below, in percent of full scale. The contractor shall supply data to substantiate that the dynamometer torque measuring system satisfies the following requirements:

Positive		**Negative**		**Random**	
Load	Unload	Load	Unload		
zero/shunt	100%	zero/shunt	-100%	20%	-40%
10%	90%	-10%	-90%	80%	-10%
20%	80%	-20%	-80%	30%	-20%
30%	70%	-30%	-70%	zero/shunt	zero/shunt
40%	60%	-40%	-60%	-80%	50%
50%	50%	-50%	-50%	-30%	40%
60%	40%	-60%	-40%	-100%	100%
70%	30%	-70%	-30%	zero/shunt	zero/shunt
80%	20%	-80%	-20%	10%	-30%
90%	10%	-90%	-10%	90%	-80%
100%	zero/shunt	-100%	zero/shunt	60%	-90%

Hysteresis	± 0.1% of full scale
Repeatability	± 0.05% of full scale
Non-Linearity	± 0.1% of full scale
Zero and Shunt Drift	± 0.1% over 24 hours
Rise Time to 90% of Load	< 10 milliseconds
Time Constant	< 50 milliseconds

4.3.3.3 Torque Transducer Virtual Span & Zero

Dynamometer controller software calculations may be used to minimize torque transducer/signal conditioning drift. The following equations describe this software technique. Other methods may be described or proposed if shown to produce comparable results. If the contractor utilizes any of these techniques, test data shall be provided to verify the accurate performance.

$$V_c = V_m(G) + B$$

where:

V_c = Corrected Output

V_m = Measured Output

$$G = \frac{(S_{ref} - Z_{ref})}{(S_{act} - Z_{act})}$$

$$B = \frac{(S_{ref} * Z_{ref})}{(S_{act} - Z_{act})}$$

and

S_{ref} = The expected shunt resistor reading determined during transducer calibration

S_{act} = The actual shunt reading

Z_{ref} = The expected transducer output with 0 torque

Z_{act} = The actual zero reading

4.3.3.4 Speed Measurement

Speed measurement accuracy shall be demonstrated and verified to be accurate to within ± 0.05 mph.

4.3.3.5 Acceleration Measurement

Measurement or determination of angular acceleration shall be demonstrated and verified to be accurate to ± 0.01 mph/sec or ± 1% whichever is greater over a range of 0 to eight mph/sec.

4.3.3.6 Time Measurement

Time measurement shall be demonstrated and verified to be accurate to the nearest 0.01 second while totalizing 1000 seconds.

4.3.3.7 Computer

The computer system shall transfer test data sets to a remote Macintosh computer. One megabyte of sample data shall either be directly transferred to the Macintosh computer in less than ten minutes or the data shall be stored as tab delimited ASCII text on an MS-DOS or Macintosh formatted 3.5" floppy disk capable of holding 1.4 megabytes per floppy.

4.4 Dynamometer Characterization Tests

4.4.1 Endurance Testing

The dynamometer shall be fully warmed and then operated for two hours at a series of various speeds including maximum plus/minus torque levels. The requirements of the remainder of Section 4.0 shall be performed after the dynamometer has been shut off for a minimum of 24 hours.

A maximum shock loading test shall be performed, to establish the structural integrity of all system components. This test sequence shall consist of:

1. The dynamometer, set at its base inertia weight, shall motor itself from 0 to 60 mph at the maximum motor hp and the emergency stop shall be activated to decelerate the dynamometer to zero mph five consecutive times within one half hour.

Immediately followed by:

2. A vehicle shall be properly positioned and normally restrained on the dynamometer. The vehicle shall be operated at wide open throttle for approximately five seconds, then the vehicle brakes locked for approximately one second (until the driver's trace speed decreases discernibly). This sequence shall be repeated until the vehicle's speed reaches 60 mph.

4.4.2 Electrical Inertia Simulation Response

Simulation response shall be reported as the dynamometer torque response to a simulated step change in speed signal. The response definitions are contained and illustrated in Appendices E and F. The inertia settings shall be base mechanical inertia, 2,000 and 5,500 lbs. Six mph/sec and 0.5 mph/sec acceleration and deceleration sawtooth profiles and square wave steady speeds shall be simulated using a signal generator.

Response time in all cases shall be less than 100 milliseconds.

4.4.3 Operational Response Characterization

4.4.3.1 Dynamometer Self-motoring

The following tests shall be performed before shipment.

A. Parasitic Losses Determinations and Stability:

The dynamometer shall assess and compensate for the vehicle loads that are attributable to tire/roller and dynamometer mechanical parasitic losses. The following tests are designed to simulate daily use and subsequent stability of the dynamometer parasitic losses.

The subject dynamometer shall perform coastdowns (with and without a vehicle), with all dynamometer load coefficients set at zero, and calculate the equation of parasitic losses (lbs. force) from 60 to 10 mph. The dynamometer shall accept a target total vehicle road load curve and calculate the required coefficients necessary to match the vehicle load curve and compensate for the previously calculated parasitic losses.

Once the dynamometer has been warmed according to the contractor's published procedure, the dynamometer shall perform a no load coastdown (at dynamometer base inertia weight) and calculate the coefficients to describe the parasitic losses.

An assessment of the parasitic friction transient behavior shall be performed. The dynamometer shall be allowed to sit for a minimum of two hours. The dynamometer shall then motor itself through a series of steady speeds each 30-seconds in duration, at 10, 20, 30, 40, 50, and 60 mph, followed by a no load neutral coastdown from 65 to 10 mph. The steady state/coastdown sequence shall be repeated for a total of five sequences performed within one hour.

NOTE: If the coastdown exceeds five minutes with no electrical load, a constant electrical force may be applied to limit the coastdown to five minutes.

On the final sequence following the 60 mph steady state, the dynamometer shall motor itself to 80 mph within ten seconds and maintain this speed for 30 seconds prior to the no load neutral coastdown.

The data supplied shall verify all coastdown calculation capabilities.

B. Steady State Verification of Parasitic Friction Stability:

The measured steady state horsepower values after ten minutes shall be within ± 0.1hp of the stabilized values, calculated using the dynamometer-produced parasitic loss equation.

C. Mechanical Base Inertia Verification:

The dynamometer shall be programmed to operate at its base inertia weight. (Base inertia shall be defined as the inertia weight with no electrical or incremental mechanical inertia engaged.) Using a constant acceleration rate the dynamometer shall accelerate to 65 mph and then decelerate at the same rate to 0 mph. The collected force data shall be corrected for the parasitic forces and then used to verify the mechanical base inertia by the following equation:

$$\text{Force} = \left(\frac{W}{g}\right) a$$

where:

W = Base Inertia Weight (lbs)
g = Gravitational Constant (32.17 ft/sec^2)
a = Accel/Decel Rate

combining with g produces the following calculated inertia equation:

$$W_{\text{calced}} = F / 0.045585(dV/dt)_m$$

where:

W_{calced} = Calculated Mechanical Inertia Weight (lbs.)
F = Sample Interval Net Roller Surface Force Measured by Dynamometer (lbs.)
$(dV/dt)_m$ = Measured Interval Acceleration (mph/sec)

The accel/decel procedure shall be repeated five times at rates of 1, 3, and 6 mph/second or whichever of these rates the dynamometer can achieve, as well as the maximum dynamometer motoring horsepower.

The average value of W_{calced} at each accel and decel rate shall be within ± 0.2% of the contractor's specified Base Inertia Weight. These tests shall be applied to verify the incremental mechanical inertia values available.

D. Verification of Friction Compensation:

Friction compensation accuracy shall be checked with a warmed dynamometer and all road-load simulation coefficients ($F = A + BV + CV^2$) set to zero for each of three separate inertia weight settings (Base Inertia Weight, 2000 lbs., and 5500 lbs.). After motoring to 50 mph, the dynamometer shall be switched to road simulation mode and shall compensate for all parasitic losses. Speed drift versus time shall be used to determine the compensation error.

f_{error} = compensation error (lbs) = m (ΔV) (0.045585)/Δt

where: m = actual inertia

ΔV = speed drift (mph)

Δt = time over speed change (sec)

In addition, the friction compensation accuracy shall be recorded at steady speeds of 10, 20, 30, 40, and 60 mph for each of the above inertia settings.

The compensation error at each speed shall not exceed the equivalent of ± 0.1 hp at any steady state speed.

E. Road-Load Curve Simulation and Repeatability:

Accuracy and repeatability of the road load curve shall be determined from five separate 65 to 10 mph continuous neutral coastdown tests (without a vehicle) at each load setting from below. Coastdown force shall be determined at speeds of 60, 50, 40, 30, 20, and 10 mph. The error (e_i) at each coastdown point is the difference between the calculated force and the measured coastdown force:

$$e_i = F_{calced} - F_m$$

$$F_{calced} = A + B * V + C * V^2$$

$$F_m = (0.045585)\ (I)\ (dV/dt)$$

where:

dV/dt = Measured (or calculated) Sample Interval Acceleration (20 samples/sec sampling rate)

I = Inertia weight setting (lbs)

The following road-load horsepower and inertia conditions shall be measured:

<u>DYNAMOMETER BASE INERTIA</u>
A = B = C =0 and I = Dynamometer Base Inertia

<u>LDV MINIMUM</u>
A = 26.25 lb., B = C = 0, and I = 2,000 lb.

<u>LDV MAXIMUM</u>
A = 187.5 lb., B = C = 0, and I = 5,500 lb.

Accuracy shall be defined as the average force error. Repeatability shall be defined as two times the standard deviation, for each speed point.

Coastdown accuracy and repeatability versus speed shall be documented for the minimum and maximum force curves and shall not be significantly different, at a 90% statistical confidence level, from the subject dynamometer's own accuracy and repeatability at its base mechanical inertia weight setting.

4.4.3.2 Steady State Speed Loading

This shall be performed before shipment, with a vehicle.

The stabilized dynamometer shall be programmed with two loading curves (see Appendix B Figure 2). The contractor shall perform steady state tests ranging from 10 to 60 mph in five mph increments. Each shall be of 30 seconds duration, (ascending or descending order) for each dynamometer load set curve. Five replicates of each run shall be recorded. All load setting and driver's trace speed signals shall remain within ± 0.1 mph during the data recording periods.

The dynamometer and vehicle wheel force data from each steady state/speed shall be graphed versus speed (mph). The dynamometer force data from five runs shall be within ± 1 % of a curve of the mean values (from 10 to 60 mph) for the five replicate runs. The mean values for each speed increment shall be calculated by the formula in the example at the end of this section. The data shall be graphed in the same manner as shown in Appendix C, Figure 4.

4.4.3.3 Fixed Acceleration Rate

This shall be performed before shipment, with a vehicle.

The dynamometer shall compensate for all dynamometer and vehicle tire/roll interface parasitic losses (i. e., the measured wheel torque, at steady state speeds, shall equal 0). The vehicle shall accelerate the dynamometer for 2000 and 5500 pound inertia weight settings. The contractor shall perform acceleration test sequences for 1, 3, and 6 mph/sec accelerations from 0 to 60 mph. The sequences shall consist of one run per acceleration rate and inertia setting (six runs).

The dynamometer roller force and vehicle wheel force data from each acceleration shall be graphed versus the dynamometer acceleration rate (dV/dt). All dynamometer roller force data shall be within ± 1 % of a curve of the calculated force values versus acceleration rate.

The vehicle wheel force data shall not exhibit a variability greater than that exhibited for the same acceleration rates performed under test track conditions. Each ideal inertial acceleration force value shall be calculated by the following formula:

$$F_{calced} = M_{set}\,(0.045585)(dV/dt)$$

where:

F_{calced} = Calculated Instantaneous Force (lbs.)
M_{set} = Set Inertia Weight (lbs.)
dV/dt = Measured (or calculated) Sample Interval Acceleration (at 20 samples/sec sampling rate)

See Appendix C Figure 3 for an example of how the data shall be graphed.

4.4.3.4 Neutral Coastdown Rolling Load

This shall be performed before shipment, with a vehicle.

The contractor shall perform neutral coastdown tests from 65 to 10 mph consisting of five replicate runs per inertia weight using the load curves and inertia weights (2000 and 5500) used in Sections 4.4.3.2 and 4.4.3.3.

The dynamometer and vehicle wheel force data shall be graphed versus dynamometer speed. The dynamometer roller force data shall be within ± 1 % of a curve of the mean values (from 60 to 10 mph) for the five runs. The data shall be graphed in the same manner as in Appendix C, Figure 4.

4.4.3.5 Urban Dynamometer Driving Schedule (UDDS-505 seconds)

This shall be performed before and after shipment, with a vehicle.

Testing at the contractor's facility shall consist of the collection of the same data on each dynamometer which the contractor shall deliver under this contract. Each set of 4WD dynamometer roll(s) shall be tested in the 2WD dynamometer configuration.

The testing shall be conducted on a dynamometer with a vehicle using load curves and a test inertia weight specified by EPA. A minimum of five sequential UDDS - 505 tests shall be run for each test specified.

The data required under Sections 4.2.1 and 4.2.4 shall be logged at a sample rate of 20Hz and stored in a disk file by the system computer for the first 505 seconds of the UDDS.

The collected data shall be supplied to EPA for review and evaluation. Statistical analysis of the replicate tests shall be performed by EPA to quantify the performance characteristics of the dynamometer/vehicle system operating under transient driving schedules. The contractor shall correct all performance deficiencies that are found to be statistically significant relative to the other dynamometers produced and tested.

Real Time Performance Monitor:

The dynamometer controller software shall perform the following analysis of the force error profile. Statistics on the values of the force error versus reference force and velocity shall be generated. The dynamometer software shall report the minimum, maximum, average, standard deviation, and number of values collected for the force error for each ten mph speed interval during the test phase. The contractor shall state the calculation frequency and cutoff speed used for data acquisition. This technique shall be used to monitor all tests.

System performance shall be verified through the analysis of the force error signal. The equation for the force error signal is as follows:

$$E_m = 100 * (F_m - F_r) / F_r$$

where:

E_m = Force Error Signal
F_m = Measured Force
F_r = Reference Force

Measurements shall be made during each vehicle UDDS - 505 seconds sequence performed in this section.

The average force error signal over the UDDS - 505 seconds shall be within ± 1% over the entire speed range.

Appendix A

Electric Dyno Acceptance Cross Reference

General Mechanical Operation

1. Ambient Conditions Operation
   a. Narrative
2. Wheel Base Adjustment
   a. Within ±0.08"
3. Roll Balance
4. IW Determination

Calibrations

1. Speed Measurement Accuracy
   a. ± 0.0.5 MPH
2. Acceleration Measurement
   a. 0-10 MPH/sec Range
   b. ± 0.01 MPH/sec Accuracy
3. Elapsed Time
   a. ±0.01 seconds
4. Torque
   a. ± 0.2 ft-lbs(min 1000 samples/sec)
   b. ± 0.1% hysteresis
   c. ± 0.1% zero shunt drift
   d. ±0.1% Repeatability
   e. ± 0.1% Linearity
5. Response
   a. < 100 msec to 90%

Motor Mode

1. Align Vehicle Procedure
2. Warm-Up
3. Coastdown/Acceleration
   a. Any from 0 to 10 MPH/sec OR Max Avail power (1, 3, 6 MPH/sec Accels)
   b. Base Inertia Verification
4. From Panel by Operator
5. Steady States Parasitic Losses Stability
   a. Shall remain < ± 0.1 HP (ALL Speeds)

Tests Performed With a Vehicle

Steady States

1. Road Load Simulation Accuracy
   a. Repeatable ± 1%
2. Access coefficients within 10 secs

Accel/Decel

1. Inertia Simulation
   a. Parasitic Losses Compensated
   b. 2000 & 5500 lbs IW (1, 3, 6 MPH/sec)
   c. M = F / (dV/dt)
2. Acceleration Measurement
   a. Include Zero
   b. Within 100 millisecs
3. Response
   a. < 100 millisec lag to 90%

1. Roll Synchronization ± 0.1 MPH ALL Tests
2. Restraint System
   a. ≤ ± 0.5"

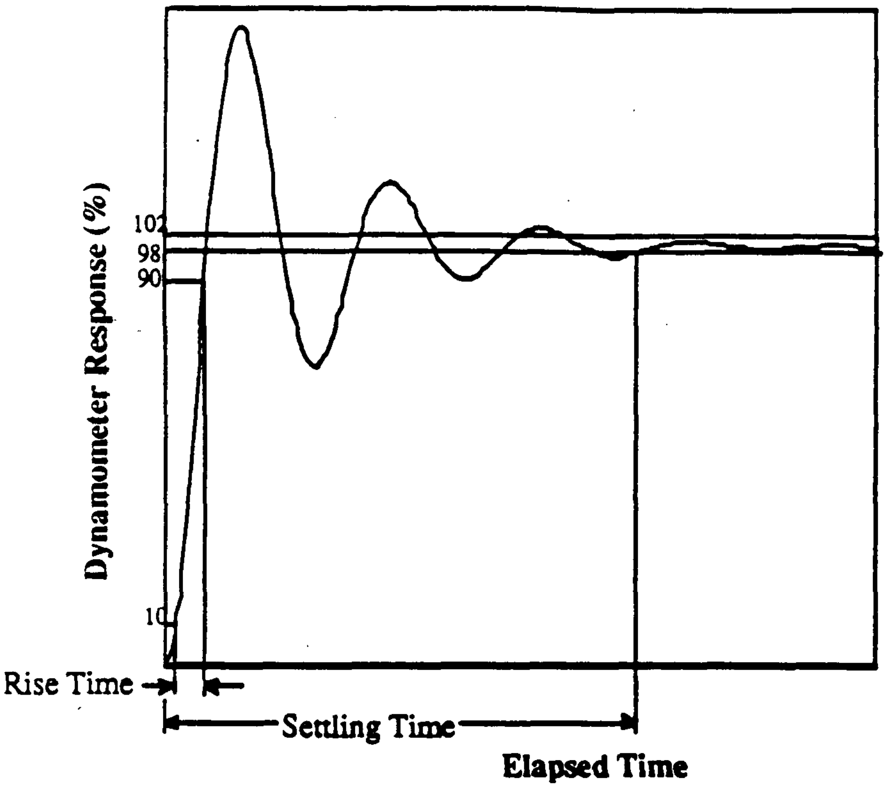
Coastdowns

1. Road Load plus Inertia Simulation
   a. ± 1% of Value Set
2. Max Velocity 80 MPH
3. Min Velocity 5 MPH
4. Min Interval 5 MPH
5. Data Display
   a. Upper & Lower Speeds of Range and Interval
   b. Elapsed Time
   c. Calced Coeffients
   d. Actual Power Absorbed

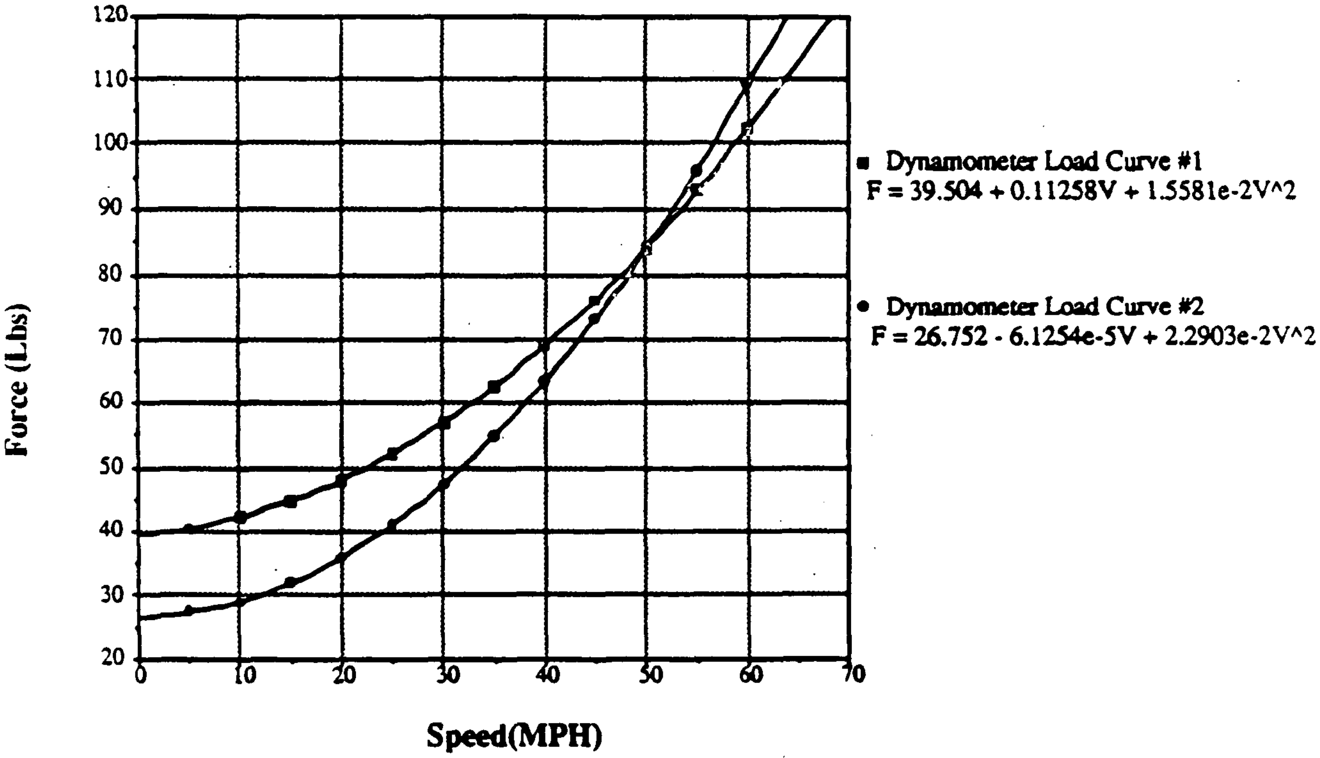
FTP (505s)

1. Test Distance
   a. ±1 Point in 2000
2. Positive Load Repeatability
3. Negative Load Repeatability
4. Error Signal Verification

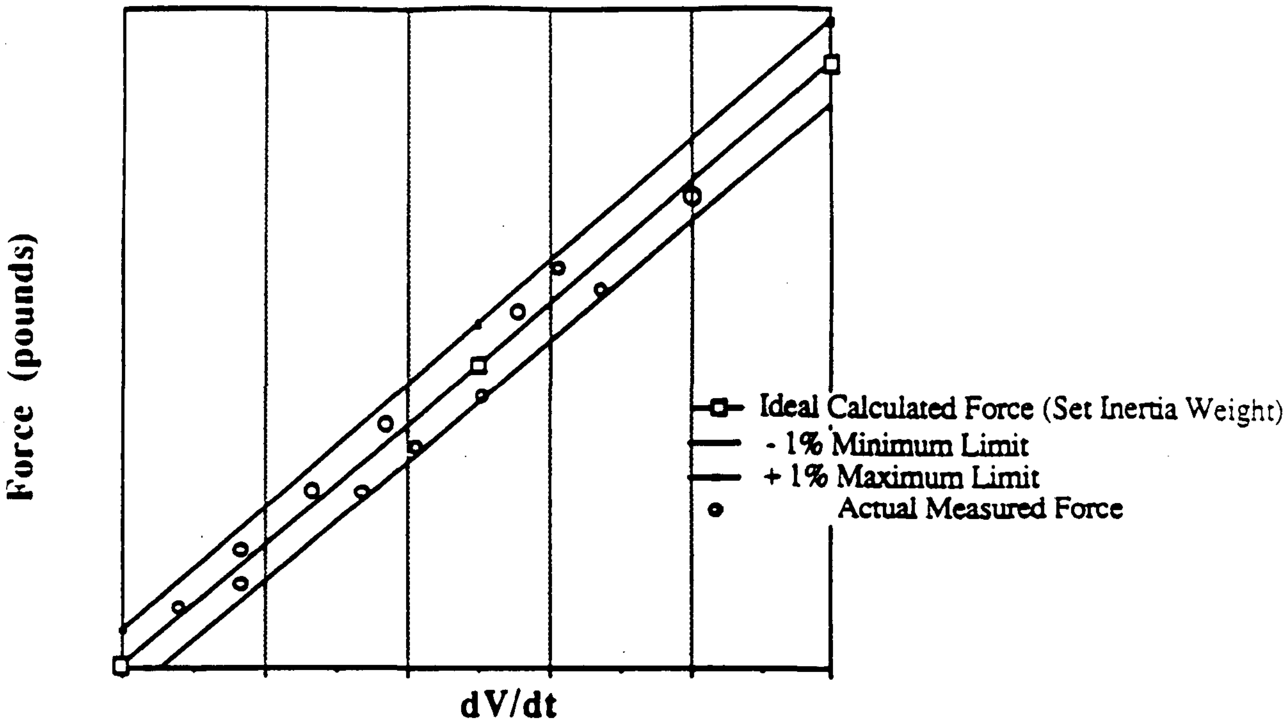
Appendix B - Figure 1 Dynamometer Response Rise and Settling Time Illustration



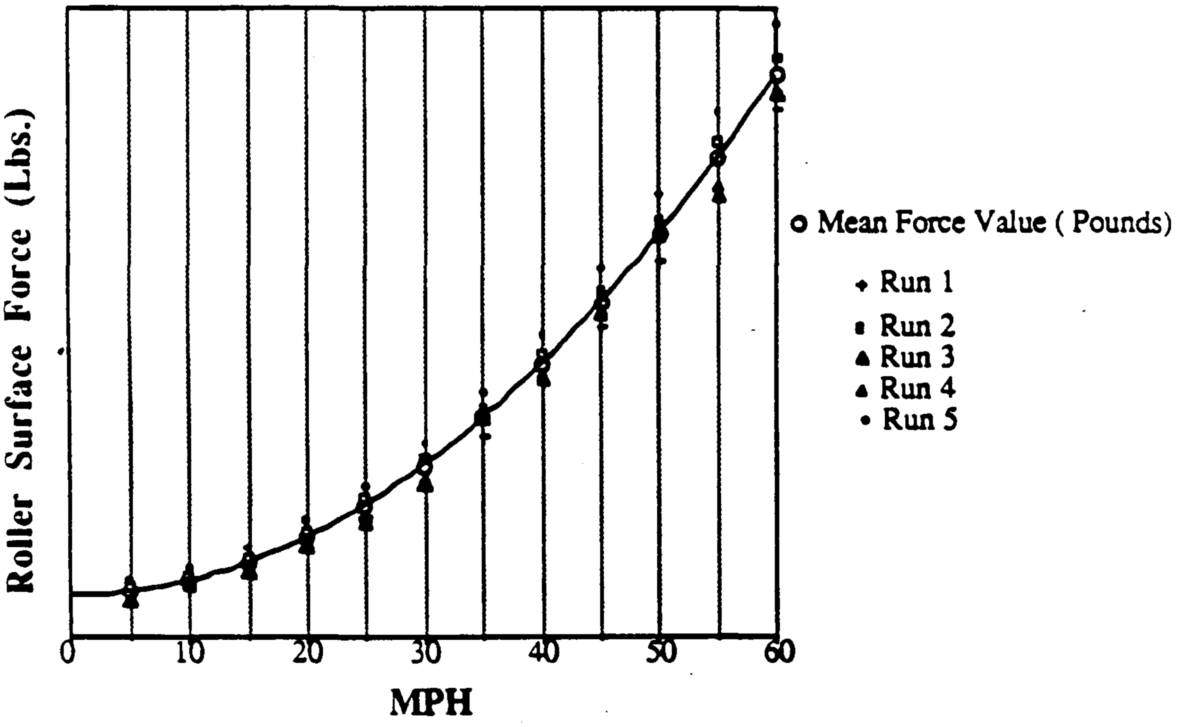
Appendix B - Figure 2 Steady State Dynamometer Load Curves



Appendix C - Figure 3
Force verses Acceleration (dV/dt)



Appendix C - Figure 4
Example of Mean Force Value Graphs



Appendix D

Symbols and Specification Terminology

SYMBOLS		UNITS
A	Constant rolling resistance parameter	N, lb
a	Constant friction characteristic	N, lb
B	Speed proportional rolling resistance parameter	N/kph, lb/mph
b	Speed proportional friction characteristic	N/kph, lb/mph
C	Speed squared (wind) resistance parameter	N/(kph)^2, lb/(mph)^2
c	Speed squared friction characteristic	N/(kph)^2, lb/(mph)^2
D	Parameter for braking and miscellaneous forces	dimensionless
F	Thrust parallel to road or tangential to roll	N, lb
FE	Force Error	N, lb
FEF	Force error fraction	dimensionless
g	Gravitational acceleration	9.807 m/sec^2 or 35.32 kph/sec 32.17 ft/sec^2 or 21.93 mph/sec
M	Effective mass	N, lb
n	Number of data points	
P	Power transmitted through roll surface	kW, hp
r^2	Regression coefficient	dimensionless
S	Distance roll surface moved since distance counter reset	m, ft
$\sin\theta$	Sine of hill angle above (+) or below (-) horizontal	dimensionless
t	Time	sec
dt	Derivative of time	sec
Δt	Finite time interval	sec
V	Speed over road or roll surface	kph, mph
VE	Speed error	kph, mph
dV	Derivative of speed	kph, mph
DV	Finite change of speed	kph, mph
W	Gross weight of vehicle including passengers	N, lb
ω	Angular velocity	rads/sec
dV/dt	Linear acceleration	m/sec^2, ft/sec^2
$d\omega/dt$	Angular acceleration	rads/sec^2

Subscripts

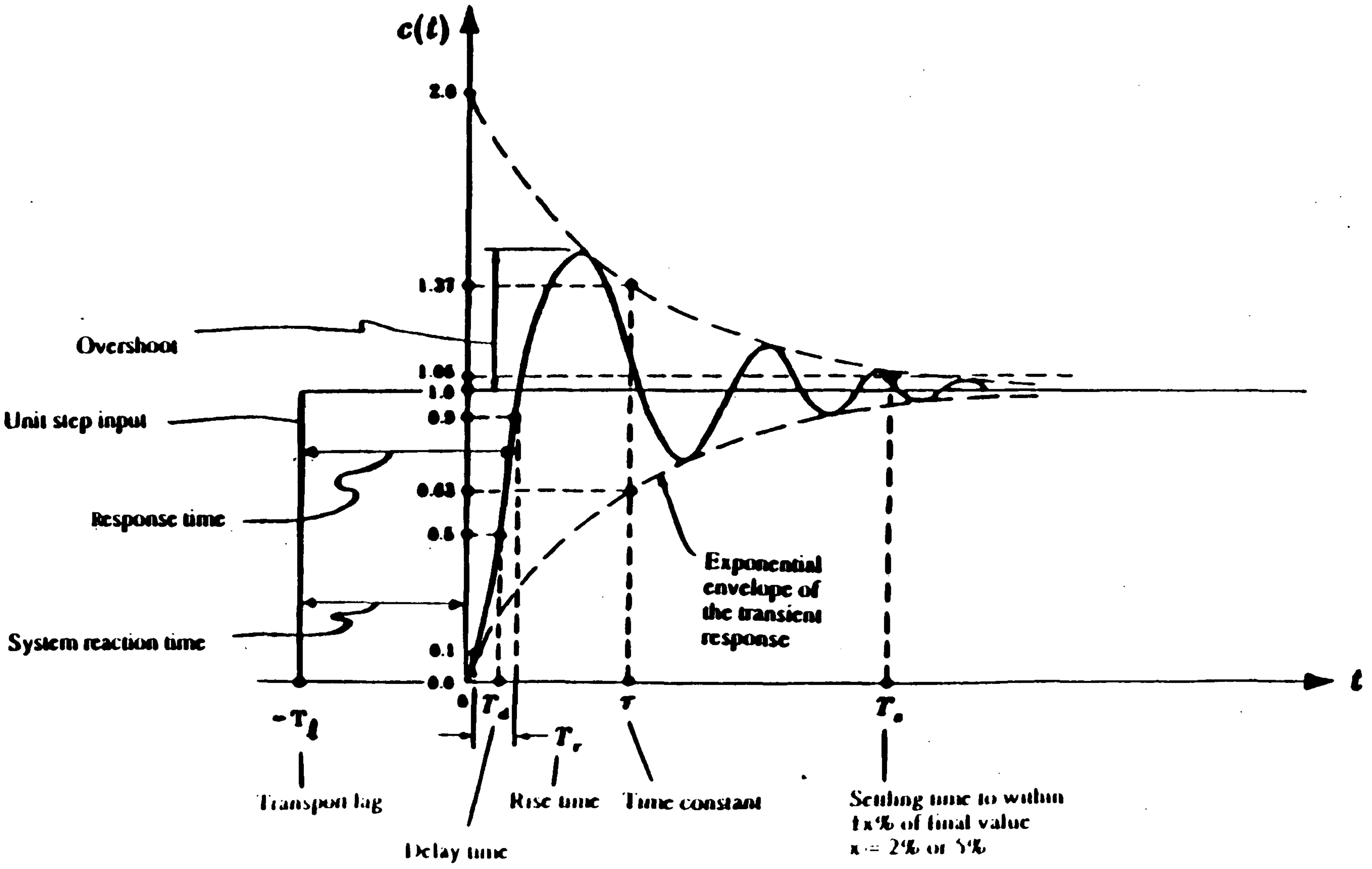
a	Average
c	Calculated
d	Device which provides load in a complex chassis roll system
g	Correction for gravitational and engineering units: Multiplied by 35.31 kph/sec in SI OR Multiplied by 21.93 mph/sec in Imperial system
i	Inside control loop
m	Measured
o	Outside control loop
R	Road equivalent
1, 1-2, 2-3	From point 1, 1 to 2, 2 to 3, etc.

Appendix E

Glossary of Acceptance Criteria Terminology

Overshoot	The overshoot is the maximum difference between the transient and steady-state output of a system in response to a unit step input. Overshoot is a measure of relative stability and is often represented as a percentage of the final value of the steady-state output.
Percent Overshoot	$= [(M_{pt} - c_{ss}) / c_{ss}] * 100\%$ where: M_{pt} = peak value c_{ss} = steady state or final value of c(t)
Delay Time (T_d)	The time delay is defined as the time required for the response to a unit step function input to reach 50 percent of the final value.
Rise Time (T_r)	The rise time is customarily defined as the time required for the response to a unit-step function input to rise from 10 to 90 percent of the final value.
Settling Time (T_s)	The settling time is defined as the time required for the response to a unit-step function input to reach and remain within a specified percentage (frequently 2 to 5 percent) of its final value.
Time Constant (τ)	The predominant time constant is an alternative measure of settling time. The envelope of the transient response decays to 37 percent of its initial value in τ seconds.
Transport Lag (T_l)	The transport lag is the delay in the onset of a change in feedback as a response to a change in system output.
Reaction Time	The system reaction time is defined as the minimum time lag between an input change and the resultant change in system output and is the direct summation of the unrelated, forward transport lags in the system. Reaction time is sometimes incorrectly referred to as Response Time.
Response Time	The response time is defined as the lag between an input change and the time the response rises to 90 percent of the final value.

RESPONSE CHARACTERISTICS OF A SECOND ORDER SYSTEM TO A UNIT STEP FUNCTION



Engineering Operations Division Test Procedures

Gas Laboratory

Col A	Col B		
		TP 101	Preparation of Gravimetric Binary Gas Mixtures
		TP 105A	Gas Naming
		TP 403	Gas Correlation
		TP 502	Gas Cylinder Change

Chemistry Laboratory

		TP 106B	Analysis of Alcohols Extracted from Gasoline
		TP 108A	Vapor Pressure of Gasoline and Gasoline-Oxygenate Blends
		TP 109	Test for Lead-in-Gasoline by Atomic Absorption Spectrometry

Calibration and Verification

		TP 202	Dynamometer Calibration - Frictional Horsepower
		TP 204	Gas Analyzer Calibration Curve Generation
		TP 205	Span Point Change Notice
		TP 207A	Dynamometer Calibration - Road Load Power Control Electronics
		TP 210	Critical Flow Orifice Calibration
		TP 211	Calibration, Operational Verification, and Preventive Maintenance of the Leeds and Northrup Ambient Temperature Monitoring System
		TP 213A	Calibration and Verification of Digital Barometers
		TP 214	Calibration, Operational Verification, and Preventive Maintenance of General Eastern Dew-point Meters
		TP 215	Dry Gas Meter Calibration
		TP 302A	Dynamometer Calibration Verification
		TP 303	Analyzer Monthly Curve Verification

Vehicle Emission Laboratory

		TP 701B	Vehicle Inspection and Acceptance
		TP 702D	Vehicle Fuel Exchange
		TP 703C	Vehicle Preconditioning (Video Drivers Aid)
		TP 704C	Diurnal Heat Build (No Evap) Test
		TP 705B	Diurnal Evaporative Emission (Heat Build) Test
		TP 707C	Sample Collection of the Urban Dynamometer Exhaust Emission Test (Video Drivers Aid)
		TP 708C	Sample Analysis of the Urban Dynamometer Exhaust Emission Test
		TP 709C	Hot Soak Evaporative Emission Test
		TP 710B	Sample Collection of the Highway Fuel Economy Test (Video Drivers Aid)
		TP 711A	Sample Analysis of the Highway Fuel Economy Test
		TP 712A	Quick Check Coastdown
		TP 713B	Sample Collection, Continuous Hydrocarbon Analysis, and Particulate Collection of the Light Duty Diesel Test
		TP 714A	Diesel Particulate Filter Handling and Weighing

Please complete the back section before returning this form

Engineering Operations Division Procedure Documentation Request

Please type or clearly print your name, mailing address, and business phone number in the area provided below.

Please register my name on the Quality Control External Mailing. I wish to receive future documentation for the procedures checked on the front of this form.

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
ANN ARBOR, MICHIGAN 48105

May 23, 1986

OFFICE OF
AIR AND RADIATION

MEMORANDUM

SUBJECT: Calibration and Maintenance Services

FROM: David W. Perkins, Supervisor
Calibration and Maintenance Group

TO: James D. Carpenter, Chief
Facility Support Branch

Attached is a summary of the services currently provided by the Gas Analysis Lab. It covers the service, tolerances, frequency and it identifys the group to whom these services are provided.

Also attached, are updated versions of diagnostic and other test equipment checks performed by the Calibration and Maintenance Group.

If you have any questions or comments please contact me.

Attachments

GAS LAB SERVICES

AREA	FREQUENCY	TOLERANCE	GROUP COVERED
Provide NBS and Gravimetric standards	2 years or as required	±0.5%	TPB, TEB(EOD), SDSB(HD)
Provide Secondary standards	Renamed every year or as required	±0.3%	"
Provide working gases	As required	±1.0%	"
Provide specialty gases	As required	--	"
Provide pure propane for CFO Kits	As required	less than 0.5% contamination	"
Provide FID fuels	As required	±2% of 40-60% blend	"
Provide N_2	As required	less than 1 ppmC hydrocarbon, 1 ppm CO, 400 ppm CO_2 and 0.1 ppm NO contamination	"
Provide zero grade air	As required	18 - 21% O_2, less than 1 ppmC hydrocarbons, 10 ppm CO, 400 ppm CO_2 and 0.1 ppm NO contamination	"

Test Equipment Checks - Analysis Systems

AREA	FREQUENCY	TOLERANCE	GROUP COVERED
I. Analysis System Checks			
A. Blended Gas Cross-check Bag (SAC)	Daily	Response based on standard deviation (sigma) levels listed in QC comments. Includes all laboratory analysis sites. Any reading outside of 3 sigma - immediate shut down. Rerun of analyzers affected after repair. Two of three readings outside of 2 sigma - Investigate within 1-2 days. Rerun of analyzers affected after repair. Four of five reading outside of 1 sigma - Investigate within 3-4 days. Rerun of analyzers affected after repair. Trends or biases - investigated as time permits and at scheduled monthly curve verifications.	TPB
B. CH_4 Sample Correlation	2 Weeks	Response based on the criterion listed above.	
C. NOx Analyzer Converter Efficiency Check	Weekly	90% minimum conversion of NO2 to NO. Investigation required below 95% level.	
D. NO/NOx Flow Balance			
1. Check the NO and NOx response with a known concentration of NO/NOx	4 months	NO should read less than NOx, ±1 ppm from tag	TPB, TEB (E&D), SDSB (HD)
E. CH_4 Peaking and Characterization			
1. CH_4 SAE procedure J-1151A	3 months	Outlined in procedure	TPB, TEB (E&D) SDSB (HD)

TEST EQUIPMENT CHECKS - Analyzers

AREA	FREQUENCY	TOLERANCE	GROUP COVERED
II. Analyzers			
A. HC			
1. Calibration Gases	----	----	TPB, TEB (E&D), SDSB (HD)
a. Zero - HC free air			
b. Major - Air			
c. Minor - C_3H_8			
2. Types of FIDs	----	----	TPB, TEB (E&D), SDSB (HD)
a. Cold FIDs			
1) Bag Measurement			
2) SHED Measurement			
b. Heated FIDs			
1) Diesel Measurement			
3. Types of Fuels	----	----	TPB, TEB (E&D), SDSB (HD)
a. H_2/N_2 Bag			
b. H_2/He Diesel & SHED			
4. Flow	----	----	TPB, TEB (E&D), SDSB (HD)
a. 4 scfh bypass			
5. Verifications	Monthly	Per Proc. 303	TPB, TEB (E&D), SDSB (HD)
6. New Curves	As needed	Per Proc. 204A[1]	TPB, TEB (E&D), SDSB (HD)

---

[1] Per final draft issued 6/1/82.

TEST EQUIPMENT CHECKS - Analyzers

AREA	FREQUENCY	TOLERANCE	GROUP COVERED
a. Curve Fit Deviations[2]	----	Secondaries ±1% of point. On-line working gas ± 1% of Nominal concentration Ave. Dev ±0.5% of point	
b. Degree of Fit	----	3rd	
c. Number of data points	----	7 or more including zero.	
7. Special checks			
a. Methane Response	Monthly	1.10 to 1.20[3]	TPB, TEB (E&D), SDSB (HD)
B. CO_2			
1. Calibration Gases	----	----	TPB, TEB (E&D), SDSB (HD)
a. Zero - N_2			
b. Major - N_2			
c. Minor - CO_2			
2. Optical Filter	----	----	TPB, TEB (E&D), SDSB (HD)
a. CaF_2			
3. Cell Length	----	----	TPB, TEB (E&D), SDSB (HD)
a. 0.3 inch			
4. Flow	----	----	TPB, TEB (E&D), SDSB (HD)

---

[2] In special cases or ranges tolerances can exceed these limits, but still meet Federal Register tolerances on non-certification sites.

[3] Ratio of the response to a 50 ppm CH_4 cylinder. $\frac{\text{Response in } C_3H_8 \times .3}{CH_4 \text{ Concentration of the cylinder}}$

TEST EQUIPMENT CHECKS - Analyzers

AREA	FREQUENCY	TOLERANCE	GROUP COVERED
5. Verifications	Monthly	Per Proc. 303	TPB, TEB (E&D), SDSB (HD)
6. New Curves	As needed	Per Proc. 204A[1]	TPB, TEB (E&D), SDSB (HD)
a. Curve Fit Deviations[2]	----	Secondaries ±1% of point. On-line working gas ± 1% of Nominal concentration Ave. Dev ±0.5% of point	
b. Degree of Fit	----	3rd	
c. Number of data points	----	9 or more including zero.	
d. Nonlinearity	----	Less than 15.0%	
7. Special CO_2 Curves Monthly Updates[4]	As needed	±0.1 defections	TPB
C. CO (LCO & HCO)			
1. Calibration Gases	----	----	TPB, TEB (E&D), SDSB (HD)
a. Zero - N_2			
b. Major - N_2			
c. Minor - CO_2			
2. Optical Filters	----	----	TPB, TEB (E&D), SDSB (HD)
a. HCO (MSA)			
1) CaF_2			
b. LCO (Bendix)			
1) Optical and Band Pass Filter			

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1. Per final draft issued 6/1/82.
2. In special cases or ranges tolerances can exceed these limits, but still meet Federal Register tolerances on non-certification sites.
4. Per EPCN No. 046 4/2/82

TEST EQUIPMENT CHECKS - Analyzers

AREA	FREQUENCY	TOLERANCE	GROUP COVERED
3. Cell Length	----	----	TPB, TEB (E&D), SDSB (HD)
a. HCO (MSA)			
1) 3.5 inch			
b. LCO (Bendix)			
1) 11 1/8 inch			
4. Flow	----	----	TPB, TEB (E&D), SDSB (HD)
a. 6 scfh (HCO & LCO)			
5. Verifications	Monthly	Per Proc. 303	TPB, TEB (E&D), SDSB (HD)
6. New Curves	As needed	Per Proc. 204A[1]	TPB, TEB (E&D), SDSB (HD)
a. Curve Fit Deviations[2]	----	Secondaries ±1% of point. On-line working gas ± 1% of Nominal concentration Ave. Dev ±0.5% of point	
b. Degree of Fit	----	3rd[5]	
c. Number of data points	----	9 or more including zero.	
d. Nonlinearity HCO & LCO	----	Less than 15.0%	
D. NOx			
1. Gases	----	----	TPB, TEB (E&D), SDSB (HD)
a. Zero - HC free air			
b. Major - N_2			
c. Minor - NO			

---

[1] Per final draft issued 6/1/82.

[2] In special cases or ranges tolerances can exceed these limits, but still meet Federal Register tolerances on non-certification sites.

[5] Can be 4th for range 22 (0 - 10,000ppm) and above.

TEST EQUIPMENT CHECKS - Analyzers

AREA	FREQUENCY	TOLERANCE	GROUP COVERED
2. Flow	----	----	TPB, TEB (E&D), SDSB (HD)
a. 2.0 lpm			
3. Verifications	Monthly	Per Proc. 303	TPB, TEB (E&D), SDSB (HD)
4. New Curves	As needed	Per Proc. 204A[1]	TPB, TEB (E&D), SDSB (HD)
a. Curve Fit Deviations[2]	----	Secondaries ±1% of point. On-line working gas ± 1% of Nominal concentration Ave. Dev ±0.5% of point	
b. Degree of Fit	----	2nd	
c. Number of data points	----	7 or more including zero.	
E. CH_4			
1. Gases	----	----	TPB, TEB (E&D), SDSB (HD)
a. Zero - HC free air			
b. Major - Air			
c. Minor - CH_4			
2. Fuel	----	----	TPB, TEB (E&D), SDSB (HD)
a. H_2/He			
3. Flow	----	----	TPB, TEB (E&D), SDSB (HD)
a. 3.5 scfh			
4. Verifications	Monthly	Per Proc. 303	TPB, TEB (E&D), SDSB (HD)

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[1] Per final draft issued 6/1/82.

[2] In special cases or ranges tolerances can exceed these limits, but still meet Federal Register tolerances on non-certification sites.

Test Equipment Checks - Analyzers

AREA	FREQUENCY	TOLERANCE	GROUP COVERED
5. New Curves	As needed	Per Proc. 204A[1]	TPB, TEB (E&D), SDSB (HD)
a. Curve Fit Deviations[2]	----	Secondaries ±1% of point. On-line working gas ± 1% of Nominal concentration Ave. Dev ±0.5% of point	
b. Degree of Fit	----	2nd	
c. Number of data points	----	7 or more including zero.	

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[1] Per final draft issued 6/1/82.

[2] In special cases or ranges tolerances can exceed these limits, but still meet Federal Register tolerances on non-certification sites.

Test Equipment Checks - VA&T Diesel Site

AREA	FREQUENCY	TOLERANCE	GROUP COVERED
III. VA&T Diesel Site			
A. Blower (over Room 532)			
1. Check oil level	Weekly	Add or change as needed	TPB
B. Pump Operation			
1. Check sample and fluid pump operation	Weekly	----	TPB
C. Bulk Stream Filter			
1. Check the differential pressure across the filter on the 700 cfm range	Weekly	Less than 6" H_2O drop	TPB
D. A004 Operation			
1. Check A004 zero, span, sample	Weekly	±0.2 deflection	TPB
E. A016 Operation			
1. Check A016 zero, span, sample	Weekly	±0.2 deflection	TPB
F. Temperatures and Oven			
1. Check the system temperatures	Weekly	As posted	TPB
G. Tunnel Inspection			
1. Visually inspect the tunnel	6 Months	Clean as needed	TPB
D. Motors on Pumps and Circulators			
1. Oil each motor and pump bearing	3 Months	----	TPB
E. Meter Calibration			
1. Check fuel dispensed with 5-gallon standard	6 Months	± 0.1 gal	TPB
F. Temperature Calibration			
1. Check fuel temperature with temperature standard	6 Months	± 2°F	TPB

Test Equipment Checks - VA&T Diesel Site

AREA	FREQUENCY	TOLERANCE	GROUP COVERED
G. Fuel Filters			
1. Replace filters in dispenser	6 Months	----	TPB
H. Process Fluid			
1. Check level	6 Months	1/2 to 7/8 full	TPB
2. Check inhibitor level in fluid	Yearly		
I. Process Tank Bottoms			
1. Draw off sediment from four process tank bottoms	Yearly	----	TPB
J. Liquid Hydrocarbon Detectors			
1. Calibrate and test for proper operation	Yearly	----	TPB
K. Diesel Particulate Dry Gas Meter Calibration			
1. Verification	Monthly	±0.5% Dev. from best fit line. Slope ±0.5% from active slope.	TPB, TEB (E&D)
2. Tylan Adjustment	As needed	±2.0%	TPB

Test Equipment Checks - Analysis Systems

AREA	FREQUENCY	TOLERANCE	GROUP COVERED
F. CO Analyzer H_2O/CO_2 Interference			
1. Inject 3% CO_2 bubbled through room temperature water using the LCO and HCO analyzers	Yearly	Federal Register tolerance = ± 1% of full scale or ±3 ppm on ranges below 300 ppm	TPB, TEB (E&D) SDSB (HD)
G. Replace FID batteries	Yearly	------	TPB, TEB (E&D), SDSB (HD)

Test Equipment Checks - Alarms

AREA	FREQUENCY	TOLERANCE	GROUP COVERED
IV. Alarms			
A. Toxic Gas Warning System			
1. Force cal and sample 50 ppm CO check one site	Weekly	± 5 ppm	TPB, TEB (E&D) SDSB (HD)
2. Sample a bag of 25 ppm NOx and 50 ppm CO from each pick-up	6 Months	± 5 ppm	TPB, TEB (E&D) SDSB (HD)
3. Random check two sites	2 Weeks	± 5 ppm	TPB, TEB (E&D) SDSB (HD)
B. Combustible Gas Alarms			
1. Check calibration of meters with a bag of 5250 ppm propane	Yearly (Change transducers every 2 yrs)	Meter set 25% of LEL, (Alarm set 20% of LEL)	TPB - SHEDS & fueling area

Test Equipment Checks - Soak Area

AREA	FREQUENCY	TOLERANCE	GROUP COVERED
V. Soak Area			
A. Check soak area temperature recorder	2 Months	± 1°F	TPB
B. Check Laboratory Barometers			
1. Calibrate barometers as outlined in TP 213 Procedure	monthly	±.03 "HG	TPB, TEB(E&D), SDSB(HD)
2. Verify barometers calibration as outlined in TP 213 Procedure	weekly	±.05 "HG	

Test Equipment Checks - Fuel System

AREA	FREQUENCY	TOLERANCE	GROUP COVERED
VI. Fuel System			
A. Temperature Controls			
1. Check fuel temperature	Daily at startup	45-52°F Test 45-70°F Prep	TPB
B. Visual Check, Indoor, and Outdoor			
1. Check reteniton dike and pits for debris and water	Weekly	----	TPB
2. Check for leaks at fittings	Weekly	----	TPB
3. Manually cycle pneumatic valves	Weekly	----	TPB
C. Heat Pump Air Filters			
1. Visually inspect and change if needed	2 Weeks	----	TPB

Test Equipment Checks - CVS's

AREA	FREQUENCY	TOLERANCE	GROUP COVERED
VII. CVS			
A. Tracer Gas Injection	Weekly	±2.0% recovery. Failure require two additional propanes within +1.8%. Includes diesel heated FID bag and continuous integrated samples.	TPB
B. Venturi Cleaning and Operational Checks			
1. Visually inspect venturi	Yearly	Clean if necessary	TPB, TEB (E&D)
2. Check pressure and temperature transducers and Vmix computer	Yearly	±2% of calculated	TPB, TEB (E&D)
3. Check CVS dilution filters	Yearly	Less than 1" H_2O drop	TPB, TEB (E&D) SDSB (HD)
C. CVS Maintenance			
1. Change sample filter elements	Weekly	----	TPB
2. Clean probes, check fittings and lines	Monthly	Probe vacuum less than 12" Hg	TPB
3. Check cyclonic separators	Monthly	----	TPB
4. Visually check exhaust pipe gaskets and boots	Weekly	Replace as necessary	TPB
5. Pressure check exhaust pipe	Yearly		TPB
6. CFO Kits. Verify active coefficients	Yearly	± 0.5%	TPB, TEB (E&D) SDSB (HD)

Test Equipment Checks - SHED's

AREA	FREQUENCY	TOLERANCE	GROUP COVERED
VIII. SHEDS			
A. Air Flow and Visual Inspection			
1. Check mixing air flow rate	Yearly	600-1000 CFM	TPB
2. Visually inspect for leaks	Yearly	----	TPB
3. Safety check the door and cable	Yearly	----	TPB
B. Background Check			
1. Check the background at the beginning and end of a 4-hour period, with the door closed.	Yearly	± 0.4 grams/4hrs	TPB
C. 4-hour Retention	Monthly	±4% Retention of injected propane for a 4-hour period. Rerun retention after repairs are completed.	TPB
D. SHED Volumetric Check	Monthly	±2% Measured versus calculated volume (based on FID response).	TPB
E. SHED SAC	Weekly	Any reading outside of the analysis sites, three sigma.	TPB

Test Equipment Checks - Dynamometer

AREA	FREQUENCY	TOLERANCE	GROUP COVERED
IX. Dynamometers			
A. Dynamometers Calibration Verification Procedure TP-302A	Weekly	±1 second - actual versus theoretical coastdown times. ±0.2 HP thumbwheel versus indicated. ±0.1 second QC timer versus master timer. Rerun procedure for area affected after repair.	TPB
B. Dyno Maintenance			
1. Check mag plugs	Monthly	Replace if needed	TPB
2. Clean screens in water lines, fittings and lines	Monthly	----	TPB
3. Lube bearings and couplings	6 Months	----	TPB
4. Check bonding on rolls	Monthly	Replace if needed	TPB
C. H_2O Softeners			
1. Check with soap test	6 Months (Replace yearly)	If less than a 50% reduction in hard water content, replace softner	TPB, TEB (E&D)
D. QC Timers			
1. Check set points 4.50 and 5.50 volts and the 5.00 volt drivers aid cal signal	4 Months	± 0.01 volts	TPB
E. Dew Point Meters			
1. As outlined in Procedures TP 211 and TP 214 Procedures	Weekly and Monthly	Per test procedure	TPB
2. Clean mirrors	30 days	----	TPB

Test Equipment Checks - Dynamometer

AREA	FREQUENCY	TOLERANCE	GROUP COVERED
F. Tire Gauges			
1. Check on site tire gauge with master gauge	6 Months	± 2 psi	TPB
G. Raw Exhaust Analyzers			
1. HC, CO, and CO_2 Span Check with bottles	2 Weeks	± 5% Full Scale	TPB

EOD TEST PROCEDURE

Page 1 of 20

TITLE Critical Flow Orifice Calibration	NUMBER **TP 210A**
ORIGINATOR David Munday, Mechanical Engineer, Calibration and Maintenance	IMPLEMENTATION DATE 02-03-92
RESPONSIBLE ORGANIZATION Calibration and Maintenance	DATA FORM NO. Form 210-01
TYPE OF TEST REPORT Computer Generated	COMPUTER PROGRAM CFO Calibration Program
REPORT DISTRIBUTION Calibration and Maintenance	SUPERSEDES TP 210

REMARKS/COMMENTS

REVISIONS

REVISION NUMBER	REVISION DATE	EPCN NUMBER	DESCRIPTION

IMPLEMENTATION APPROVAL

Test Procedure authorized on 02-03-92 by EPCN #102

TABLE OF CONTENTS

1. Purpose

The purpose of this procedure is to calibrate the Critical Flow Orifice (CFO) Kit for verifying Constant Volume Sampler (CVS) performance.

2. Test Article Description

Critical flow orifices are used for propane tracer gas injections.

3. References

3.1 "Instruction Manual for the Critical Flow Orifice Kit Model 210;" Horiba Instruments Inc.; November 1978

3.2 Letter from Horiba Instruments, Inc., to MSAPC QA Staff, August 1979

3.3 "Brooks Vol-U-Meter Operating Instructions," Models 1052 through 1058; Brooks Instrument Division, Emerson Electric Company, 407 West Vine Street, Hatfield, PA 19440; December 1977; Revision A

3.4 Code of Federal Regulations, Vol. 40; Revised as of July 1, 1990; Parts 86 to 99, Section 86.119

3.5 Memo; David L. Munday; November 5, 1991; Subject: "Equations for CFO Calibration"

4. Required Equipment

The following is a list of the equipment used to perform a CFO calibration:

4.1 Instrument grade propane

4.2 Conoflow single stage regulator; 0-125 lb spring, non-relief type

4.3 Shutoff valve

4.4 The following components are contained in the CFO kit (see Attachment A, page 15):

4.4.1 Precision pressure gauge; 0-100 psig, 8-inch diameter scale or larger, graduated in 0.2-psig increments

4.4.2 Thermometer, 0-120 °F, graduated in 0.5 °F increments

4.5 The following components are contained in the Brooks Vol-U-Meter System (see Attachment B, page 16):

4.5.1 Brooks Vol-U-Meter Control Box

4.5.2 Valves; 3-way solenoid activated; two required

4.5.3 Connection tubing and large, non-restricting vent and dump lines

4.5.4 Back-pressure manometer; 0-4 inches of water, graduated in 0.5-inch increments

4.5.5 Brooks Vol-U-Meter, Model 1057; 3500-cc capacity (this is known as the Brooks Prover)

4.6 Seeka F5 optical sensors; two required

Note: One sensor is mounted at the 500-cc mark and the other is mounted at the 2000-cc mark (see Attachment B, Figure 2, page 16).

4.7 DCI Timer with toggle switch

4.8 Mensor Digital Pressure Gauge (central barometer), Model 11900; 0-32 inches of Hg, graduated in 0.001-inch increments.

4.9 Vertex Floor Scale, Model 2158; equipped with Toledo Indicators, Model 8146

Note: The scale is located in the large soak area.

4.10 CFO Kit/Cart Information (see Attachment C, page 17)

4.11 Form 210-01, "CFO Calibration Data" (see Attachment D, page 18)

4.12 "CFO Calibration Report" (see Attachment E, page 19)

4.13 "MTS CFO Implementation Report" (see Attachment F, page 20)

5. *Precautions*

5.1 Cylinders containing compressed gases are used for this procedure. The technician must be familiar with the "EPA Laboratory Safety Manual" sections dealing with the safe handling, storage, and use of compressed gas cylinders.

5.2 The gas cylinders and equipment must be checked for leakage, damage, and cleanliness.

5.3 Use the Brooks Vol-U-Meter only with approved gases (see the operating manual for details).

5.4 Although CFO kits have orifices for use with CO, pure CO should not be used because of its extremely toxic properties. For safety reasons, EPA does not permit CO injections as a routine practice.

5.5 The CFO kit must be in the gas lab prior to the start of the calibration for a minimum of 20 minutes to ensure the kit is at room temperature.

5.6 After each adjustment is made to the targeted pressure, the flow rate is allowed to stabilize for a minimum of two minutes.

5.7 The precision pressure gauge is graduated in 0.2-psig increments but must be read to the nearest 0.1 psig.

6. *Visual Inspection*

6.1 Inspect all fittings with a leak detection fluid when the system is pressurized to 85 psig (see Section 7 for details).

6.2 Verify that the CFO kit precision pressure gauge reading is zero when the shutoff valve is closed.

6.3 Verify that the Brooks Vol-U-Meter back-pressure manometer reading is zero on the left side of the u-tube when the Control Box is in the "**off**" position. If it is not zero, release the set screws on the sliding metal scale and adjust it so the zero mark lines up with the bottom of the meniscus (on the left side).

7. *Test Article Preparation*

7.1 Disconnect the rosette from the cylinder pressure line.

7.2 Using the Vertex floor scale, weigh the CFO kit/cart (CFO kit, propane cylinder, and cart). Record the CFO total weight on Form 210-01. The CFO Calibration Program calculates the net weight of the propane in the tank by subtracting the tare weight (displayed on each kit/cart combination) from the total CFO kit/cart weight. (See Attachment C, page 17 for details.)

For a valid calibration, the net weight of the propane in the tank must be greater than 25 lbs. If it is not, replace the propane cylinder.

7.3 Ensure that the DCI timer and the Brooks Vol-U-Meter Control Box are plugged into an electrical outlet. If not, plug them in and allow the equipment to warm up for a minimum of two hours.

7.4 Push the Brooks Vol-U-Meter Control Box button to the "**off**" position.

7.5 Connect the cylinder pressure line to the Brooks Vol-U-Meter Control Box inlet pressure fitting.

7.6 Adjust the regulator to 85 psig and allow the pressure to stabilize for a minimum of two minutes.

7.7 Push the Brooks Vol-U-Meter Control Box button to the "**flow**" position.

7.8 Verify that there are no fluctuations in the piston movement and back-pressure manometer reading. If fluctuations exist, notify the Calibration and Maintenance (C&M) Manager.

7.9 When the piston reaches the top optical sensor, turn the cylinder valve counterclockwise to the "**closed**" position. The system will now be pressurized.

7.10 Inspect all fittings with a leak detection fluid.

7.11 Push the Brooks Vol-U-Meter Control Box button to the "**off**" position.

7.12 On Form 210-01, Section A, record all the required data. The previous calibration date and active coefficients are stored in the CFO folder. The CFO folder is stored in the Gas Lab. The cylinder number, purity, and vendor are located on the tank.

8. *Test Procedure*

A total of 24 data points are collected for a CFO calibration. Each data point consists of a measured supply pressure, within the 60 to 95 psig range, and an elapsed time reading. The target pressure starts at 60 psig and increases to 95 psig, in 5-psig increments, then decreases from 95 to 60 psig in 5-psig increments.

To provide random confirmation data, the operator then sets 60, 75, 85, 70, 90, 95, 80, and 65 psig.

For each of the target pressures, perform the following steps:

Sequence	Description
100	Turn the cylinder valve clockwise to the "**open**" position.
101	Push the Brooks Vol-U-Meter Control Box button to the "**off**" position.
102	Adjust the regulator to set the supply pressure to within ±0.4 psi of the target pressure, e.g., 60 psig must be 59.6 - 60.4 psig, 75 psig must be 74.6 - 75.4 psig, etc., for all target data points.
103	Allow the set pressure to stabilize for a minimum of two minutes. The stabilized pressure must be within ±0.4 psig of the target pressure.
104	Read the precision pressure gauge to the nearest 0.1 psig.
105	On Form 210-01, Section B, record the observed pressure under the column **Actual psig**.
106	When the Brooks Vol-U-Meter piston has descended to the bottom of the chamber, push the DCI toggle switch to the right to stop the timer. Reset the timer to zero by pushing the toggle switch to the left.
Note:	If this is the start of the calibration process, the piston will already be at the bottom of the chamber.
107	Push the Brooks Vol-U-Meter Control Box button marked "**flow.**" This directs the flow into the Brooks Vol-U-Meter, causing the piston to rise.

Sequence **Description**

108 Verify that the Brooks Vol-U-Meter back-pressure manometer reading is 1.5 inches of water. If it is not, notify the C&M Manager.

109 The DCI timer will start when the optical sensor is activated by the top edge of the piston reaching the 500 cc mark on the steel scale.

110 Continue to flow the gas until the piston reaches the upper optical sensor (2000-cc mark). The DCI timer will automatically stop when the top edge of the piston reaches this point, thus indicating the elapsed time to flow 1500 cc.

111 Push the Brooks Vol-U-Meter Control Box button marked "**off.**"

On Form 210-01, under the column marked **Δt seconds** (**XX.XXX**), record the elapsed time obtained from the timer readout.

Note: The Δt must be recorded before the Brooks Vol-U-Meter piston reaches the lower optical sensor (timer automatically resets). If the time has not been recorded prior to the piston reaching this point, repeat Steps 102 through 111.

112 Repeat Steps 102 through 111 for each of the 24 calibration target pressures listed on Form 210-01 and record the required data. Each target pressure must be set in the order shown on Form 210-01.

113 When all of the required data points have been collected, complete Form 210-01, Section C.

Note: See the Data Processing Flow Chart on page 9.

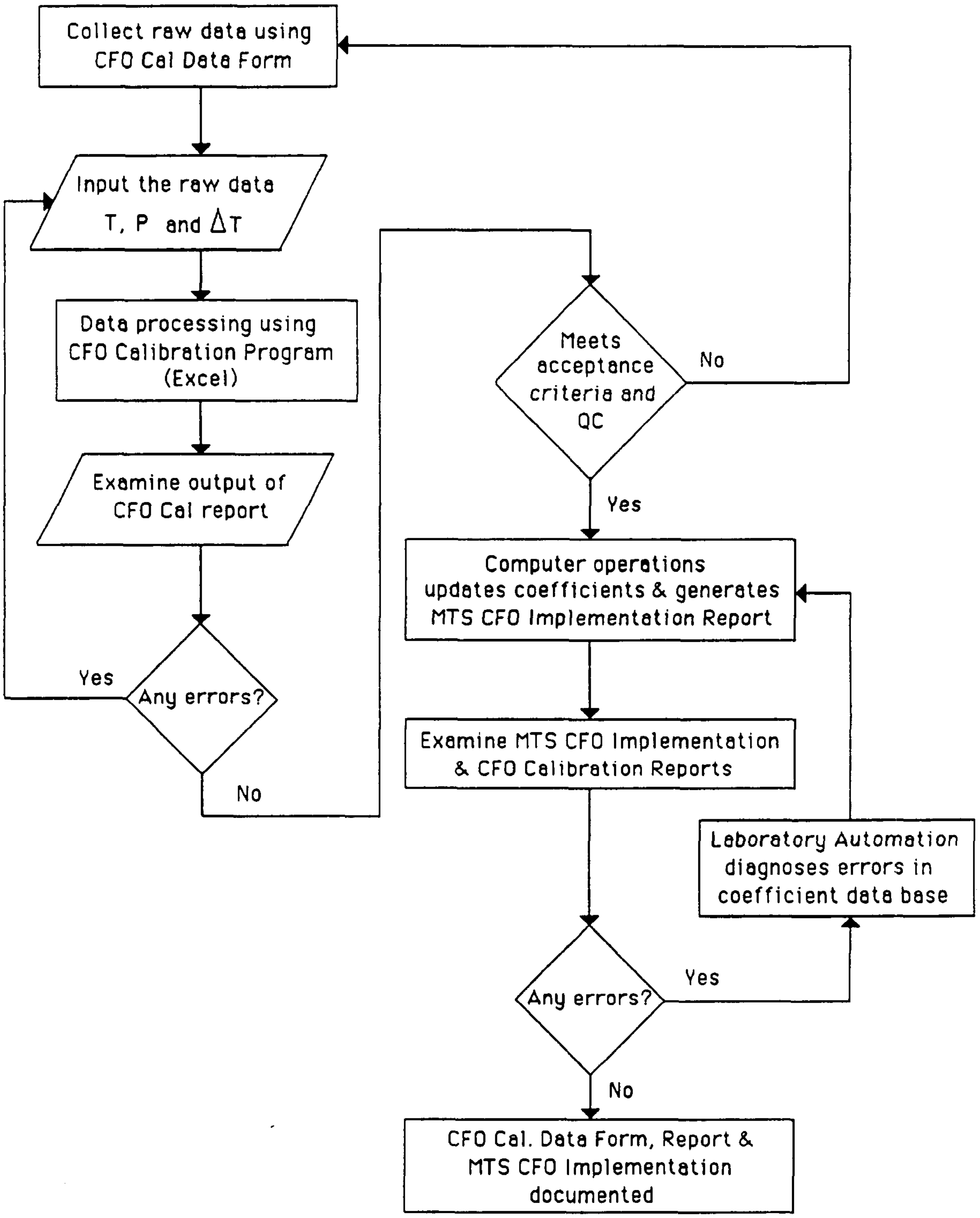
9. *Data Input*

9.1 The technician opens the CFO Calibration Program (on the C&M Macintosh computer) and enters the data recorded on Form 210-01.

9.2 When all data has been entered, use the scroll bar and move the screen view to the right and preview the "CFO Calibration Report."

9.3 The technician verifies that the "CFO Calibration Report" does not contain any acceptance criteria flags. If flags appear, see Section 12 for corrective action.

Data Processing Flow Chart



9.4 The technician saves the file by pressing the **"Save Report"** button. This will automatically save the data to the CFO Calibration folder on the hard drive and assign the file name as "CFO Cal Kit # NNNNN MM/DD/YY." The NNNNN will contain the kit number, and the MM/DD/YY will have the date that the data were entered into the computer.

9.5 The technician then prints the "CFO Calibration Report" by clicking on the **"Print Report"** button.

9.6 A technician, other than the one performing the CFO calibration, verifies that the data in the "CFO Calibration Report" and Form 210-01 are the same.

If no corrections are needed, the technician signs and dates the "CFO Verification Report." The report is taken to the C&M Manager.

If corrections are needed, they are identified on the report and it is returned for corrective action to the technician who performed the CFO calibration. The technician makes the corrections and repeats Steps 9.1 through 9.5.

9.7 The C&M Manager then signs and dates the "CFO Calibration Report," indicating that the coefficients can be updated on MTS.

9.8 The technician inserts a blank 4-inch floppy diskette into the Macintosh drive. He/She opens the CFO Calibration folder and copies the file named 1011D-CFOCAL onto the floppy.

9.9 At the computer input/output window, the technician completes a job request form. He/She then places the job request form, the 4-inch floppy diskette (with the electronic copy of the 1011D-CFOCAL file), and the signed paper copy of the "CFO Calibration Report " into an envelope.

The envelope is then placed in the input basket. Computer operations will check that the C&M Manager has signed the report before implementing the MTS coefficients. Implementation of the new coefficients on MTS makes them available to the Tracer Gas Injection Program (1011S-TGI).

9.10 Computer operations will generate an MTS CFO Implementation Report (see attached sample) containing the following information:

Kit #

Coefficients A, B, and C

Entered By

Implementation Date

9.11 The envelope containing the 4-inch floppy diskette and paper copies of the "CFO Calibration Report" and the "MTS CFO Implementation Report" are placed in the output basket where they can be picked up by the technician.

9.12 The technician verifies that the data in the "CFO Calibration Report" and "MTS CFO Implementation Report" are the same. If no corrections are needed, the technician signs and dates the "CFO Calibration Report."

If corrections are needed, they are identified on the "MTS CFO Implementation Report" and it is taken to the Laboratory Automation Group for corrective action.

9.13 When Steps 9.1 through 9.12 have been completed, the technician opens the CFO Calibration Program and pushes the **"Update Data Base"** button. This will update the CFO calibration data file named "1011D-CFOCAL" with the new coefficients.

10. Data Analysis

10.1 The "CFO Calibration Report" is examined for acceptance criteria flags. If flags appear, see Section 12 for corrective action.

10.2 The data in the "CFO Calibration Report" and Form 210-01 are compared independently by two technicians.

10.3 The "CFO Calibration Report" is reviewed and signed by the C&M Manager authorizing that the coefficients can be updated on MTS.

10.4 The technician compares data in the "CFO Calibration Report" and "MTS CFO Implementation Report" to ensure that they are the same.

If no corrections are needed, the technician signs and dates the CFO Calibration Report.

11. Data Output

11.1 The "CFO Calibration Report," "MTS CFO Implementation Report," and Form 210-01 are filed in the C&M CFO folder.

11.2 The technician notifies the C&M midnight shift that the CFO kit has been calibrated and is ready for use.

12. Acceptance Criteria

The data must meet the following six criteria to be valid; a flag will be displayed on the "CFO Calibration Report" if the data do not meet the criteria.

12.1 The net weight of propane in the tank must be greater than 25 lbs. prior to the start of the calibration. If not, **Flag #1** appears on the spreadsheet and the calibration is void. Replace the propane cylinder, return to Section 7, complete a new Form 210-01, and repeat the calibration procedure.

12.2 The difference between the start and end back-pressure readings must be 0.0 inches H_2O (a reading other than zero indicates friction in the Vol-U-Meter tube). If it is not zero, **Flag #2** appears on the spreadsheet and the calibration is void. Notify the C&M Manager, return to Section 7, complete a new Form 210-01, and repeat the calibration procedure.

12.3 The difference between the start and end barometric pressure readings must be less than or equal to 0.12 inches Hg. If not, **Flag #3** appears on the spreadsheet and the calibration is void. Return to Section 7, complete a new Form 210-01, and repeat the calibration procedure. If after a second calibration attempt the data are not within this limit, notify the C&M Manager.

12.4 The difference between the start and end CFO kit thermometer temperature readings must be less than or equal to 2.0 °F. If not, **Flag #4** appears on the spreadsheet and the calibration is void. Allow the kit temperature to stabilize for a minimum of two hours, return to Section 7, complete a new Form 210-01, and repeat the calibration procedure. If after a second calibration attempt the data are not within this limit, notify the C&M Manager.

12.5 The percent of point deviation from the best fit curve must be within ±0.3% . If not, **Flag #5** appears on the spreadsheet and the out-of-tolerance data points (actual psig and Δt seconds) may be rerun one more time. Cross out the bad data with a single line and initial the area. Open the CFO Calibration Program and make the necessary changes. If the flag persists, the calibration is void.

12.5.1 Clean the CFO kit ruby orifice fitting in a sonic bath.

12.5.2 Return to Section 7, complete a new Form 210-01, and complete the calibration procedure.

12.5.3 If after a second complete calibration attempt the data are not within the specified tolerance, replace the ruby. Return to Section 7, complete a new Form 210-01, and complete the calibration procedure.

12.6 The previous calibration date entered into the computer must match the previous calibration date stored in the data base. If not, **Flag #6** appears on the spreadsheet indicating that the coefficients are inactive. Look up the previous calibration date in the CFO folder and verify that the correct date has been recorded on Form 210-01. If the calibration date is recorded correctly, a computer problem may exist or a report may be missing in the CFO folder; notify the C&M Manager.

13. Quality Control Provisions

13.1 The fittings are inspected with a leak detection fluid.

13.2 The CFO kit precision pressure gauge is verified to read zero when the shutoff valve is closed.

13.3 The Brooks Vol-U-Meter back-pressure manometer is verified to be reading zero (for the left side of the u-tube) when the Control Box is in the "**off**" position and the piston is at rest on the bottom.

13.4 If the DCI timer and the Brooks Vol-U-Meter Control Box are not plugged in, they are allowed to warm up for a minimum of two hours.

13.5 The piston movement and back-pressure manometer reading are verified to ensure that there are no fluctuations.

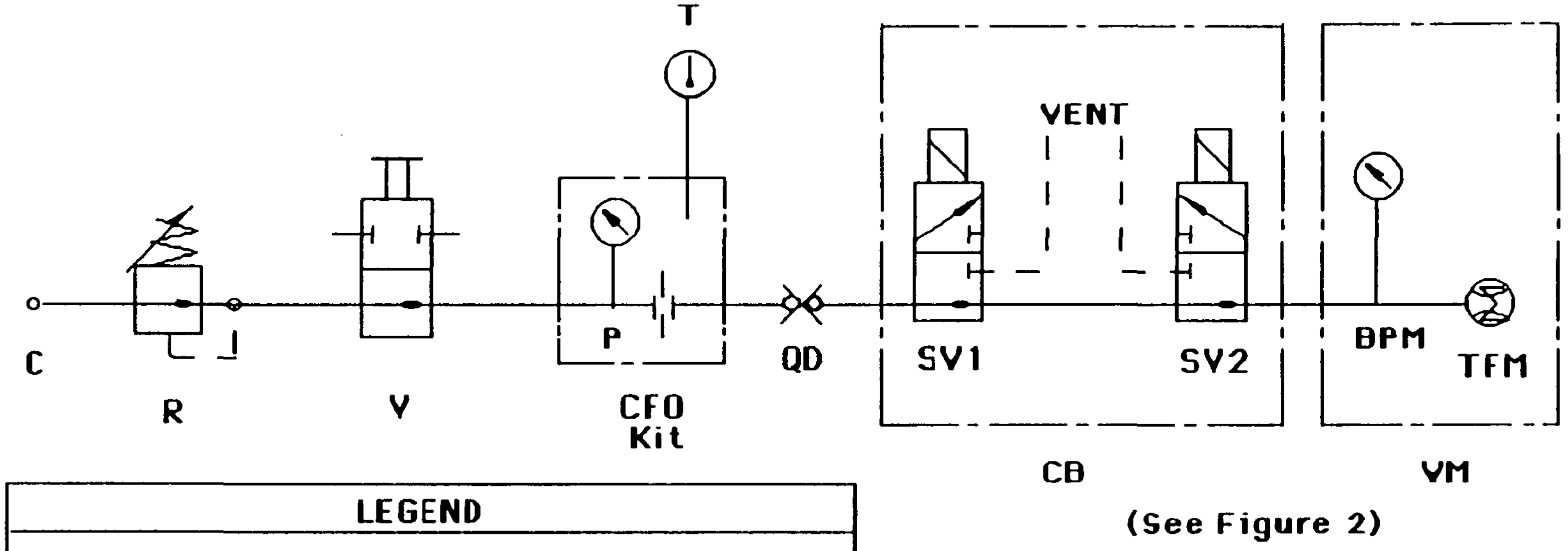
13.6 The flow rate is allowed to stabilize for a minimum of two minutes after each adjustment.

13.7 The net weight of the propane in the tank must be greater than 25 lbs.

13.8 The CFO kit temperature is allowed to stabilize for 20 minutes prior to performing the calibration.

13.9 When the piston is moving, the back-pressure manometer must read 1.5 inches of water.

13.10 Actual pressure must be within ± 0.4 psig of the target pressure.



LEGEND

C---------	Cylinder, propane
R---------	Regulator, non-relief type
V---------	Valve, shutoff
CFO------	Critical Flow Orifice kit
P---------	Pressure gauge, precision
T---------	Thermometer, kit
QD-------	Quick Disconnect
CB-------	Control Box, Brooks Vol-U-Meter
SV1,2----	Solenoid Valve, three-way
VM-------	Vol-U-Meter, Brooks
BPM------	Back-Pressure Manometer
TFM------	Totalizing Flow Meter (Tube/Piston)

Figure 1 CFO Calibration Schematic

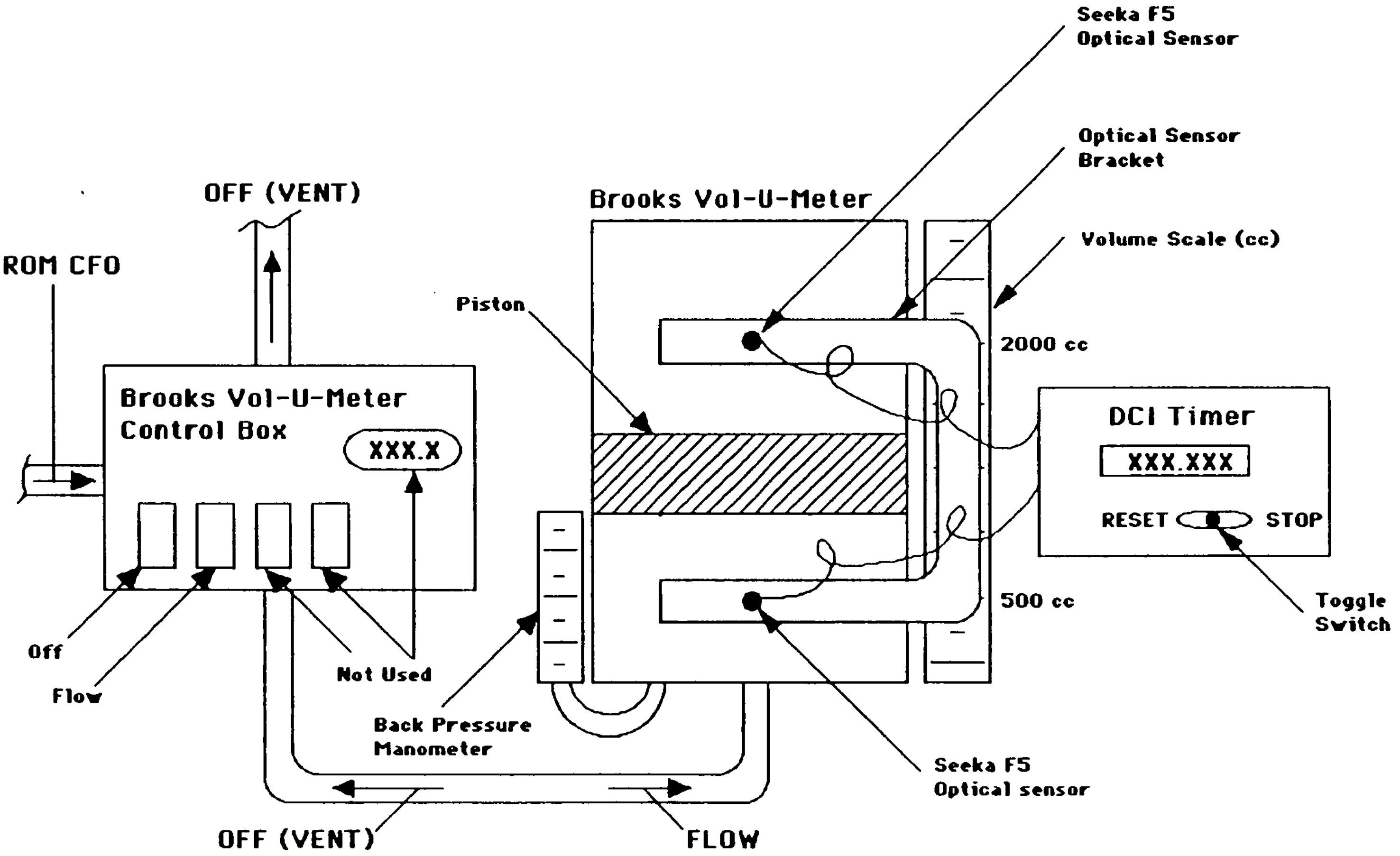


Figure 2 Brooks Vol-U-Meter, Control Box and DCI Timer

CFO Kit/Cart Information

The propane weight is determined by subtracting the CFO kit/cart tare weight, displayed on each kit/cart combination, from the CFO kit/cart total weight. The propane weight must be greater than 25 lbs. for a valid calibration.

The following items contribute to the CFO kit/cart total weight:

1. CFO kit
2. Propane cylinder with valve, regulator, and propane gas
3. Portable cart

The following items contribute to the CFO kit/cart tare weight:

1. CFO kit
2. Empty propane cylinder with valve and regulator
3. Portable cart

Listed below are the tare weights of the CFO kits currently in use. Note that the CFO tare weights differ from kit to kit.

Kit Number	Empty Propane Cylinder (lb)	CFO Kit/Cart (lb)	Tare Weight (lb)
038625	95	183	278
086942	95	180	275
181102	95	150	245
181103	95	150	245
106380	95	182	277

CFO Calibration Data

Section A:

Technician's Name: ____________________

CFO Kit Number: ____________________

Current Date: ____________________

Date of Previous Calibration: ____________

Calibration Start Time: ____________

Start CFO Kit Thermometer Temp: __________ °F

Cylinder #: ______________

Cylinder Vendor: ______________

Cylinder Purity: ______________

CFO Total Weight: ____________ lb

Start Back Pressure: ____________ inches H_2O

Start Barometer: ____________ inches Hg

Section B: Collect 24 calibration points in the order listed below.

Target psig	Actual psig, (XX.X)	Δt seconds, (XX.XXX)
(1) **60**	(1) ________	(1) ________
(2) **65**	(2) ________	(2) ________
(3) **70**	(3) ________	(3) ________
(4) **75**	(4) ________	(4) ________
(5) **80**	(5) ________	(5) ________
(6) **85**	(6) ________	(6) ________
(7) **90**	(7) ________	(7) ________
(8) **95**	(8) ________	(8) ________
(9) **95**	(9) ________	(9) ________
(10) **90**	(10) ________	(10) ________
(11) **85**	(11) ________	(11) ________
(12) **80**	(12) ________	(12) ________
(13) **75**	(13) ________	(13) ________
(14) **70**	(14) ________	(14) ________
(15) **65**	(15) ________	(15) ________
(16) **60**	(16) ________	(16) ________
(17) **60**	(17) ________	(17) ________
(18) **75**	(18) ________	(18) ________
(19) **85**	(19) ________	(19) ________
(20) **70**	(20) ________	(20) ________
(21) **90**	(21) ________	(21) ________
(22) **95**	(22) ________	(22) ________
(23) **80**	(23) ________	(23) ________
(24) **65**	(24) ________	(24) ________

Section C:

Calibration End Time: ____________________

End CFO Kit Thermometer Temp: __________ °F

Ruby Cleaned ______ YES ______ NO

End Back Pressure: ____________ inches H_2O

End Barometer: ____________ inches Hg

Ruby Replaced ______ YES ______ NO

Comments: ____

CFO Kit No: 106380 **CFO Calibration Report** **Processed: Jan-30-1992 13:34**

CFO Kit Number	Technician Name	Cylinder Number	Cylinder Purity	Cylinder Vendor	CFO Total Wght (lbs)	Date of Previous Calibration	Current Date
106380	Parker	RC5864	99.50%	Liquid Carbonic	300	8/1/91	11/8/91

	Back Pressure ("H2O)	Barom. Pressure ("Hg)	Kit Temp °F	Cal. Time
START	1.5	29.26	75.5	1228
END	1.6	29.20	74.5	1431
AVG.	1.6	29.23	75.0	
Range	-0.1	0.06	1.0	
FLAGS	# 2			

Delta Vol (cc)	CFO Tare Weight (lbs)
1500	277

Propane Weight (lbs)
23

FLAG # 1

8/1/91 Coefficients		New Coefficients	
A=	2.56113E-06	A=	-8.90518E-06
B=	7.44287E-03	B=	9.43086E-03
C=	-1.33618E-02	C=	-1.21324E-01

RUBY	YES/NO
CLEANED	No
REPLACED	No

#	Actual PSIG	Delta t (SECS)	$Q_s \cdot \sqrt{T_{abs}}$	$A \cdot P_{abs}^2 + B \cdot P_{abs} + C$	% Diff	FLAGS
1	60.0	134.061	0.530292	0.530696	-0.08%	
2	65.0	124.454	0.571227	0.571006	0.04%	
3	70.0	117.014	0.607547	0.610871	-0.54%	# 5
4	75.0	109.331	0.650241	0.650290	-0.01%	
5	80.0	103.084	0.689646	0.689264	0.06%	
6	85.0	97.832	0.726669	0.727793	-0.15%	
7	90.0	92.953	0.764811	0.765877	-0.14%	
8	95.0	88.491	0.803376	0.803515	-0.02%	
9	95.0	88.507	0.803230	0.803515	-0.04%	
10	90.0	92.775	0.766279	0.765877	0.05%	
11	85.0	97.755	0.727242	0.727793	-0.08%	
12	80.0	102.711	0.692151	0.689264	0.42%	# 5
13	75.0	109.021	0.652090	0.650290	0.28%	
14	70.0	116.598	0.609715	0.610871	-0.19%	
15	65.0	124.761	0.569822	0.571006	-0.21%	
16	60.0	133.854	0.531112	0.530696	0.08%	
17	60.0	133.628	0.532011	0.530696	0.25%	
18	75.0	108.959	0.652461	0.650290	0.33%	# 5
19	85.0	97.796	0.726937	0.727793	-0.12%	
20	70.0	116.894	0.608171	0.610871	-0.44%	# 5
21	90.0	92.847	0.765685	0.765877	-0.03%	
22	95.0	88.387	0.804321	0.803515	0.10%	
23	80.0	102.993	0.690256	0.689264	0.14%	
24	65.0	124.146	0.572644	0.571006	0.29%	

#	Actual PSIG	Delta t (SECS)	$Q_s \cdot \sqrt{T_{abs}}$	$A \cdot P_{abs}^2 + B \cdot P_{abs} + C$	% Diff	FLAGS
1	60	134.061	0.530292	0.530696	-0.08%	
16	60	133.854	0.531112	0.530696	0.08%	
17	60	133.628	0.532011	0.530696	0.25%	
2	65	124.454	0.571227	0.571006	0.04%	
15	65	124.761	0.569822	0.571006	-0.21%	
24	65	124.146	0.572644	0.571006	0.29%	
3	70	117.014	0.607547	0.610871	-0.54%	# 5
14	70	116.598	0.609715	0.610871	-0.19%	
20	70	116.894	0.608171	0.610871	-0.44%	# 5
4	75	109.331	0.650241	0.650290	-0.01%	
13	75	109.021	0.652090	0.650290	0.28%	
18	75	108.959	0.652461	0.650290	0.33%	# 5
5	80	103.084	0.689646	0.689264	0.06%	
12	80	102.711	0.692151	0.689264	0.42%	# 5
23	80	102.993	0.690256	0.689264	0.14%	
6	85	97.832	0.726669	0.727793	-0.15%	
11	85	97.755	0.727242	0.727793	-0.08%	
19	85	97.796	0.726937	0.727793	-0.12%	
7	90	92.953	0.764811	0.765877	-0.14%	
10	90	92.775	0.766279	0.765877	0.05%	
21	90	92.847	0.765685	0.765877	-0.03%	
8	95	88.491	0.803376	0.803515	-0.02%	
9	95	88.507	0.803230	0.803515	-0.04%	
22	95	88.387	0.804321	0.803515	0.10%	

COMMENTS: QC Limit Flags are present.
This CFO Kit has problems. This is a sample report.

DATA VERIFIED BY: DATE:

COEFFICIENTS OK TO IMPLEMENT: DATE:

COEFFICIENTS VERIFIED BY: DATE:

MTS CFO Implementation Report

Kit :

New Coefficients:

A=

B=

C=

Entered By:

Implementation Date:

EOD TEST PROCEDURE

TITLE Gas Analyzer Calibration Curve Generation	NUMBER **TP 204**
ORIGINATOR Linda Hormes	IMPLEMENTATION DATE 11-14-79
RESPONSIBLE ORGANIZATION Laboratory Engineering Branch, Calibration and Maintenance Group	DATA FORM NO. LB-205 DB-AA-601
TYPE OF TEST REPORT Analyzer Calibration Curve Analysis	COMPUTER PROGRAM 1251C-CALB
REPORT DISTRIBUTION C&M, Analyzer Sites, QC, and Data Validation	SUPERSEDES N/A

REMARKS/COMMENTS

-

REVISIONS

REVISION NUMBER	REVISION DATE	EPCN NUMBER	DESCRIPTION
(1)	12/15/88	EPCN 70	This EPCN authorized use of the Horiba NDIR CO/CO2 analyzers.

IMPLEMENTATION APPROVAL

Test Procedure authorized on 11/14/79

TABLE OF CONTENTS

1. *Purpose*

The purpose of this procedure is to generate analyzer calibration curves for all ranges of all analyzers used by Light Duty, Heavy Duty, and Evaluation and Development. These curves are then used in the monthly analyzer calibration verifications (TP-303) which are done to assess analyzer curve stability. A new curve must be generated whenever an existing curve is found to be out of tolerance, when a new analyzer is placed into service, when two or more secondary standard cylinders have been replaced, or when the top secondary standard cylinder is named or replaced. NOTE: Whenever a new curve is generated, a Span Point Change Notice must be completed. Refer to Test Procedure 205, Span Point Change Notice.

2. *Test Article Description*

All gas analyzers used for measuring vehicle exhaust and evaporative emissions

3. *References*

3.1 Federal Register, Vol. 42, No. 124; June 28, 1977; Sections 86.121-78 to 86.124-78

3.2 EPA memo, Subject: Light Duty Testing Operations Tolerances; T. Hudyma; April 14, 1977

3.3 EPA Laboratory Safety Manual

4. *Required Equipment*

4.1 Calibrated digital voltmeter (DVM) with .01 volt resolution or better

4.2 Secondary standard calibration cylinders for the appropriate gas and range being analyzed. See Step 7.13 for the method of selecting the correct cylinders. All secondary cylinders must have undergone Test Procedure 403, Gas Correlation, before they may be used as calibration gases.

4.3 Portable calibration line of Teflon covered with braided stainless steel for introducing the calibration gases into the analysis system

4.4 Form AA-601, Exhaust Gas Analyzer Data Form

4.5 Form LB-205, Span Point Change Notice

5. *Precautions*

5.1 The technician performing the calibration <u>must</u> be familiar with the Laboratory Safety Manual, especially Chapters 2 through 6, which deal with the safe handling of compressed gases.

5.2 Cylinder carts must not obstruct doorways at the analysis sites. Doorways must remain closed to insure effectiveness of the fire extinguishing system.

5.3 The technician must insure that there is no leakage of toxic gases and that the analyzer is properly vented to the exhaust ventilation system.

5.4 Any time a new curve is generated or updated, a span point change notice <u>must</u> be filed and the new span point posted at that analysis site as soon as the point is known. No official testing may be done until the new span point is posted.

6. *Visual Inspection*

Inspect the portable calibration line for cracks, bends, worn spots, etc.

7. *Test Article Preparation*

7.1 Verify that the analyzer is operating according to the specifications given in the instruction manual and/or in-house analyzer specification sheet.

(1) 7.2 Verify that the analyzer is set in the proper operating configuration:

NOx analyzer (TECO 10A): OZONE - "ON"
POWER - "ON"
NO-NOx - "NOx"

Methane analyzer: "CONTINUOUS CYCLE"
(Bendix 8295) timer switch - "AUTO"
valve switch - "AUTO"

Values for pressure, temperature, and flow rates which must be observed are posted at the individual sites and on the curve printout. Refer to the instruction manual and/or the in-house analyzer specification sheet for more detailed instructions, or consult with the Team Leader.

7.3 Check that the strip chart recorder has sufficient paper and is inking properly.

7.4 Check the calibration label on the calibrated DVM to insure that the due date has not been exceeded. If it has, the DVM must be recalibrated before the curve generation can proceed.

7.5 Allow the strip chart recorder sufficient warm-up time (minimum of 20 minutes).

7.6 Check the electrical zero of the strip chart by shorting the input terminals and adjusting to zero ± .1% of full scale.

7.7 Attach the calibrated DVM to the analyzer output jack.

7.8 Using the on-line working gases, zero and span the instrument on the appropriate multiplier range to verify that the strip chart recorder reading and analysis bench DVM reading equal the calibrated DVM reading ± .2% of full scale. If this tolerance is exceeded, make the necessary adjustments to the recorder or bench DVM and repeat the zero and span check.

7.9 While performing Step 7.8, verify that the analyzer output noise level is less than ± .5% of full scale. Noise is defined as short-term cyclical variation of a signal from some average value.

7.10 While performing Step 7.7, verify that the analyzer output drift does not exceed ± .2% of full scale per two minutes. Drift is defined as long-term directional change of value.

7.11 Record the following data on the strip chart:

Analyzer vendor
Date
Test site number
Operator's name and ID number
Gas analyzed and dilutent gas (e.g., CO/N_2)
Full scale (100%) voltage
Sample flow rate
Monitor set point on magnehelic
Zero gain setting
Span gain setting
Air pressure (FID and GC analyzers)
Fuel pressure (FID and GC analyzers)
Sample pressure (FID and GC analyzers)
Fuel type (FID and GC analyzers)
Standard laboratory range
Full scale concentration value of range being analyzed
Analyzer property ID number

7.12 At analysis sites where a calibration port IS provided, turn off the span gas flow to the untested analyzers by closing the valves of the appropriate gases located in the master gas control box at the site. This prevents waste of span gases. Switch the analyzer being used to the OFF mode and select SPAN for the on-site analyzers not being tested. This prevents waste of calibration gases.

At analysis sites where a calibration port is NOT provided, switch the analyzer to the SPAN mode.

7.13 Select the proper secondary standards to be used as data points in the curve. The curve should include these cylinders whose concentrations will produce the following approximate deflection reading at the range being calibrated:

Nonlinear Analyzers	Approximate Chart Deflections
(NDIR - minimum of 8 data points)	95
	80
	70
	60
	50
	40
	25
	15

Linear Analyzers	Approximate Chart Deflections
(FID, HFID, Chemil,	90
GC minimum of 6 data points)	75
	60
	45
	30
	15

If enough cylinders are not available to meet these requirements, consult the Team Leader for further action. More cylinders may be used in the curve to provide Quality Control data on gas concentration uniformity.

All secondary standards must have black sticker labels giving the EPA-named concentration.

8. *Test Procedure*

Test Sequence	Test Description
101	Using the portable calibration line, connect the top secondary cylinder to be used in the curve to the appropriate instrument gas input port.
102	Adjust the instrument gas flow rate and pressure as closely as possible to the rates posted at the analysis site. Continue to monitor them throughout the procedure.
103	Zero the instrument using the on-line zero gas adjust the zero potentiometer until a stable and accurate zero is obtained.

Test Sequence **Test Description**

A stable reading is defined as one minute of measurement in which the drift variation is not more than ± .2% of full scale from the set point and the noise variation is not more than ± .5% from that same set point. The numerical value of the reading is the operator's estimate of the average reading occurring during the measurement period. The calibrated DVM is used for all measurements.

104 Span the instrument by connecting the highest concentration secondary cylinder to the analyzer and adjusting the span potentiometer until the DVM reading reflects the percent of the actual concentration compared with the full scale of the range being analyzed. For example, if the range is 0-250 ppm and the top bottle is 230 ppm, adjust the DVM reading to 92% of full scale (230 ppm = 92% of 250 ppm). Or the span reading from the previous curve may be used again if the top bottle has not been renamed or replaced.

105 Zero the instrument and allow the reading to stabilize. If the original zero does not return within ± .3% of full scale, adjust the potentiometer until it does and repeat Step 104. Indicate the measurement area on the strip chart.

106 Span the instrument using the highest concentration secondary cylinder and allow the reading to stabilize without adjusting the potentiometer. If the DVM reading does not match the original span reading obtained in Step 104, repeat Steps 105-106. For each reading taken, write the cylinder number, the EPA-named concentration, and the observed DVM reading on the strip chart near the measurement area. Circle the DVM reading.

107 Run the curve.

Introduce the sequence of secondary calibration cylinders to be used as data points in the curve, in descending order of concentration. Obtain a stable DVM reading for each without adjusting the potentiometer.

108 Zero the instrument.

After the lowest concentration standard has been recorded, reintroduce the zero gas and obtain a stable reading. If the reading has drifted more than ± .3% of full scale from the reading obtained in Step 105, repeat Steps 101-108. If the tolerance limit is still exceeded, the drift problem must be corrected before the curve can be completed.

Test Sequence   Test Description

109 Respan the instrument.

Reintroduce the highest concentration standard for a reference span point. If the reading has drifted more than ± .3% of full scale from the reading obtained in Step 106, repeat Steps 101-108. If the tolerance limit is still exceeded, the drift problem must be corrected before the curve can be completed.

110 Introduce the working span gas and obtain a stable reading without adjusting the potentiometer. Record the reading on the strip chart where it occurs along with the actual concentration and cylinder number. (This step provides information for TP-205.)

111 Zero the instrument.

If the zero point has drifted more than ± .3% of full scale, repeat Steps 103-110. If the zero point is still out of tolerance, the drift problem must be corrected before the curve can be completed.

112 After testing is completed, turn the site span gases back on if they have been shut off.

9. *Data Input*

9.1 The operator writes the cylinder number, the EPA-named concentration (found on the sticker tape attached to the cylinder), and the observed DVM reading on the strip chart near the measurement area. Zero and span points are indicated as such. The on-line working gas is identified as "WG." All DVM readings are circled.

9.2 The operator completes Form AA-601 for each range analyzed.

9.2.1 Lines 1-3, Instrument Identification, are completed using the codes on the back of the form.

9.2.2 Line 4, Limits, is completed. The deflection limits define the upper and lower limits of valid deflection readings on the DVM. The range change limits define the upper and lower deflection readings on the DVM that signal the need for a range change to computers on real-time systems.

On Line 5, Operator's Comments, the range being analyzed is given in % or ppm. The reason for the curve generation is given (e.g., analyzer maintenance, new top cylinder, old curve out of tolerance, etc.). Any special operating instructions or comments about the test must appear here.

Columns 1-11 of Line 7 are completed using the codes on the back of the form as follows:

Cols. 1-2	"zero-span type" - always "01" (no software zero and span)
Cols. 4-5	"curve form" - "01," which forces the curve through zero
Col. 8	"degree of fit" - depends on the linearity of the analyzer; usually "2" for NOx, methane and "3" for CO, CO_2, and HC
Col. 11	"weight factor" - always "2," which minimizes percent of point deviations
Col. 23	"X" in "to be filed"

9.2.5 Lines 10-29 are concerned with the cylinders involved in the analysis.

Cols. 1-12	the cylinder numbers are listed
Col. 14	applicable only if a gas blender was used
Col. 16	"X" if the cylinder is "to be named" (working gases)
Cols. 20-32	not applicable
Cols. 34-44	the known or nominal concentration is listed for each cylinder
Col. 46	"X" if the cylinder is to be used as a calibration data point (secondary standard cylinders)

All such cylinders must have a known concentration value.

Cols. 48-55	the DVM readings written on the strip chart are entered

9.3 The operator completes Form LB-205 for each range analyzed. Refer to TP-205.

10. Data Handling

10.1 The completed Form AA-601 is submitted for processing.

10.2 The printout, Analyzer Calibration Curve Analysis, is obtained after processing.

11. Data Review and Validation

11.1 The technician examines the Analyzer Calibration Curve Analysis for each analyzer range and determines the validity of the curves.

11.1.1 All figures in the column under "curve fit deviation" marked "% point" must be within ± 1% for the curve to be valid. The "average deviation" found at the bottom of this section may not be more than ± .5%.

11.1.2 Percent deviations should be random with respect to +/- signs. If like signs are clustered in the center and/or at the ends of the curve, the degree of fit may have to be increased by one order. Consult with the Team Leader in such cases.

11.1.3 If inflection points are flagged in the printout, these must be investigated by Quality Control before the curve is accepted.

11.1.4 The percent of nonlinearity should not be more than 10% for all analyzers except NDIRs. If the nonlinearity of an NDIR exceeds 15%, it is investigated by the Team Leader before the curve is accepted.

If the curve is valid, the procedure is complete and a Span Point Change Notice must be generated. Refer to TP-205.

If the curve is not valid, refer to the attachment, Troubleshooting Flowchart for Invalid Analyzer Curves, for corrective measures.

12. Acceptance Criteria

12.1 All zero and span rechecks must fall within ± .3% of full scale of the original readings.

The curve must be valid according to the criteria set in Section 11.1.

13. Quality Control Provisions

13.1 All analytical instruments must be properly warmed up and in a test-ready mode prior to use.

13.2 All DVMs used in the procedure must have undergone a routine calibration within the past 90 days.

13.3 At least eight data points should be used in curves for nonlinear analyzers. At least six data points should be used in curves for linear analyzers. If these numbers cannot be met, the Team Leader is consulted before the curve is run.

14. Documentation

14.1 Copies of the Analyzer Calibration Curve Analysis are signed and dated by the Calibration and Maintenance Supervisor and distributed as follows:

One copy is retained by Computer Operations for update purposes.

One copy is stored in the Calibration and Maintenance active curve file, replacing the old curve if applicable. The old curve is stored in the inactive file.

One copy is kept in a file at the analyzer site. The old curve is destroyed.

One copy is sent to Quality Control through Computer Operations.

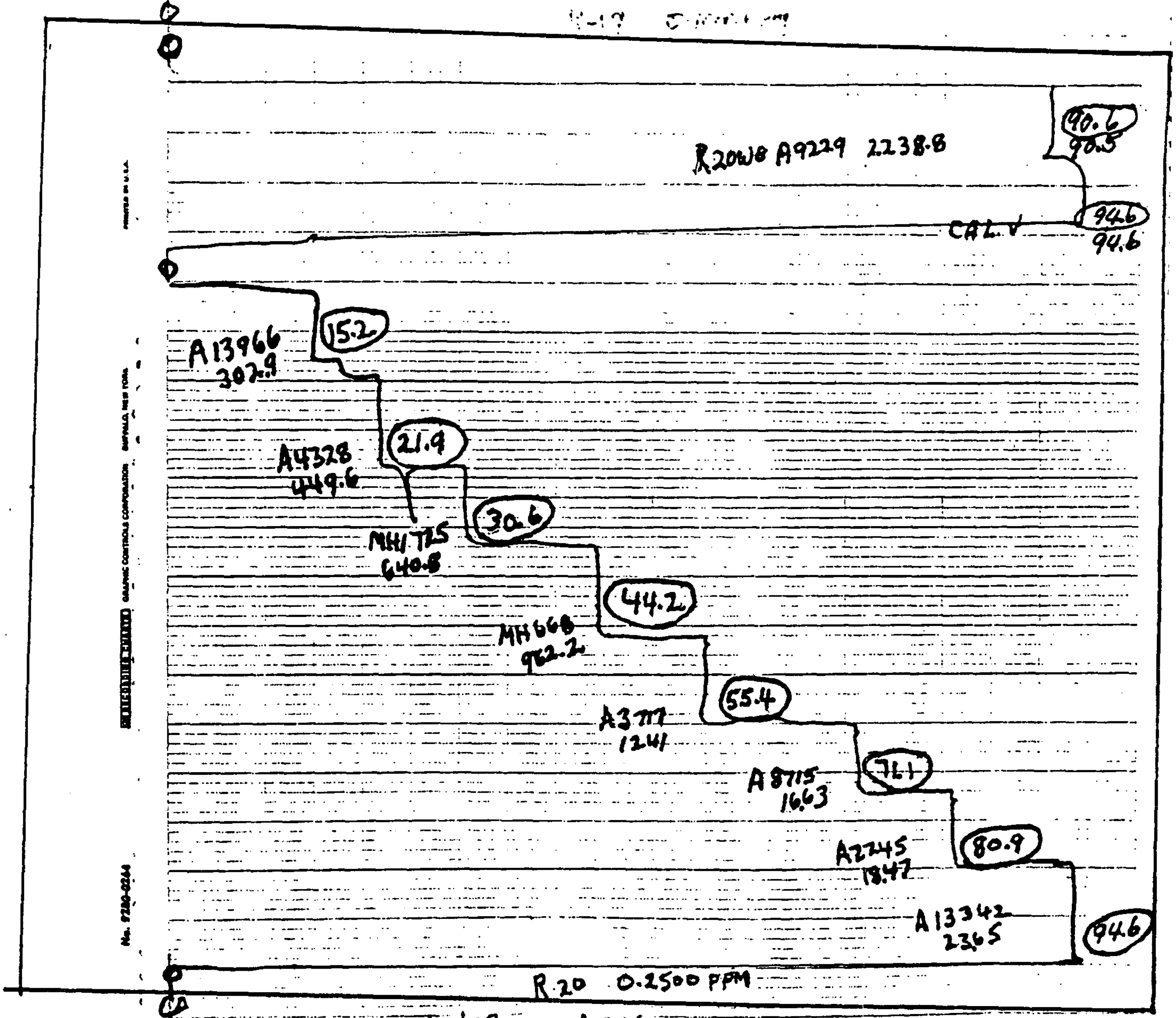
14.2 The Span Point Change Notice is submitted to Data Validation for verification and distribution.

14.3 The strip chart is filed in Calibration and Maintenance under the analyzer site number and date of completion.

A copy of Form AA-601 is filed under the analyzer site number and date of completion in Calibration and Maintenance.

TP204 - Gas Analyzer Calibration Curve Generation

Strip Chart Documentation



DATE 6-5-79 OPR. JD/CR SITE A216

ANAL ID No. 109643 REC TYPE DVM

MINOR CO MAJOR N_2 VFS 10

SMPL FLOW 4 SCFH MON SET PT

ZERO SPAN TUNE

FID PRESSURE

AIR FUEL SMPL

FUEL TYPE CURVE REQ. ALL

EXHAUST GAS ANALYZER CALIBRATION DATA FORM

USE 0 FOR ZERO
Ø FOR LETTER "O"

INSTRUMENT IDENTIFICATION (card 01)

ANALYZER PROP. ID.: 109643
SITE: A216
INST. TYPE: COAN
SIGNAL NAME: COAN-C
STD. RANGE: 20
USAGE: ABAG
END OF CALIBRATION TIME: 0400
END OF CALIBRATION DATE: 06-05-79
#INPUT CARDS: 18

(card 02)

OPERATOR ID: 13925
RECORDER TYPE: DVM
ANALYZER VENDOR: MSA
GAS CODES MINOR: 021
GAS CODES MAJOR: 081
PPM OR PCT: PPM
SAMPLE FLOW RATE: 4.0
FLOW RATE UNITS: SCFW

(card 03)

MONITOR SET POINT: .
UNITS:
ZERO GAIN: .
SPAN GAIN: .
TUNE: .
FID AIR PRESSURE: .
UNITS:
FID FUEL PRESSURE: .
UNITS:
FID SAMPLE PRESSURE: .
UNITS:

LIMITS (card 04)

VALID DEFLECTION LOWER LIMIT: +10.00
VALID DEFLECTION UPPER LIMIT: 110.00
RANGE CHANGE LOWER LIMIT: 20.00
RANGE CHANGE UPPER LIMIT: 100.00
FULL-SCALE (100%) VOLTAGE: 0.1

COMMENTS (card 05)

OPERATOR'S COMMENT – THIS COMMENT WILL ONLY BE PRINTED ON THE CALIBRATION REPORT.

(card 06)

FILE COMMENT *

(card 07)

Z-SPAN TYPE: 01
CURVE* FORM: 01
DEGREE* FIT: 3
WEIGHT* FACTOR: 2
BLENDER PROP. ID.:
X
STANDARD PRESSURE*: .
UNITS*:
BAROMETRIC PRESSURE: .
UNITS:

	CYLINDER NUMBER	blend	known cyl.	cyl. to be named	SPAN BLEND RATE (CHAN 1)	DILUENT BLEND RATE (CHAN 2)	KNOWN OR NOMINAL CONCENTRATION	calib. point	DEFLECTION	
SPAN BLEND CYL.					.	.	.		.	08
DIL. BLEND CYL.					.	.	.		.	09
UP TO 20 CYLINDERS AND BLENDS	A-13342		X		.	.	2365.00	X	94.6	10
	A-2245		X		.	.	1947.00	X	80.9	11
	A-8775		X		.	.	1668.00	X	71.1	12
	A-3717		X		.	.	1241.00	X	55.4	13
	AH-669		X		.	.	962.20	X	44.2	14
	MH-1725		X		.	.	640.80		30.6	15
	A-4328		X		.	.	449.60		21.9	16
	A-13966		X		.	.	307.90		15.2	17
	A-9226			X	.	.	2238.80		90.6	18
					.	.	.		.	19
					.	.	.		.	20
					.	.	.		.	21
					.	.	.		.	22
					.	.	.		.	23
					.	.	.		.	24
					.	.	.		.	25
					.	.	.		.	26
					.	.	.		.	27
					.	.	.		.	28
					.	.	.		.	29

EPA (AA-001) 08-78 *DATA FROM THE PREVIOUS CALIBRATION WILL BE USED IF BLANK.

NOTE: RIGHT JUSTIFY ALL NUMERIC FIELDS; LEFT JUSTIFY ALL ALPHA-NUMERIC FIELDS.

INSTRUMENTS AND SIGNALS
CARD 1 (COLS 11-16, 18-25)

SUBSTANCE ANALYZED	INST TYPE	CALIBRATION TYPE	SIGNAL NAME
HYDROCARBON	HCAN	CONCENTRATION 02 CORRECTION	HCAN-C $HCAN-02
CARBON MONOXIDE	COAN	CONCENTRATION	COAN-C
CARBON DIOXIDE	CO2A	CONCENTRATION	CO2A-C
OXIDES OF NITROGEN	NOXA	CONCENTRATION	NOXA-C
OXYGEN	OXGA	CONCENTRATION	OXGA-C
SMOKE	SMKM	OPACITY	SMKM-OP
SULFATE	SLFA	CONCENTRATION	SLFA-C

STANDARD LABORATORY RANGES
CARD 1 (COLS 30-31)

CODE	EQUIVALENCE	
28	0-1,000,000 PPM	0-100 PCT
27	0- 500,000	0- 50
26	0- 250,000	0- 15, 0-25
25	0- 100,000	0- 10
24	0- 50,000	0- 5
23	0- 25,000	0- 2.5
22	0- 10,000	0- 1.0
21	0- 5,000	0- .5
20	0- 2,500	
19	0- 1,000	
18	0- 500	
17	0- 250	
16	0- 100	
15	0- 50	
14	0- 25	
13	0- 10	
12	0- 5	
11	0- 2.5	
10	0- 1.0	
09	0- .5	
08	0- .25	
07	0- .10	
06	0- .05	
05	0- .025	
04	0- .010	
03	0- .005	
02	0- .0025	
01	0- .0010	

USAGE
CARD 1 (COLS 33-36)

CODE	EQUIVALENCE
BAGA	BAG ANALYSIS
HBAG	BAG ANALYSIS - HIGH INSTRUMENT
LBAG	BAG ANALYSIS - LOW INSTRUMENT
MODA	MODAL ANALYSIS
HMOD	MODAL ANALYSIS - HIGH INSTRUMENT
LMOD	MODAL ANALYSIS - LOW INSTRUMENT
MAST	MASTER ANALYSIS
HMST	MASTER ANALYSIS - HIGH INSTRUMENT
LMST	MASTER ANALYSIS - LOW INSTRUMENT

GAS TYPES
CARD 2 (COLS 28-30, 32-34)

CODE	EQUIVALENCE
011	CARBON EQUIVALENT
012	METHANE
014	PROPANE
021	CARBON MONOXIDE
022	CARBON DIOXIDE
031	NOX
032	NO
041	SULFUR
042	SO2
043	SO4
044	H2S
045	H2SO4
051	SMOKE
061	OXYGEN
062	OZONE
071	AIR
081	NITROGEN
091	HELIUM

PRESSURE UNITS
CARD 3 (COLS 7-8, 38-39, 48-49, 58-59)
CARD 7 (COLS 37-38, 50-51)

CODE	EQUIVALENCE
01	PASCALS - NT/SQ METER
02	BARYES - DYNES/SQ CM
03	BARS
04	MILLIBARS
05	CM HG (0 DEG C) - TORR
06	MM HG (0 DEG C)
07	CM H2O (4 DEG C)
08	MM H2O (4 DEG C)
09	CM OIL (1.75 SG)
10	MM OIL (1.75 SG)
20	ATMOSPHERES
21	IN HG (32 DEG F)
22	IN H2O (4 DEG C)
23	IN OIL (1.75 SG)
24	PSIA
25	PSIG

ZERO SPAN TYPE
CARD 7 (COLS 1-2)

CODE	EQUIVALENCE
01	NO SOFTWARE ZERO AND SPAN
02	SOFTWARE ZERO AND SPAN WITH SIGNAL DRIFT CORRECTION
03	SOFTWARE ZERO AND SPAN WITH SIGNAL DRIFT AND PRESSURE CORRECTION

CURVE FORM
CARD 7 (COLS 4-5)

CODE	EQUIVALENCE
01	POLYNOMIAL WITH A ZERO INTERCEPT
02	POLYNOMIAL WITH A NONZERO INTERCEPT
03	CURVEALL TYPE FIT. HISTORIC ONLY--NOT SUPPORTED

DEGREE OF FIT
CARD 7 (COL 8)

CODE	EQUIVALENCE
1-4	FIT A POLYNOMIAL OF DEGREE 1-4. (USE 1 FOR LINEAR ANALYZERS AND 4 FOR NDIR)

WEIGHTING FACTOR
CARD 7 (COL 11)

CODE	EQUIVALENCE
1	WEIGHT THE SQUARE OF THE DEVIATION OF THE CURVE FROM THE DATA POINT WITH A WEIGHTING FACTOR OF 1.
2	WEIGHT THE SQUARE OF THE DEVIATION OF THE CURVE FROM THE DATA POINT WITH A WEIGHTING FACTOR OF 1/Y (1/CONCENTRATION).

TO BE FILED
CARD 7 (COL 23)

ENTER A LETTER "X" IF THE CALIBRATION SHOULD BE FILED AS A PENDING CALIBRATION. OTHERWISE NO RESULTS WILL BE SAVED.

MEASUREMENT TYPE
CARDS 10-29 (COLS 14, 16, 18)

ENTER A LETTER "X" IN ONE OF THREE COLUMNS TO INDICATE WHETHER GAS IS FROM A BLEND, A KNOWN CYLINDER, OR A CYLINDER TO BE NAMED.

CODE	COLUMN ABBREVIATION	GAS
X	BLEND	BLEND FROM TWO CYLINDERS
X	KNOWN CYL.	KNOWN CYLINDER CONCENTRATION
X	CYL. TO BE NAMED	UNKNOWN CYLINDER TO BE NAMED

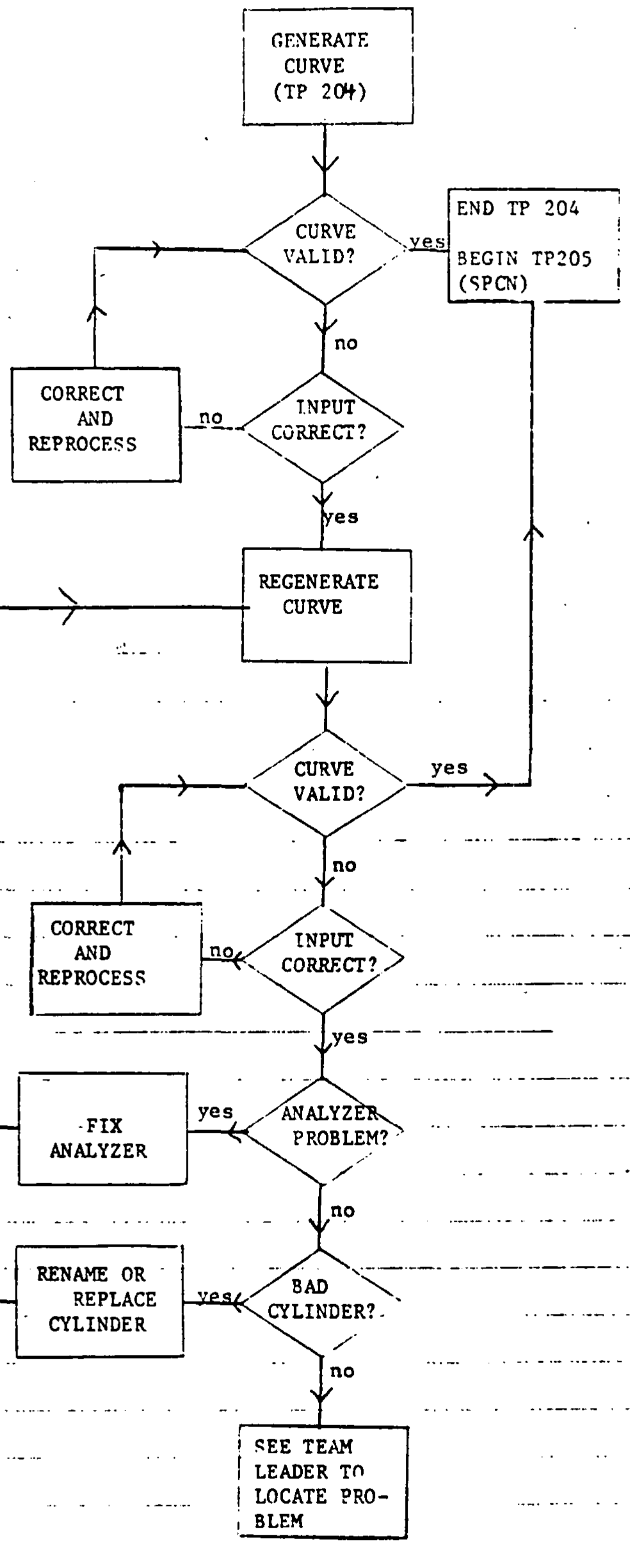
CALIBRATION DATA POINT
CARDS 10-29 (COL 44)

ENTER A LETTER "X" FOR EVERY MEASUREMENT THAT REPRESENTS A KNOWN DATA POINT FOR COMPUTING A CALIBRATION CURVE OR NAMING CYLINDERS.

```
**** PROCESSED: 10:03:30  06-05-79            ********************************************       AAA      22222        11      66666
                                              ********************************************      AAAAA    2222222      111     6666666
                                              ***                                      ***     AA   AA        22    1 11      66
                                              *** ANALYZER CALIBRATION CURVE ANALYSIS ***     AAAAAAA      222       11      666666
                                              ***                                      ***     AAAAAAA    222         11      66   66
                                              ********************************************     AA   AA  2222222      11      6666666
                                              ********************************************     AA   AA  2222222    11111     66666


END CALIB AT TIME :   4: 0   ANALYZER VENDOR    :MSA         SAMPLE FLOW RATE  :    4.0 SCFH        VALID DEFL.  UPPER LIMIT : 110.000
CALIBRATION DATE  : 6- 5-79  INSTRUMENT NAME    :  COAN      MONITOR SET POINT :    0.0             VALID DEFL.  LOWER LIMIT : -10.000
TEST SITE NUMBER  :  A216    EPA DECAL ID NO    : 109643     ZERO GAIN SETTING :    0.0             RANGE CHANGE UPPER LIMIT : 100.000
GAS ANALYZED      :CO        SIGNAL LEAD        :COAN-C      SPAN GAIN SETTING :    0.0             RANGE CHANGE LOWER LIMIT :  20.000
DILUENT GAS       :NITROGEN  HARDWARE RANGE     :            TUNE READING      :    0.0             FULL-SCALE (100%) DEFL.  : 100.000
CONCENTRATION UNIT:  PPM     USAGE              :  MBAG      FID AIR PRESSURE  :    0.0             FULL-SCALE (100%) VOLTAGE:   0.100
STANDARD LAB RANGE:   20     CALB GAS SOURCE    :            FID FUEL PRESSURE :    0.0             FULL-SCALE (100%) CONC.  :  2540.2
OPERATOR ID NO    : 13925    BLENDER DECAL ID   :            FID SAMP PRESSURE :    0.0             RECORDER TYPE            :DVM

PREVIOUS FILE COMMENT: 0-2500 PPM CO
FILE COMMENT         :.0-2500 PPM CO
OPERATOR COMMENT     :
----------------------------------------------------------------------------------------------------------------------------------------------------
|  CYLINDER   |BLENDER METER| BLEND |        CONCENTRATIONS          |   ANALYZER SIGNAL   |CALIBRATION|         CURVE FIT DEVIATIONS              |
|   NUMBER    |   READINGS  | RATIO |  CYLINDER                      | MEASURED CORRECTED  |   DATA    |       %           %        % FROM LAST    |
|             |SPAN DILUENT|       |  (BLENDED)     CALCULATED      |    X          X     |   POINT   |     POINT    FULL-SCALE  CALIBRATION     |
|-------------+-------------+-------+--------------------------------+---- M ------ C -----+-----------+-------------------------------------------|
|             |  X          |       |      0.0                       |                     |           |                                           |
|             |        X    |       |      0.0                       |                     |           |                                           |
|A-13342      |  0.0   0.0  | 0.0   |   2365.0        2365.8         |   94.600    94.600  |     X     |     0.035       0.032       -0.004        |
|A-2245       |  0.0   0.0  | 0.0   |   1947.0        1945.5         |   80.900    80.900  |     X     |    -0.076      -0.058       -0.095        |
|A-9715       |  0.0   0.0  | 0.0   |   1663.0        1663.4         |   71.100    71.100  |     X     |     0.024       0.016       -0.197        |
|A-3717       |  0.0   0.0  | 0.0   |   1241.0        1241.3         |   55.400    55.400  |     X     |     0.025       0.014       -0.431        |
|MM-668       |  0.0   0.0  | 0.0   |    962.2         961.2         |   44.200    44.200  |     X     |    -0.108      -0.041       -0.657        |
|MM-1725      |  0.0   0.0  | 0.0   |    640.8         642.4         |   30.600    30.600  |     X     |     0.242       0.061       -1.001        |
|A-4328       |  0.0   0.0  | 0.0   |    449.6         449.8         |   21.900    21.900  |     X     |     0.040       0.007       -1.264        |
|A-13466      |  0.0   0.0  | 0.0   |    307.9         307.1         |   15.200    15.200  |     X     |    -0.263      -0.032       -1.491        |
|A-9226       |  0.0   0.0  | 0.0   |   2238.8        2239.9         |   90.600    90.600  |           |     0.0         0.0          0.0          |
----------------------------------------------------------------------------------------------------------------------------------------------------
                                                                                                      |                                           |
         NONLINEARITY =     6.5 PERCENT                                          AVERAGE DEVIATION |     0.102       0.033        0.642        |
                                                                                 --------------------|-------------------------------------------|

ANALYSIS OF "CYLINDERS TO BE NAMED"
---------------------------------------------------------------------------------------------------------------------------
|  CYLINDER   |    NOMINAL     |      LINEAR FIT SIGNAL        | LINEAR FIT   | CURVE FIT    |    CONCENTRATION    |
|   NUMBER    | CONCENTRATION  |                               | CALC. CONC.  | CALC. CONC.  |       RATIOS        |
|             |     (NC)       |   LOW     HIGH   CYLINDER     |    (LC)      |    (CC)      |  NC/CC     LC/CC    |
|-------------+----------------+-------------------------------+--------------+--------------+---------------------|
| A-9226      |     2238.8     |  80.900  94.600  90.600       |    2243.0    |    2239.9    | 0.99952   1.00137   |
---------------------------------------------------------------------------------------------------------------------------
```

```
**** [illegible] 10103130  06-05-79      ****************************************      AAA     22222      11      66665
                                         ****************************************     AAAAA   2222222    111     6666666
                                         ***                                  ***    AA   AA       22   1 11     66
                                         *** ANALYZER CALIBRATION CURVE ANALYSIS ***  AAAAAAA      222     11     666666
                                         ***                                  ***    AAAAAAA   222        11     66   66
                                         ****************************************    AA   AA  2222222     11     6666666
                                         ****************************************    AA   AA  2222222   11111     66666

END CALIB AT TIME  :   4: 0    ANALYZER VENDOR   :MSA        ZERO SPAN TYPE     :      1
CALIBRATION DATE   : 6- 5-79   INSTRUMENT NAME   :  COAN     CURVE FORM         :      1
TEST SITE NUMBER   :  A216     EPA DECAL ID NO   : 109641    DEGREE FIT         :      3
GAS ANALYZED       :CO         SIGNAL LEAD       :COAN-C     WEIGHTING FACTOR   :      2
FULL-SCALE CONC    :   2540.2  HARDWARE RANGE    :
CONCENTRATION UNIT:  PPM       USAGE             :  HBAG
STANDARD LAB RANGE:   20       OPERATOR ID NO    : 13925

EQUATIONS AND COEFFICIENTS
**************************
                                                                    4         3         2
                         X  = X   ;                           (A5*X   + A4*X   + A3*X   + A2*X   + A1) =   PPM CO/NITROGEN
                          C    M                                   C        C        C        C

                                                                             A1  =   0.0
                                                                             A2  =   0.1949270E+02
   CALIBRATION R(LABO) =  0.0                                                A3  =   0.4454308E-01
                                                                             A4  =   0.1455097E-03
                                                                             A5  =   0.0

CALIBRATION TABLE ____PERCENT FULL-SCALE CHART DEFLECTION VS PPM CO/NITROGEN______________________________________________
|  0.      0.0|             |             |             |             |             |             |             |             |             |
|  1.     19.5| 11.    220.0| 21.    430.3| 31.    651.4| 41.    884.1| 51.   1129.3| 61.   1387.8| 71.   1660.6| 81.   1948.5| 91.   2252.3|
|  2.     39.2| 12.    240.6| 22.    451.9| 32.    674.1| 42.    908.0| 52.   1154.5| 62.   1414.4| 72.   1688.7| 82.   1978.1| 92.   2283.6|
|  3.     58.9| 13.    261.3| 23.    473.7| 33.    697.0| 43.    932.1| 53.   1179.9| 63.   1441.2| 73.   1716.9| 83.   2006.0| 93.   2315.1|
|  4.     78.7| 14.    282.0| 24.    495.5| 34.    720.0| 44.    956.3| 54.   1205.4| 64.   1468.1| 74.   1745.3| 84.   2037.9| 94.   2346.8|
|  5.     98.6| 15.    302.9| 25.    517.4| 35.    743.0| 45.    980.6| 55.   1231.1| 65.   1495.2| 75.   1773.9| 85.   2068.1| 95.   2378.6|
|             |             |             |             |             |             |             |             |             |             |
|  6.    118.6| 16.    323.9| 26.    539.5| 36.    766.3| 46.   1005.1| 56.   1256.8| 66.   1522.4| 76.   1802.6| 86.   2098.4| 96.   2410.5|
|  7.    138.7| 17.    345.0| 27.    561.6| 37.    789.6| 47.   1029.7| 57.   1282.8| 67.   1549.7| 77.   1831.5| 87.   2128.8| 97.   2442.7|
|  8.    158.9| 18.    366.1| 28.    583.9| 38.    813.0| 48.   1054.4| 58.   1308.8| 68.   1577.2| 78.   1860.5| 88.   2159.5| 98.   2475.0|
|  9.    179.1| 19.    387.4| 29.    606.3| 39.    836.6| 49.   1079.2| 59.   1335.0| 69.   1604.9| 79.   1889.7| 89.   2190.3| 99.   2507.5|
| 10.    199.5| 20.    408.8| 30.    628.8| 40.    860.3| 50.   1104.2| 60.   1361.3| 70.   1632.7| 80.   1919.0| 90.   2221.2|100.   2540.2|
|_____________|_____________|_____________|_____________|_____________|_____________|_____________|_____________|_____________|_____________|

QUALITY CONTROL COMMENTS
************************

                                                                  THIS CURVE HAS BEEN REVIEWED AND APPROVED FOR OFFICIAL
                                                                  UPDATE.  PLEASE UPDATE THE CALIBRATION FILE.

                                                                  AUTHORIZED SIGNATURE:_______Mark Jones___________

*** CURVE ON FILE AS A PENDING CALIBRATION.                       EFFECTIVE DATE AND TIME:6-5-79    11:30________
                                                                                          MON DAY YEAR  HR MIN
```

TROUBLESHOOTING FLOWCHART FOR INVALID ANALYZER CURVES



DO NOT COPY THIS PAGE

SPAN POINT CHANGE NOTICE

NEW SPAN BOTTLE

	ANALYZER SITE NUMBER					
	GAS TYPE					
	RANGE NUMBER					
CURRENT CYLINDER	CURRENT SPAN CYLINDER NUMBER					
	EPA TAG CONCENTRATION					
	POSTED SPAN SET POINT					
NEW CYLINDER	NEW SPAN CYLINDER NUMBER					
	EPA TAG CONCENTRATION	Y3				
	CHECK RESPONSE	X0				
	UPPER CHART DEFL. BRACKET	X2				
	LOWER CHART DEFL. BRACKET	X1				
	X2 - X1	ΔX				
	UPPER CONCENTRATION BRACKET	Y2				
	LOWER CONCENTRATION BRACKET	Y1				
	Y2 - Y1	ΔY				
	CALCULATED BOTTLE CONC. $Y0 = Y1 + (\Delta Y/\Delta X)(X0 - X1)$	Y0				
	% DIFFERENCE = $\frac{Y0 - Y3}{Y3}$ X 100% (MUST BE <±1%)					
	NEW SPAN SET POINT $X3 = X1 + (\Delta X/\Delta Y)(Y3 - Y1)$	X3				

CALCULATED BY: ____________________

VALIDATED BY: ____________________

DATE/TIME EFFECTIVE: ____________________

NOTE: If no data is available for the old span bottle, the new bottle must be checked using secondaries. See form LB205B.

X2 = the next higher chart deflection to X0 on the curve calibration table
X1 = the next lower chart deflection to X0 on the curve calibration table
Y2 = the next higher conc. corresponding to X2 on the curve calibration table
Y1 = the next lower conc. corresponding to X1 on the curve calibration table

LB205A

EOD TEST PROCEDURE

	Page 1 of 12
TITLE Dynamometer Calibration Verification	NUMBER **TP 302A**
ORIGINATOR Don Paulsell	IMPLEMENTATION DATE 8/16/82
RESPONSIBLE ORGANIZATION Calibration and Maintenance, Light Duty Diagnostics	DATA FORM NO. Form EOD 302-01
TYPE OF TEST REPORT Computer Report, Data Base Analysis	COMPUTER PROGRAM LCS E.DCHECK, DYPLOT
REPORT DISTRIBUTION File hard copy in diagnostics; data and results are in computer file.	SUPERSEDES TP 302

REMARKS/COMMENTS

The three test procedures which deal with calibration and verification of Clayton chassis dynaometers are:

TP 202, Dynamometer Calibration - Frictional Horsepower
TP 207A, Dynamometer Calibration - RLPC Electronics
TP 302A, Dynamometer Calibration Verification

REVISIONS

REVISION NUMBER	REVISION DATE	EPCN NUMBER	DESCRIPTION

IMPLEMENTATION APPROVAL

Test Procedure authorized on 08/16/82

TABLE OF CONTENTS

1. Purpose

This procedure is used to verify several aspects about the calibration of a Clayton ECE-50 dynamometer in fulfillment of the requirements of 40 CFR 86. The verification involves making simple checks on the control and display functions and performing several coastdowns at different inertia weight and horsepower settings. It is assumed that the electronics have been calibrated as specified in the Clayton manual and TP 207A and that the dynamometer has been calibrated using TP 202.

2. Test Article Description

2.1 A direct drive, variable inertia (1000-6875 in 125-pound increments) chassis dynamometer (Clayton ECE-50) with automatic road load power control capability and digital display of horsepower and speed

2.2 The original Clayton circuit has been rewired so that the indicated horsepower is based solely on front roll speed and torque, but the front/rear roll speed indication is still selectable.

2.3 Some dynamometers have been modified to display a 5-volt reference signal for driver trace recorders and speed displays.

3. References

3.1 Federal Register; Vol. 42, No. 124; Tuesday, June 28, 1977; 86.116-82 (d)(3), 86.118-78 (b)

3.2 Clayton Instruction Manual R-8713

3.3 "Proceedings of the Quality Control Symposium on Dynamometers" - June 27, 1977, held at EPA

3.4 Engineering Operations Division files on dynamometers

4. Required Equipment

4.1 Dyno calibrator vehicle - 4000 point, V-8, fitted with lifting jacks and recording equipment

4.2 Master coastdown timer and cabling, plus the 60-tooth gear speed sensor assembly

4.3 Extension cords, as required

4.4 Data Sheet (Form EOD 302-01)

5. *Precautions*

5.1 Inflate the drive tires to 45 psig to protect against damage from heat and distortion.

5.2 Align the vehicle on the dynamometer rolls and attach the cable winch loosely enough to allow the vehicle to rise to its full lift height.

5.3 Operate the cooling fan within 12 inches of the vehicle radiator.

5.4 Vent the vehicle exhaust to the building exhaust system.

5.5 The coastdowns should be run right after warm-up of the dynamometer to insure that the bearing friction remains stable.

5.6 The cable between the master coastdown timer and the dynamometer electronics box must be securely connected to insure good electrical contact.

5.7 Verify the action of the vehicle lift while the car is stopped. It should raise quickly but lower slowly.

5.8 Always verify that the cable, chocks, and electrical lines to the vehicle are disconnected before the vehicle is removed from the dyno.

6. *Visual Inspection*

6.1 Verify that the speed and torque meters read 00.0 when the car is off the dynamometer and the roll brake is not applied. Have C&M check and adjust the voltages or meters if the readings exceed ± .1.

6.2 Other visual inspections are performed as part of the test procedure.

7. *Test Article Preparation*

7.1 Place the coastdown vehicle on the dyno and set the MECO brake switch on to enable the lift; connect the 60-tooth gear, torque and speed signals, and the 115 VAC power plug.

7.2 Chock the front wheels and attach the winch cable loosely.

7.3 Verify the proper operation of the vehicle lift jacks, coastdown timer, and totalizing counters.

7.4 Verify that the vehicle factor pot is set to a value of zero.

7.5 Verify that the master timer is triggered by the Clayton tach signal and that the speed counter totalizes the "digital" tach signal from the 60-tooth gear.

8. *Test Procedure*

Eight inertia weights are verified twice a month. Four weights and horsepowers are done each week as shown in Table A and on the data sheet. The rear roll friction is verified weekly as part of the warm-up process.

Sequence	Description
101	Obtain a blank data sheet (Form EOD 302A-01) for the dyno being tested.
102	Enter all data and obtain the calibration thumbwheel values needed for the coastdowns. These are on the dyno calibration tables and/or on a lookup table in the calibrator vehicle.
103	Review the recent data for the dynamometer to highlight aspects which may require close observation or need to be noted in the comments.
201	Engage the 6875-pound inertia and set the thumbwheel to the value shown in the current version of Table A.

Sequence	Description
202	Place the speed selector to **FRONT**.
203	Lower the dyno lift brake and slowly turn the rollers to verify all flywheels are engaged.
204	Accelerate to a steady 50 mph and maintain this speed to warm up the PAU and flywheel bearings. Perform Steps 205-210 during this warm-up period.
205	Dial the four thumbwheel values shown on line 2 of the data sheet and record the indicated horsepower at FR=50 mph.
206	Set TW=10 and set the timer module to **MANUAL/STOP**. Reset all counters to zero. Resume and maintain the speed a FR=50± .1 mph.
207	Switch the Count/Stop switch to **COUNT** for about 10 seconds. On the data sheet, record the torque, speed, and time counts, as well as the IHp meter reading. Reset the timer module to **AUTO/STOP**. Verify that the set points are dialed to 45 and 55.
208	Verify the operation of the coastdown timer module four times during the last 5 minutes of warm-up by performing a dyno coastdown (vehicle lift activated). The 6875-pound inertia is used; the thumbwheel setting is selected to give AHp equal to 13.5. The thumbwheel can be selected from the dyno calibration or the current version of Table A.
209	Record the coastdown time for each run on line 3 of the data sheet. This time should be approximately 31 seconds.
210	If the difference in times (MAX-MIN) is less than .3 seconds, the dynamometer is stable and the inertia coastdowns may begin. If not, perform additional coastdowns to see if four consistent values can be obtained. If the tolerance cannot be achieved, continue testing but report the condition to C&M and VA&T.
211	Change the coastdown timer trigger input from the Front Roll to the Rear Roll tach banana jack on the dyno.
212	Accelerate to 60± 2 mph, hold that speed for about five seconds, and activate the vehicle lift, allowing the dyno to coast down by itself to 30 mph.

Sequence	Description
213	Record the RR coastdown time on line 3 of the data sheet and the value of RRFHp Cal from the current version of Table A.
214	Listen for abnormal noise during this coastdown and verify that the coastdown timer trigger points are functioning within ± .1 mph of 55 and 45.
215	Lower the vehicle and stop the dyno.
216	Raise the dyno lift and engage the 4000-pound inertia. Set the thumbwheel to a value of 10.0. Change the coastdown input to the Front Roll tach banana jack and set the master timer selector to **AUTO/STOP**.
217	Trace the template ramp-up and ramp-down profiles (0-60 @ 2.5 mph/sec separated by a 1-minute cruise at 60 mph) on a driving trace. Thread the driver's aid to prepare for the transient PAU performance test.
218	Set the low trigger point at 5 mph. Leave the high trigger at 55 mph.
219	Lower the dyno lift. Accelerate to 50 mph FR to verify the horsepower and inertia operation. Stop the vehicle. Reset the counters.
220	Turn on the driver's aid chart feed. When the ramp trace is reached, accelerate the vehicle at the constant rate to 60 mph, staying within ± 2 mph at any point in time.
221	Switch the Auto/Manual switch to **MANUAL** to hold the counts until they can be recorded on line 4 of the data sheet.
222	Maintain about 60 mph, switch to **AUTO**, and reset the counters.
223	When the ramp-down trace is reached, decelerate at the constant rate to a complete stop. Record the counter readings.
224	Shut off the driver's aid. Reset the low trigger point to 45 mph.
225	Remove the driver's trace so it can be stapled to the data sheet later.

Sequence	Description
300	**INERTIA COASTDOWN TESTS**
301	For each inertia coastdown shown in Table A, perform the following steps:
302	Stop the vehicle and raise the roll brake.
303	Select the inertia weight and set the thumbwheel horsepower determined from the current version of Table A. Inertia weights are to be run in the sequence specified in Table A for the respective weeks.
304	Lower the roll brake and verify the inertia flywheel engagement.
305	Accelerate to 50 mph as indicated on the speed meter and note the indicated horsepower at a steady 50 mph.
306	Record the indicated horsepower on the data sheet.
307	Accelerate to 60 mph and maintain speed until the readings stabilize. Set to **AUTO/STOP** and reset all the counters to zero.
308	Activate the vehicle lifting device, maintaining dyno speed until the tires clear the rollers; then release the accelerator pedal.
309	Allow the inertia assembly to decelerate through the 55-45 speed interval. Note the indicated horsepower as the inertia speed passes 50 mph.
310	Record this indicated horsepower on the data sheet.
311	Record the times from the master and quick check timers on the data sheet. If the master timer does not work, record the quick check timer data in the master time column and indicate the switch in the comments on Line 1.
312	Repeat Steps 302 - 312 for each inertia included on the schedule specified in Table A.
313	Lower the vehicle, stop the dyno, and raise the lift brake.

Sequence	Description
314	Perform the visual check of the 1-second tolerance (master-theoretical) and submit the data for computer processing as specified in Section 10. Validate the results as specified in Section 12. Repeat any points that exceed the tolerances.
315	If all results are acceptable, disconnect all electrical wires and restraints from the vehicle.
316	Verify that the lift pads are fully retracted, turn off the MECO brake switch, and remove the vehicle from the dyno site.

9. *Data Input*

9.1 Verify that all entries on the data sheet are complete and within the ranges of reasonableness. Data not collected can be blank or zeros.

9.2 Submit the data sheet to Operations for processing by the LCS program E.DCHECK.

10. *Data Handling*

10.1 The attached flow chart illustrates how the data are processed and stored.

10.2 Data sheet entries should be keypunched and batch processed on LCS.

10.3 The report will be printed and the data stored. The report consists of three pages - the data echo, the verification report, and a quality control summary. These are shown in the attachments. Read/Write errors on the data file are also indicated by a record dump in the QC summary.

10.4 The results also are written to an LCS file for statistical and graphical analyses, obtainable by typing **BREAK**, then **"$RUN DYPLOT"** on a production "Prod" DecWriter.

11. Data Review and Validation

11.1 All entries and calculations are checked by Data Control for reasonable results. If entry errors are detected, the data is corrected and reprocessed.

11.2 Data Control verifies that the acceptance criteria of Section 12 are met.

11.3 Any data or results on the printout that do not meet the criteria are either flagged on page 2 under Quality Control Comments or circled in black ink by Data Control. This printout is used for the copy distribution.

12. Acceptance Criteria

The following criteria are checked by the technician responsible at the time the procedure is performed. These criteria represent Federal Register compliance. If either of them cannot be met, the dynamometer is immediately removed from service, and may not be used until C&M has resolved the problem and verified the acceptability of the dynamometer:

12.1 Verification Data Coastdown Time Difference (Master/Theoretical): (Step 311) This value must not exceed ± 1.0 second. Any value outside these limits should be reconfirmed by the technician performing the verification.

12.2 Verification Data IHp @ Steady 50 mph: (Step 306) All values must be less than or equal to ± 0.2 Hp of the thumbwheel setting.

The following criteria are checked by Data Control after the data are processed and are either flagged under Quality Control Comments or circled if they are exceeded. Copies of the data report are distributed to the C&M and VA&T Supervisors for evaluation. The C&M Supervisor is responsible for resolution of the indicated problem(s) as soon as time permits. The dynamometer remains in use until the investigation is complete. At that time, the C&M Supervisor will document the justification for deviation or remove the dynamometer from service.

12.3 Warm-up Thumbwheel Check: (Step 205) The differences between IHp @ 50 readings and the thumbwheel settings should not exceed ± 0.3. The average difference should not exceed ± 0.2.

12.4 PAU Hysteresis Check: (Steps 220-223) The hysteresis between ramp-up and ramp-down data should not exceed 1 mph, 1 ft-lb, or 0.4 Hp.

12.5 Warm-up Coastdown: (Step 209) The difference (MAX-MIN) in coastdown times should not exceed 0.3 seconds.

12.6 50 mph Speed Check, 60-Tooth Gear: (Step 207) The front roll speed calibration should agree within ± 0.2 mph of the 60-tooth absolute measurement. If the speed calibration is acceptable, the torque and Hp differences from theoretical should be ± 1 ft-lb and ± 0.4 Hp, or approximately ± 4%.

12.7 Rear Roll FHp Check: (Step 213) This value should not be less than 0.150 FHp and not greater than 0.350 FHp.

12.8 Verification Data IHp @ 50 mph During Coastdown: (Step 310) These values should not exceed ± 0.2 Hp of the indicated horsepower at a steady 50 mph and should not exceed ± 0.3 Hp of the thumbwheel setting.

12.9 Master/Quick Check Δt Difference: The quick check timer on the site should agree with the master timer within ± 0.1 second.

13. *Quality Control Provisions*

13.1 The acceptance criteria in Section 12 are monitored by the Quality Control Group for trends and offsets. If a significant offset is noticed, QC immediately brings it to the attention of C&M, who must take corrective action to restore the central tendency of the data to near the zero line. If the four-month average of the verification coastdowns exceeds ± 0.5 seconds, C&M will investigate the trend.

13.2 The general behavior of each dynamometer is presented at the monthly diagnostic meeting and priorities for corrective action are set at that time. Any outstanding deviations (Steps 12.3-12.9) are also discussed.

13.3 Corrective actions must be reviewed and approved by the C&M Supervisor before the dyno site is released for testing. Verbal notification of approval should be made to the VA&T Supervisor. A written description of the corrective action should be sent to VA&T and QC for documentation purposes.

13.4 After any repair that does not require a full calibration (TP 202 or TP 207A), this procedure or the applicable parts should be repeated before the dyno is accepted for testing.

14. Documentation

14.1 The monthly summaries are copied and distributed to VA&T, C&M, and Quality Control. The data sheet, printout, and ramp trace are filed in a dyno file folder as specified.

14.2 Corrective actions must be documented in sufficient detail to provide a "before" and "after" comparison of dynamometer performance. Quality Control must receive a copy for audit purposes.

DYNAMOMETER CALIBRATION VERIFICATION DATA SHEET

		DYNO SITE	DATE MO DAY YR	TIME HR MIN	BARO "HG	OPERATOR EPA ID	COMMENTS
GENERAL INFORMATION	0 1	D					

		WARM-UP and CHECK TW v.s. IHp					SPEED CHECK 60 TOOTH GEAR TW=10			
		TW=10.0	TW=5.0	TW=15.0	TW=10.0		SPEED COUNTS	TORQUE COUNTS	ΔT	IHp 50
50mph FR @IW=6875	0 2									

05 10 15 20 25 30 35 40 45

		TW	IW	ΔT_1	ΔT_2	ΔT_3	ΔT_4	REAR ROLL ΔT	FHp CAL REAR ROLL
WARM-UP COASTDOWNS	0 3								

				RAMP-UP (5-55) @ 2.5 mph/sec			RAMP-DOWN (55-5) @ 2.5 mph/sec		
		TW	IW	SPEED COUNTS	TORQUE COUNTS	ΔT	SPEED COUNTS	TORQUE COUNTS	ΔT
SPEED TORQUE PAU HYSTERESIS	0 4								

05 10 15 20 25 30 35 40 45 50

		IW	AHp	TW	Hp @ 50 ss	Hp @ 50 cd	ΔT MASTER	ΔT QCHECK
VERIFICATION DATA	0 5							
	0 6							
	0 7							
	0 8							
	0 9							

05 10 15 20 25 30 35

********* NOTE *********

ΔT (MASTER-THEOR.) MUST
BE LESS THAN
±1.00 SECONDS

IF NOT, REPEAT THAT
COASTDOWN (CARD 09)

First and Third Weeks of Month

AHp	INERTIA	THEOR. ΔT
7.6	2500	19.977
6.9	2250	19.803
6.5	2125	19.850
6.0	2000	20.243

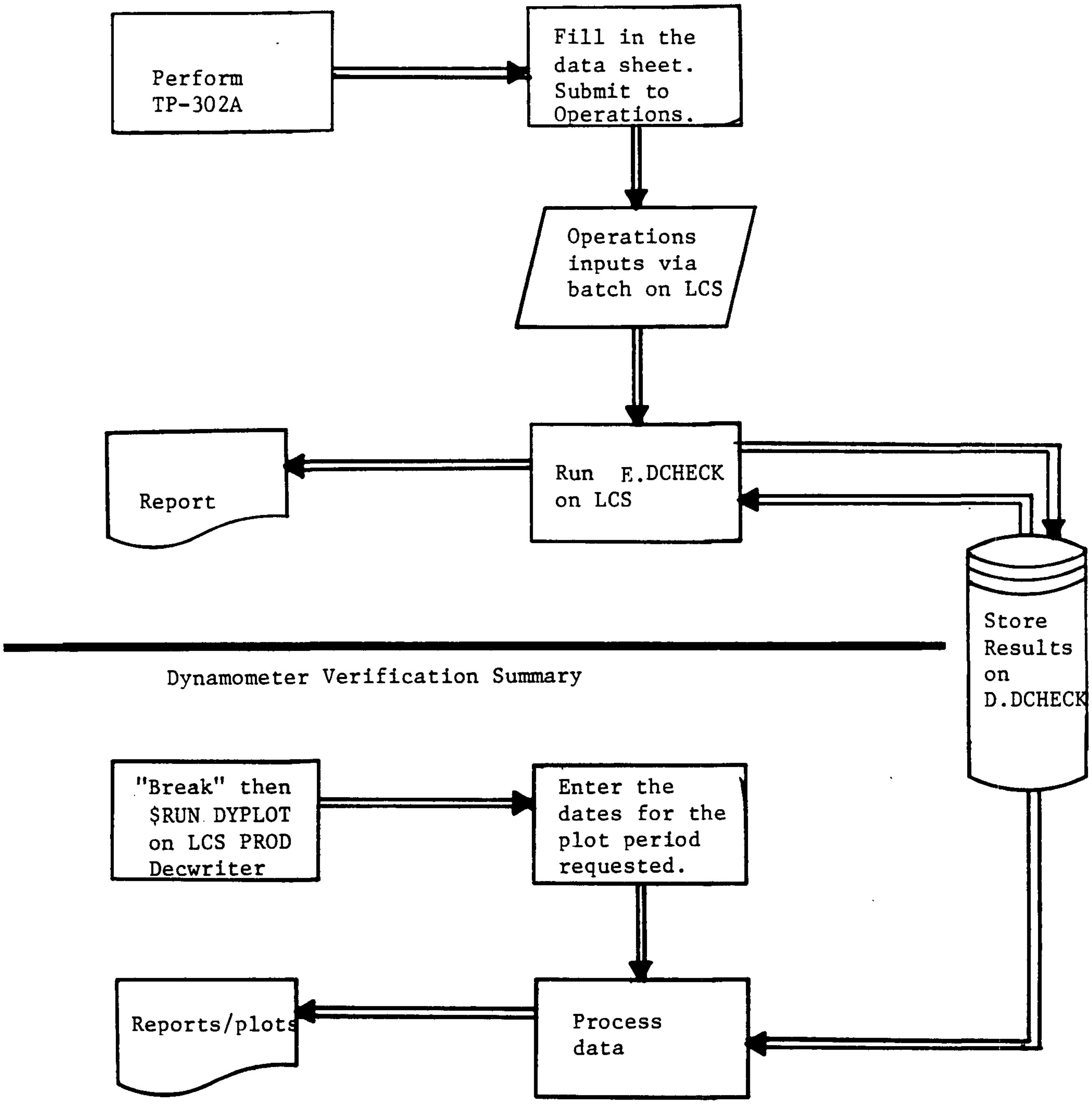
Second and Fourth Weeks of Month

AHp	INERTIA	THEOR. ΔT
15.2	5000	19.977
12.2	4000	19.911
10.6	3500	20.052
9.2	3000	19.803

TABLE A - DYNAMOMETER VERIFICATION TEST DATA (AS OF 07/01/82) AND FLYWHEEL ENGAGEMENT CHART

DYNO SITE	CAL DATE MM-DD-YY	AVG. RRFHP		THUMBWHEEL HP SETTINGS FOR PREP AND VERIFICATION COASTDOWNS								
			IW =	6875	5000	4000	3500	3000	2500	2250	2125	2000
			AHP =	13.5	15.2	12.2	10.6	9.2	7.6	6.9	6.5	6.0
			t.Δt =	30.927	19.977	19.911	20.052	19.803	19.977	19.803	19.850	20.243
D001	08-14-81	.308		10.6	12.9	10.2	8.8	7.5	5.9	5.2	4.8	4.4
D002	02-23-81	.262		10.2	12.7	9.9	8.4	7.1	5.5	5.0	4.6	4.2
D003	05-19-82	.169		10.8	13.1	10.1	8.6	7.5	5.6	4.8	4.6	4.2
D004	10-30-80	.239		10.4	12.8	10.0	8.8	7.5	5.8	5.2	4.9	4.5
D005	03-27-80	.235		10.2	12.9	10.1	8.5	7.4	5.6	5.0	4.7	4.3
D006	09-26-81	.257		9.9	12.4	9.5	8.1	7.1	5.2	4.5	4.2	3.8
D007	01-30-80	.301		9.5	12.2	9.4	7.9	6.8	5.2	4.5	4.1	3.8
D207	03-23-81	.195		10.5	12.7	9.9	8.7	7.5	5.7	5.1	4.7	4.4
D208	06-25-80	.272		9.7	12.2	9.4	8.0	7.1	5.3	4.7	4.5	4.1
D209	08-09-79	.341		9.8	12.2	9.4	8.1	6.8	5.2	4.5	4.0	3.8
				PREP	FIRST & THIRD WEEKS				SECOND & FOURTH WEEKS			
			$2K_2$	X	X							
			$2K_1$	X	X	X	X	X				
	FLYWHEEL		1K	X		X			X	X	X	X
	ENGAGEMENT		TRIM	X	X	X	X	X	X	X	X	X
	CHART		500	X			X		X			
			250	X						X		
			125	X							X	

Dynamometer Verification Data Processing



```
                                           *********************************************
                                           ** DYNAMOMETER CALIBRATION VERIFICATION **
                                           **            INPUT DATA ECHO            **
                                           **     SITE: 0007    DATE:  6-30-82      **
                                           *********************************************



                                  DATE      TIME      BARO-
       GENERAL         SITE     MO DY YR    HR MN     METER      ID       COMMENTS
       INFORMATION     ****     **-**-**    **:**     ***.**     *****    *****************************************************
                       0007      6-30-82     5:30      28.98     17281.   USED QC TIMER


                                       WARM-UP AND CHECK                                    SPEED CHECK TW=10.0
                                           TW VS IHP                                         60 TOOTH GEAR
                                                                                  GEAR       TORQUE
       50MPH FR        TW=10.0    TW=5.0    TW=15.0    TW=10.0                    COUNTS     COUNTS      DEL T      IHP
       @IW=6875        .**.*       **.*       **.*      **.*        **.*          ******.    ******.     **.***     **.*
                        10.0        5.0       15.0      10.0         0.0           18903.      9517.      9.613     10.0


       WARM-UP         TW        IW     DEL T1     DEL T2    DEL T3     DEL T4     DEL T(RR)     FHP CAL
       COASTDOWNS      **.*     ****.   **.***     **.***    **.***     **.***     ***.***       *.***
                        9.5     6875.   31.713     31.786    31.742     31.816      31.152       0.301


                                            RAMP-UP @ 2.5 MPH/SEC              RAMP-DOWN @ 2.5 MPH/SEC
       SPEED TORQUE                              ( 5-55 MPH )                           ( 55-5 MPH )
       PAU                              GEAR        TORQUE                    GEAR        TORQUE
       HYSTERESIS      TW       IW      COUNTS      COUNTS      DEL T         COUNTS      COUNTS      DEL T
                       **.*     ****.   ******.     ******.     **.***        ******.     ******.     **.***
                       10.0     4000.    25009.      10003.     20.415         24964.       9914.     20.025


                                                 HP @     HP @      MASTER    QCHECK
       VERIFICATION    IW       AHP     TW       50 SS    50 QC     DEL T     DEL T
       DATA            ****.    **.*    **.*     **.*     **.*      **.***    **.***
                       5000.    15.2    12.2     12.3     12.3      19.840    19.840
                       4000.    1[illegible].2     9.4      9.4      9.5      19.930    19.930
                       3500.    10.6     8.0      8.0      8.1      19.840    19.840
                       3000.     9.2     6.8      6.9      7.0      19.790    19.790
```

```
                                        ******************************************
                                        ** DYNAMOMETER CALIBRATION VERIFICATION **
                                        **          VERIFICATION REPORT         **
                                        **     SITE: D007     DATE:  6-30-82    **
                                        ******************************************

                                                                    2.5 MPH/SEC IW= 4000 TW= 10.0
GENERAL INPUT DATA                         WARM-UP AND CHECK        PAU HYSTERESIS CHECK
******************                         *****************        ******************************
DATE:  6-30-82   BAROMETER: 28.98 INHG           IHP@  DIFF    %DIFF
                                           TW    50SS  IHP-TW  IHP-TW            SPEED   TORQUE   IHP
OPERATOR ID: 17281  DYNO SITE: D007
COMMENTS: USED QC TIMER                    10.0  10.0   0.00   0.000  RAMP-UP    31.524  13.244   3.089
                                            5.0   5.0   0.00   0.000  RAMP-DOWN  32.080  13.382   3.177
PROCESSED: 07/02/82  09:29:20              15.0  15.0   0.00   0.000  DIFF        0.556   0.138   0.087
                                           10.0  10.0   0.00   0.000  AVE        31.802  13.313   3.133
ALL DATA AND RESULTS HAVE BEEN VERIFIED                               THEOR      30.000  12.000   2.664
FOR CORRECTNESS AND ACCEPTABILITY          AVE          0.00   0.00   DIFF(A-T)   1.802   1.313   0.469
                                                                      %DIFF       6.007  10.943  17.609
VERIFIED BY Pam Wiley  DATE 7-2-82
            ----------      ---------

FILE ONE COPY IN THE DIAGNOSTICS
DOCUMENTATION FILE AND DISTRIBUTE THE OTHERS


WARM-UP COASTDOWN                             50-MPH SPEED CHECK             QUALITY-CONTROL COMMENTS
TW=  9.5 IW= 6875      REAR ROLL  IW=155      TW=10.0, 60-TOOTH GEAR         (#S REFER TO TP-302A CRITERIA)
****************       ****************       **************************     ****************************************
DEL T1 =   31.713      DEL T =     31.152                                    5)50MPH CHK, @DIFF(SPD>.2;TORQ>1;IHP>.4)
DEL T2 =   31.786      FHP CHK =    0.302            SPEED   TORQUE   IHP
DEL T3 =   31.742      FHP CAL =    0.301
DEL T4 =   31.816      DEL FHP =    0.001     AVE    50.602  26.760   10.0
MAX-MIN =   0.1030     %DEL FHP =   0.388     THEOR  50.000  27.645   10.2
MEAN =     31.764                             DIFF    0.602  -0.270   -0.2
ST DEV =    0.0442                            %DIFF   1.204  -0.999   -2.2
%CV =       0.1391


DYNAMOMETER VERIFICATION DATA
*****************************
                                                                        DIFF     %DIFF
                     HP @   HP @   MASTER  QCHECK   DIFF    THEOR      MASTER-  MASTER-
IW     AHP    TW     50SS   50QC   DEL T   DEL T    DEL T   DEL T      THEOR    THEOR

5000   15.2   12.2   12.3   12.3   19.840  19.840   0.000   19.977    -0.137   -0.686
4000   12.2    9.4    9.4    9.5   19.930  19.930   0.000   19.911     0.019    0.093
3500   10.6    8.0    8.0    8.1   19.840  19.840   0.000   20.052    -0.212   -1.059
3000    9.2    6.8    6.9    7.0   19.790  19.790   0.000   19.803    -0.013   -0.067

                                    AVERAGES        0.000             -0.086   -0.430
```

```
                                  ******************************************
                                  ** DYNAMOMETER CALIBRATION VERIFICATION **
                                  **  FOUR MONTH QUALITY CONTROL SUMMARY  **
                                  **       SITE: D007    DATE:  6-30-82   **
                                  ******************************************


                                                                                              AVERAGE DIFF
DATE      RR     DIFF    %DIFF      PAU DIFF(DOWN-UP)   68/5      50 FR DIFF CHECK       TIMER   DIFF     %DIFF
MM-DD-YR  FHP    IHP-TW  IHP-TW   SPEED  TORQUE  IHP    MEAN    SPEED   TORQUE  IHP      M-QC    M-THEOR  M-THEOR

 3- 3-82  0.296  -0.020   -0.30   -0.80  -0.163  -0.11  31.083  -0.006  -0.261  -0.100  -0.059    0.254    1.273
 3-10-82  0.267  -0.050   -0.50   -0.40  -0.288  -0.10  29.968  -0.019   0.000   0.000  -0.066   -0.105   -0.530
 3-17-82  0.315  -0.050   -0.50    0.47   0.585   0.17  31.302   0.036  -0.314  -0.100  -0.066    0.619    3.100
 3-24-82  0.309   0.000    0.00    0.21   0.345   0.10  31.028   0.042  -0.317  -0.100  -0.064    0.023    0.112
 3-30-82  0.305   0.000    0.00   -0.78  -0.350  -0.15  30.956   0.116  -0.214  -0.100  -0.056    0.177    0.885
 4- 8-82  0.320   0.000    0.00   -0.04   0.144   0.03  30.703   0.185  -0.172   0.000  -0.073   -0.221   -1.108
 4-22-82  0.307   0.000    0.00    0.00   0.000   0.00  30.876   0.104   0.175   0.000   0.000   -0.207   -1.038
 4-28-82  0.298  -0.050   -0.50    0.11   0.038   0.02  30.885   0.060  -0.277  -0.100  -0.075   -0.089   -0.445
 5- 4-82  0.268  -0.070   -0.80   -0.11   0.083   0.01  30.916   0.049  -0.279  -0.100  -0.074   -0.208   -1.041
 5-12-82  0.316   0.050    0.50    0.54   0.382   0.14  30.779   0.080  -0.267  -0.100  -0.087    0.072    0.362
 5-19-82  0.000   0.000    0.00    0.00   0.000   0.00   0.000   0.000   0.000   0.000  -0.081   -0.263   -1.317
 5-26-82  0.304  -0.050   -0.50   -0.07   0.235   0.05  31.047   0.034  -0.364  -0.100  -0.100    0.438    2.192
 6- 3-82  0.420  -0.020   -0.30    0.00   0.000   0.00  30.638   0.020  -0.385  -0.100  -0.092   -0.263   -1.320
 6-11-82  0.305   0.000    0.00    0.00   0.000   0.00  30.773   0.000   0.000   0.000  -0.103    0.048    0.241
 6-16-82  0.290  -0.050   -0.50    0.00   0.000   0.00  31.214   0.000  -0.351  -0.100   0.088    0.021    0.105
 6-23-82  0.321   0.050    0.50    0.38   0.446   0.13  30.985   0.060  -0.181  -0.100   0.076    0.260    1.301
 6-30-82  0.302   0.000    0.00    0.56   0.138   0.09  31.764   0.602  -0.270  -0.200   0.000   -0.086   -0.430


AVERAGES
********

N=           16      10      10      12      12     12      16      14      14      12      15       17       17
MIN       0.267  -0.070   -0.80   -0.80  -0.350  -0.15  29.968  -0.019  -0.385  -0.200  -0.103   -0.263   -1.320
MAX       0.420   0.050    0.50    0.56   0.585   0.17  31.764   0.602   0.175  -0.100   0.088    0.619    3.100

AVERAGE   0.310  -0.026   -0.29    0.01   0.133   0.03  30.932   0.099  -0.248  -0.108  -0.055    0.028    0.138

STD DEV   0.031   0.032    0.33    0.39   0.241   0.09   0.360   0.139   0.124   0.024   0.054    0.254    1.273
```

in water, the water in the exhaust gas must not be allowed to condense. The NO_2 sample train must be heated to about 175°F.

Exhaust gas samples (such as those collected in bags), which have been allowed to stand for a few minutes or longer, will contain larger concentrations of NO_2 than tail pipe exhaust samples which were analyzed immediately, because upon standing the NO oxidizes to NO_2.

C2.1 Theory—The principle of operation of the ultraviolet analyzers is based on the differential absorption of light energy at 4000 A where NO_2 has a strong absorption band. Light is supplied by a tungsten filament lamp with calibration accomplished with known low concentrations of NO_2 in stainless steel cylinders. Extreme caution must be used in achieving a clean sample system for calibration and exhaust analysis.

C2.2 Interference—No response is obtained from an NO_2 ultraviolet analyzer with a 13.5 in cell for the following gases:

12% CO_2 + 5% CO
567 ppm hexane
1000 ppm propane
Water saturated N_2

There is a slight interference from NO. Approximately 1 ppm NO_2 is indicated for each 130 ppm of NO.

◊ CONSTANT VOLUME SAMPLER SYSTEM FOR EXHAUST EMISSIONS MEASUREMENT—SAE J1094a

SAE Recommended Practice

Report of Automotive Emissions Committee approved June 1974 and completely revised by Automotive Emissions Committee April 1978. Editorial change November 1978

Scope—This SAE Recommended Practice describes uniform laboratory techniques for employing the constant volume sampler (CVS) system in measuring various constituents in the exhaust gas of gasoline engines installed on passenger cars and light trucks. The techniques described relate particularly to CVS systems employing positive displacement pumps. In some areas of CVS practice, alternate procedures are given as a guide toward development of uniform laboratory techniques.

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*1. **Introduction: Development of CVS System***—Constant volume sampler (CVS) systems have been used since the late 1950s. The engine exhaust to be sampled is diluted with ambient air so that the total combined flow rate of exhaust and dilution air mix is nearly constant for all engine operating conditions. The CVS system is sometimes called a variable dilution sampler. Recently constant volume sampler systems have been abbreviated PDP-CVS or CFV-CVS. The PDP-CVS system is the older system that uses a positive displacement pump to maintain a constant total flow. The CFV-CVS system uses a critical flow venturi to maintain a nearly constant total flow. Some of the newer CFV systems no longer use a heat exchanger to bring the mix of engine exhaust and dilution air to a constant temperature, but instead monitor the mix temperature continuously in order to calculate the total flow accurately. These CFV systems are not constant volume samplers, but since they are used to measure emissions, the units are discussed here.

Hydrocarbons in the dilution air were recognized from the first as a problem in the CVS procedure. Studies were initiated on the feasibility of removing the unwanted hydrocarbons. As a result, the installation of charcoal filters in the dilution air system was chosen as the most practical solution. Charcoal does not remove any of the hydrocarbon materials, but it does stabilize their concentration level during a given test and thereby permit the collection of an accurate background sample.

*2. **Definitions***—The following definitions apply to the term indicated as the term is used in this recommended practice.

2.1 Analytical Train—A general term to define the entire system required to sample and analyze a particular constituent in exhaust gas. Typically, this train will include items such as tubing, condenser, particulate filter, sample pump, analytical instrument, and flow meter.

2.2 Calibration Curve—Normally, the dependent variable y, the concentration of the calibration gas, is plotted as a function of the independent variable x, the instrumental voltage. For nonlinear analyzers, a polynomial of degree no greater than the fourth power is used. Sufficient data points should be used to adequately define the analyzer response. The calibration curve should agree to within 1% of the measured data point.

2.3 Calibration Frequency—Analyzers should be checked at least monthly to determine if significant change has occurred in the calibration. In addition, the calibration should be verified when a problem is suspected and when large gain shifts are observed.

2.4 Calibrating Gas—A gas mixture of accurately known concentration which is used periodically to calibrate the analytical instruments. Usually, calibration requires a number of mixtures of different concentrations. Calibrating gases are usually divided into groups such as NBS standard reference gases, golden standards, primary standards, and working gases. The naming of the working gases should be traceable to the NBS standard reference gases.

2.5 Chassis Dynamometer—A laboratory power absorption unit capable of simulating to a limited degree the road operation of a vehicle. The dynamometer should possess the capability to simulate the inertia and road load power developed by a vehicle.

2.6 Chemiluminescent (CL) Analyzer—An instrument which measures nitric oxide by measuring the intensity of chemiluminescent radiation from the reaction of nitric oxide with ozone. The addition of a converter will permit the measurement of the oxides of nitrogen.

2.7 Chock—A block or wedge that prevents movement of the wheels of a vehicle.

2.8 Coastdown—The procedure used to determine the total horsepower absorbed by a dynamometer at 50 mph (80 km/h). The time required for the rolls to coast down from 55-45 mph (88-72 km/h) is observed.

2.9 Constant Volume Sampler (CVS)—A device for collecting samples of diluted exhaust gas. The exhaust gas is diluted with air in a manner that keeps the total flow rate of exhaust gas and dilution air constant throughout the test. The device permits measuring mass emissions on a continuous basis and also, through use of a second pump, allows a proportional mass sample to be collected.

2.10 Converter—A thermal or catalytic reaction device which usually precedes the chemiluminescent analyzer and converts oxides of nitrogen to nitric oxide. The converter may also convert ammonia and other nitrogen containing compounds to nitric oxide.

2.11 Counter—A mechanical and/or electrical device that totalizes the number of revolutions of the CVS for each test phase.

2.12 Curve Fitting—See calibration curve, Lagrangian fit, polynomial fit.

2.13 Detector—That component in an analytical instrument which is sensitive to a particular gas.

2.14 Dilution Air—Ambient air which is passed through filters to stabilize the background hydrocarbon concentration and which is used to dilute the vehicle exhaust.

2.15 Dilution Factor—Based on stoichiometric equation for fuel with composition $CH_{1.85}$, the dilution factor is defined as:

$$\frac{13.4}{CO_2 + (HC + CO) \times 10^{-4}}$$

where CO_2 is equal to the concentration in dilute exhaust sample in mole percent, HC in ppm carbon equivalent, and CO in ppm corrected for water vapor and CO_2 extraction.

2.16 Dilution Ratio—The ratio of CVS volume to exhaust volume, usually found by dividing the undiluted exhaust CO_2 concentration by the dilute CO_2 concentration.

2.17 Driver Aid—An instrument used to guide the vehicle driver in operating the vehicle in accordance with the specified acceleration, deceleration, and cruise operating modes of a specific driving procedure.

2.18 Exhaust Emissions—Substances emitted to the atmosphere from any opening downstream from the exhaust port of a motor vehicle engine.

2.19 **Fifth Wheel**—A calibrated wheel, axle and tachometer generator assembly that can be used to determine the true speed of the vehicle (by towing the wheel assembly), or true speed of the dynamometer rolls (by permitting the rolls to drive the fifth wheel assembly).

2.20 **Filter Cell**—That portion of the NDIR instrument which is filled with a particular gas in order to reduce interference signals.

2.21 **Flame Ionization Detector (FID)**—A hydrogen-air flame detector that produces a signal proportional to the mass flow rate of hydrocarbons entering the flame per unit time.

2.22 **Hang-Up**—The absorption-desorption of sample (mainly higher molecular weight hydrocarbons) from the surfaces of the sample system that can cause instrument response delay and lower concentration at the analyzer, followed by higher readings in subsequent tests.

2.23 **Heat Exchanger**—An air-to-air or air-to-water heat exchanger, which is used to control the temperature of the dilution air-exhaust gas mixture.

2.24 **Horsepower**

2.24.1 Absorbed Horsepower—Total horsepower absorbed by the absorption unit of the dynamometer and by the frictional components of the dynamometer.

2.24.2 Absorbed Horsepower at 50 mph (80.5 km/h) Road Load—The dynamometer setting values for various inertia weight vehicles published in the Federal Register.

2.24.3 Frictional Horsepower—Horsepower absorbed by the frictional components of the dynamometer.

2.24.4 Indicated Horsepower—Horsepower values indicated by the horsepower meter of the dynamometer.

2.24.5 Indicated Horsepower at 50 mph (80.5 km/h) Road Load—The dynamometer setting values, determined by calibration, that correspond to the dynamometer setting values published in the Federal Register.

2.25 **Inertia Weights**—A series of rotating disks used on a chassis dynamometer to simulate to the nearest 125, 250, or 500 lb (57, 113, or 227 kg) increments of the test weight of a vehicle during accelerations and decelerations. The inertia weights have no effect during steady states.

2.26 **Lagrangian Fit**—A computer technique used to interpolate polynomial curves generated from a set of data points (calibration points). N data points are required to generate a curve to N − 1 deg. A feature of this technique is that the interpolated curve goes through each data point exactly.

2.27 **Laminar Flow Element (LFE)**—A flow rate measuring device that has a linear relationship between flow rate and pressure drop.

2.28 **Light-Duty Vehicle**—A motor vehicle designed for transportation of persons or property on a street or highway and weighing 6000 lb (2722 kg) gvw or less.

2.29 **Loaded Vehicle Weight**—The curb weight of a light-duty vehicle plus 300 lb (136 kg).

2.30 **Mixing Device**—A device that is used in the main flow stream of a CVS to promote mixing of the exhaust gas with the dilution air.

2.31 **Mode**—A particular operating condition (for example, acceleration, cruise, deceleration, or idle) of a test cycle.

2.32 **Nondispersive Infrared (NDIR) Analyzer**—An instrument to determine carbon monoxide, carbon dioxide, nitric oxide, and hydrocarbons in exhaust gas. Now primarily being used for carbon monoxide and carbon dioxide determinations.

2.33 **Normalizing Gas (Span Gas)**—A single calibrating gas blend routinely used in calibration of each analytical instrument.

2.34 **Optical Filter**—That portion of the NDIR instrument which eliminates wavelength regions where interference signals are obtained.

2.35 **Oxides of Nitrogen**—The sum total of the nitric oxide and nitrogen dioxide in a sample expressed as nitrogen dioxide.

2.36 **Ozonator**—An electrical device that generates ozone from oxygen or air.

2.37 **Parts per Million Carbon**—The mole fraction of hydrocarbon measured on a methane equivalence basis.

2.38 **Polynomial Fit**—A technique of generating a calibration curve from a set of points.

2.39 **Positive Displacement Pump**—A CVS blower, gas pump, or constant displacement pump that delivers a metered amount of air per revolution measured at inlet conditions.

2.40 **Probe**—A sample line inserted into the exhaust stream of a vehicle or engine in such a manner as to obtain a homogeneous or well-mixed exhaust sample.

2.41 **Reference Cell**—That portion of the NDIR instrument that is usually filled with air (sometimes nitrogen) and provides the reference signal to the detector.

2.42 **Remote Filter Box**—Particular CVS design that has the dilution air filters and mixing chamber housed in a separate cabinet which can be located close to the tailpipe of the test vehicle.

2.43 **Sample Cell**—That portion of the NDIR instrument which contains the flowing sample gas.

2.44 **Stratification**—Variation in concentration of a sample stream when samples are taken at different points on a cross section of the mixed CVS stream just ahead of the CVS positive displacement pump.

2.45 **Tailpipe Pressure**—The static pressure measured at the tailpipe when a CVS is connected to a test vehicle.

3. *Test Facilities and Equipment*

3.1 **Sampler**—CVS systems can exist in a variety of physical configurations, but all of them permit measuring emissions of vehicles.

3.1.1 Basic Equipment—The principal component of a CVS is either the positive displacement pump (PDP) of the older models or the critical flow venturi (CFV) of more recent designs. The positive displacement pump consists of a pair of symmetrical rotating, two-lobe impellers driven in opposite directions and encased by a housing. A critical flow venturi CVS has a CVS compressor unit that is used in conjunction with the critical flow venturi. Fig. 1 shows a sketch of a CFV-CVS.

3.1.1.1 A dilution air filter system consisting of a particulate (dust) filter, a charcoal filter, and a second particulate filter which removes airborne particles, stabilizes hydrocarbons, and traps charcoal particles.

3.1.1.2 A flexible coupling to the tailpipe of the test car brings in undiluted exhaust gas to the mixing chamber.

3.1.1.3 A mixing chamber combines the automotive exhaust from the test car and the dilution air into a homogeneous (nonstratified) mixture.

3.1.1.4 A heat exchanger is used to control the temperature of the exhaust gas dilution air mixture. The heat exchanger should be capable of controlling the temperature of the dilute exhaust gas ±10°F (5.6°C) during testing. In some models of CVS, a temperature controller regulates both the flow of cooling water or hot water (from a hot water heater) through the heat exchanger to control mixture temperature. In other models of CVS, the dilution air is preheated so that the temperature controller regulates the flow of cooling water through the heat exchanger in order to control the mixture temperature.

3.1.1.5 A secondary heater system maintains the heat exchanger at a temperature to prevent water condensation.

3.1.1.6 A sampling system transfers the exhaust-air mixture from the positive displacement pump inlet to the bag at a constant flow rate. The minimum sample flow rate should be 10 ft^3/h (0.28 m^3/h). Each sampling system consists of fiberglass filter, a diaphragm type pump, a flow control valve, and a flow meter or other gas measuring device. All of the surfaces in contact with the sample air or air-gas mixture are stainless steel or other nonreactive material.

3.1.1.7 A similar sampling system collects dilution air from a point just downstream of the air filter and transfers it to a separate bag.

3.1.1.8 An evacuation and purge pump to remove the excess sample from the bags and purge the bags with clean air.

3.1.1.9 A set of bags (sample and background) and appropriate controls is needed for each of the test phases.

3.1.2 Supplementary Equipment—In addition to the above basic equipment, the following items can be added for operating convenience:

3.1.2.1 A muffler located after the CVS pump to reduce the noise.

3.1.2.2 A four-speed motor, transmission, or other suitable means for driving the positive displacement pump will permit a choice of different dilution ratios.

3.1.2.3 An optional remote control operating station containing the counter, the operations logic module, and the various control function switches and indicator lights that permit convenient operator control at a distance from the CVS console.

3.1.2.4 Optional modal analysis at the analytical bench during the filling of the bag is made possible through the use of a separate sampling probe(s). One probe is used if continuous modal analysis is conducted using undiluted exhaust.[1] The second probe in this case is used to monitor diluted CO_2 which is used as a tracer gas to determine engine flow. Tail pipe sample should either be returned to the CVS bulk stream if the amount withdrawn is a significant fraction of total exhaust flow (greater than 1%), or the loss in tail pipe sample should be corrected mathematically.

3.2 **Analysis Instrumentation—Bag Analysis**

3.2.1 Schematic—Fig. 1 is a sketch of the sampling and analysis train that is a typical flow schematic for the bag analysis of engine exhaust using the CVS.

3.2.2 Component Description—The following components are suggested for the CVS bag sampling and analytical systems for the analysis of carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NO_x), carbon dioxide (CO_2), and oxygen (O_2):

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[1] Two probes are required if continuous modal analysis is conducted using undiluted exhaust.

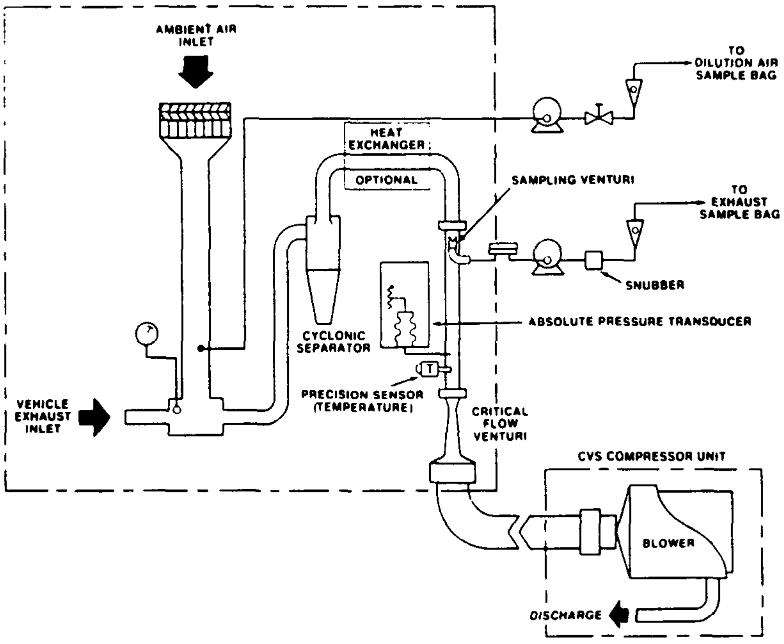

FIG. 1—CFV-CVS SAMPLER UNIT

3.2.2.1 NDIR analyzers for measurement of CO and CO_2 with cells of appropriate length for concentration ranges being measured. Typical ranges are shown in Table 1.

3.2.2.2 Chemiluminescent (CL) NO analyzer or equivalent NDIR NO analyzer are both equipped with a bypass and NO_2 to NO converter for the measurement of NO_x with concentration range selection as shown in Table 1.

3.2.2.3 FID for measurement of HC. The instrument employed should be capable of measuring HC for ranges shown in Table 1.

3.2.2.4 Oxygen analyzer for measurement of O_2 with range of measurement as shown in Table 1.

3.2.2.5 Values V_{12} used to direct the sample or purge air to the analyzers.

3.2.2.6 Valves V_1, V_4, V_8 (optional), V_9, and V_{10} used to direct the sample, zero gas, or span gas streams to the analyzers.

3.2.2.7 Filters F_1 and F_2 for removing particulate materials from the sample prior to analysis. A glass fiber filter of at least 7 cm diameter is suitable.

3.2.2.8 Pumps P_1 and P_2 to move the sample through the system. Pumps should have stainless steel or aluminum chambers with diaphragms and valves made from or covered with an inert material, such as Teflon. Free air capacity should be approximately 40 ft^3/h (1.1 m^3/h). Pumps P_3 for bypass flow of chemiluminescent analyzer and vacuum pump P_4 (optional depending upon the design of the chemiluminescent analyzer) for evacuation of the chemiluminescent reactor chamber.

3.2.2.9 Needle valves N_1, N_4, N_7, and N_{11} to regulate sample gas flow to the analyzers.

3.2.2.10 Needle valves N_2, N_5, N_8, and N_{12} to regulate span gas flow to the analyzers.

3.2.2.11 Optional valve V_9 used to direct CO_2 span gas through the water bubbler for checking the performance of drier and absorber system or to check the H_2O and CO_2 interference rejection characteristics of the CO analyzer. Needle valve N_{20} is used to regulate CO_2 flow.

3.2.2.12 Needle valves N_3, N_6, N_9, N_{13}, and N_{15} to regulate zero gas flow to the analyzers.

TABLE 1—TYPICAL LOW RANGES FOR ANALYSIS OF HC, CO, CO_2, NO_x, AND O_2 IN SPARK IGNITION ENGINE EXHAUST

Component	Ranges	
	CVS Bag Sample	Undiluted Exhaust Gas
HC	0–30 ppmC	0–500 ppmC
CO	0–100 ppm	0–0.3%
NO_x		
1975	0–250 ppm	0–2500 ppm
1976	0–10 ppm	0–250 ppm
CO_2	0–2.0%	0–15%
Dilute CO_2	—	0–5%
O_2	0–21%	0–10%

3.2.2.13 Flow meters FL_1, FL_2, FL_3, and FL_4 to indicate span gas, zero gas, and sample flow to the analyzers.

3.2.2.14 Water trap T_1, if necessary, to partially remove water and a valve N_{14} to allow the trap to be drained.

3.2.2.15 Optional[2] sample conditioning columns CR_1 and CR_2 containing ascarite to remove CO_2 from the CO analysis stream, and WR_1 and WR_2 containing indicating $CaSO_4$ or indicating silica gel to remove the remainder of the water. Equivalent drying techniques such as diffusion driers may be used.

3.2.2.16 Optional valves V_6 and V_7 to permit switching from exhausted absorbing columns to fresh columns.

3.2.2.17 Optional water bubbler W_1 to allow saturation of CO_2 span gas to check the efficiency of the absorbing columns in the CO system.

3.3 Analysis Instrumentation—Modal Analysis (Undiluted Exhaust Gas)

3.3.1 GENERAL—Fig. 3 is a schematic drawing of the sampling and analysis train that is recommended for the modal analysis of spark ignition engine exhaust using the CVS. The system is very similar to that required for bag analysis, with the exception that water traps are required on all instrument sampling streams and an additional CO_2 analyzer is required. In addition, instruments of only approximately $\frac{1}{10}$ the sensitivity of those used for bag analysis are needed. This system is based upon measuring continuously undiluted exhaust gas concentrations of HC, CO, NO_x, and CO_2 and the diluted exhaust CO_2 concentration.

The undiluted and diluted exhaust CO_2 concentrations are used to calculate a dilution factor which, in conjunction with the total diluted volume, can be used to calculate the vehicle exhaust volume. With the calculated exhaust volume and the undiluted exhaust concentrations, the modal mass emissions of each pollutant can be calculated as described in paragraph 5.2.2.

3.3.2 COMPONENT DESCRIPTION—The following components are recommended for the analytical systems for the modal analysis of CO, HC, NO_x, CO_2, and O_2.

3.3.2.1 NDIR analyzers for measurement of CO and CO_2 with cells of appropriate length for the concentration ranges being measured. Typical ranges are shown in Table 1.

3.3.2.2 The CO_2 analyzer for the measurement of CO_2 in the diluted exhaust stream can be modified to the extent that the reference cell is replaced with a second sampling cell through which dilution air is passed during sampling. This feature will automatically correct the measured CO_2 in the diluted exhaust for the amount of CO_2 in the dilution air.

3.3.2.3 Chemiluminescent (CL) NO analyzer equipped with a bypass

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[2] The criteria for CO interference by CO_2 and water is given in the Federal Register, Vol. 39, No. 101, May 23, 1974: "A CO instrument will be considered to be essentially free of CO_2 and water vapor interference if its response to a mixture of 3% CO_2 in N_2, which has been bubbled through water at room temperature (68–86°F), produces an equivalent CO response, as measured on the most sensitive CO range, which is less than 1% of full scale CO concentration on instrument ranges above 300 ppm CO or less than 3 ppm on instrument ranges below 300 ppm CO."

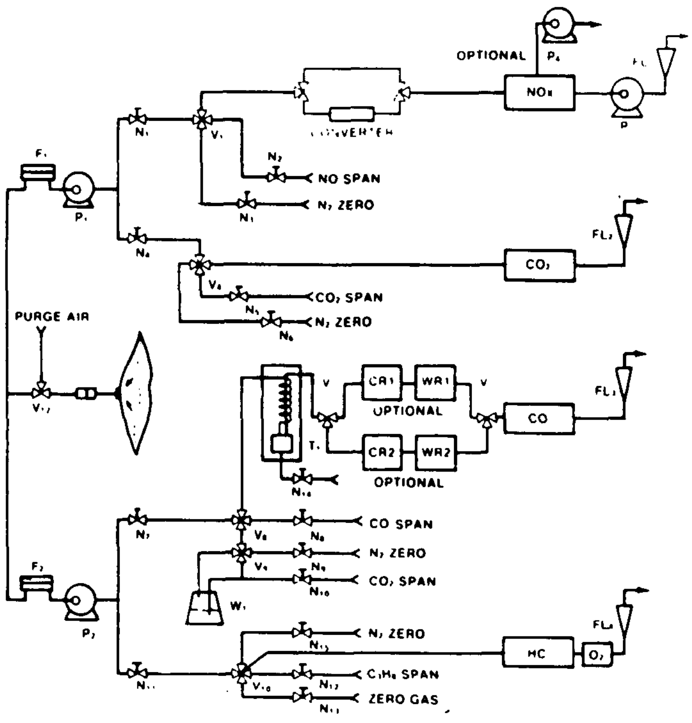

FIG. 2—BAG SAMPLING AND ANALYSIS TRAIN

and a NO_2 to NO converter for the measurement of NO_x with the concentration range selection as shown in Table 1.

3.3.2.4 FID for measurement of HC. The instrument should be capable of measuring HC for the ranges shown in Table 1.

3.3.2.5 Oxygen analyzer for measurement of O_2 with range of measurement shown in Table 1.

3.3.2.6 Valves V_1 and V_{13} used to direct the sample of purge air to the analyzers or to purge air to the blowout traps.

3.3.2.7 Valves V_2, V_4, V_9, V_{10}, V_{14}, and V_{16} used to direct the sample, zero gas, or span gas streams to the analyzers. Valve V_4 is used to direct the span gas to the O_2 sensor.

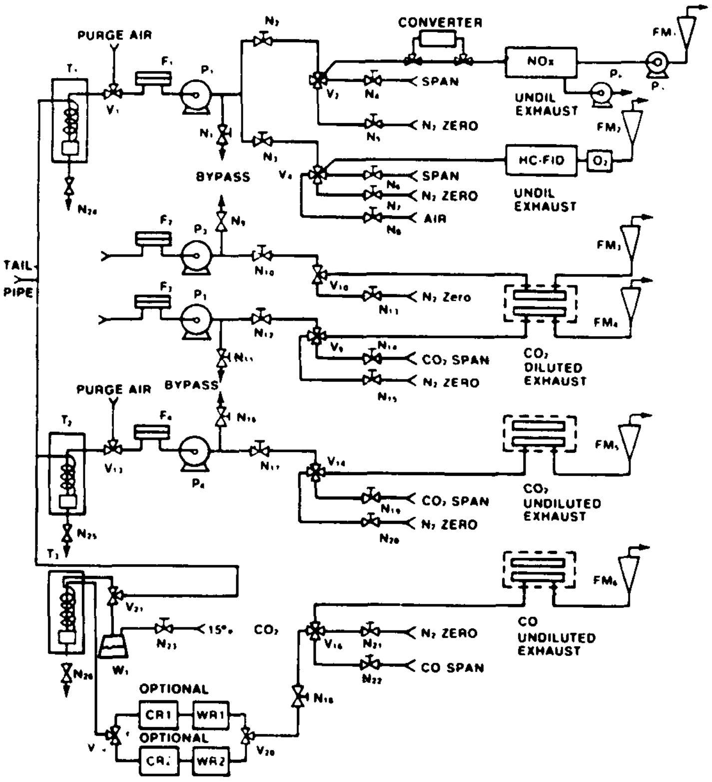

FIG. 3—MODAL SAMPLING AND ANALYSIS TRAIN

3.3.2.8 Filters F_1, F_2, F_3, and F_4 for removing the particulate from the sample prior to analysis. A glass fiber type of at least 7 cm in diameter is suitable.

3.3.2.9 Pumps P_1, P_2, P_3, and P_4 to move the sample through the system. Pump P_5 for bypass flow of the chemiluminescent analyzer and vacuum pump P_6 (optional dependent on design of chemiluminescent analyzer) for evacuation of the chemiluminescent reactor chamber. Pumps should have stainless steel or aluminum chambers with diaphragms and valves made from or covered with an inert material, such as Teflon. Free air capacity should be approximately 40 ft^3/h (1.1 m^3/h).

3.3.2.10 Needle valves N_2, N_3, N_{10}, N_{12}, N_{17}, and N_{18} to regulate sample gas flow to the analyzers.

3.3.2.11 Needle valves N_4, N_8, N_{14}, N_{19}, and N_{22} to regulate span gas flow to the analyzers.

3.3.2.12 Optional valve V_{21} used to direct CO_2 span gas through the water bubbler for checking the performance of the absorbers in the CO analyzer stream. Needle valve N_{23} (optional) is used to regulate CO_2 flow.

3.3.2.13 Needle valves N_5, N_7, N_{13}, N_{15}, N_{20}, and N_{21} to regulate zero gas flow to the analyzers.

3.3.2.14 Flow meters FM_1, FM_2, FM_3, FM_4, FM_5, and FM_6 to indicate span gas, zero gas, and sample flow to the analyzers.

3.2.2.15 Water traps T_1, T_2, and T_3 to partially remove water and valves N_{24}, N_{25}, and N_{26} to allow the traps to be drained.

3.2.2.16 Optional sample conditioning columns CR_1 and CR_2 containing ascarite to remove CO_2 from the CO analysis stream, and WR_1 and WR_2 containing indicating $CaSO_4$ or indicating silica gel to remove the remainder of the water. Ascarite produces water when it removes CO_2 from the stream. Equivalent drying techniques such as diffusion driers may be used. The volume of the conditioning columns must be sufficient to be effective for the duration of the test. Some operational ranges for continuous analysis may not require water and CO_2 removal. Some new CO instruments do not have water or CO_2 response.

3.3.2.17 Optional valves V_{19} and V_{20} to permit switching from the exhausted absorbing columns to fresh columns.

3.3.2.18 Optional water bubbler W_1 to allow saturation of CO_2 span gas to check the efficiency of the absorbing columns in the CO system.

3.3.2.19 Needle valves N_1, N_9, N_{11}, and N_{16} to regulate the bypass sample flow.

3.4 Instrument Operating Procedures—Follow the instrument manufacturer's start-up and operating procedure for the particular type instrument being used. In addition, the following minimum calibration and instrument checks should be included.

3.4.1 INITIAL—The following instrument checks should be accomplished prior to making emission measurements with the instruments:

3.4.1.1 *Optimize FID Response*

(a) Set burner fuel and air settings as prescribed by the manufacturer. Present burner fuel composition now recommended is 60% He, 40% H_2. However, best composition for burner fuel is now being investigated. Ignite the burner and set sample flow. Wait until the analyzer stabilizes before proceeding. Optimize the FID as suggested in SAE Procedure J254 (June, 1971).

(b) Determine the optimum burner fuel flow for maximum response. A blend of 60% He and 40% H_2 is recommended for use as the burner fuel. The use of other fuels could produce a correlation problem. Introduce propane in N_2 at a concentration level of approximately 300 ppmC for undiluted gas analysis and propane in air for bag analysis. Vary the burner fuel flow to obtain the peak response. Normally, there is a plateau in the region of peak response. Select a flow in this region which results in the least variation in response with minor fuel flow variations.

(c) Determine optimum airflow. Set the burner fuel flow as determined in paragraph 3.4.1.1(b) and vary airflow to obtain maximum response. If the airflow is too high, excessive noise may result.

(d) If the airflow is significantly different from that used in paragraph 3.4.1.1(b), repeat step (b) with the new airflow.

3.4.1.2 *Determine Oxygen Response of FID Analyzer*—Variations in the oxygen content of the sample can affect the FID response. This effect must be determined and minimized.

(a) CVS bag analysis

(1) Set flows as determined in paragraph 3.4.1.1 and ignite the burner. Wait for stabilization. Normally, the burner is operated continuously to avoid the stabilization problem.

(2) Zero the analyzer on HC free air.

(3) Determine the oxygen response by introducing propane gas at a concentration of approximately 30 ppmC in the following diluents: 100% N_2, 95% N_2/5% O_2, 90% N_2/10% O_2, 85% N_2/15% O_2, and 100% air.

(4) Using the propane in the air gas as the baseline for no O_2 correction, plot a curve of the oxygen correction factor versus the percent O_2 in the sample:

$$O_2 \text{ correction factor} = 1.0 - \frac{(A - B)}{B}$$

where: A = HC response in N_2/O_2 blends
B = HC response in air

(5) Check the effect of O_2 using a propane concentration of 50 ppmC. If it is significantly different from the 30 ppmC correction data, establish a curve and apply the O_2 correction on a prorated basis as a function of HC concentration.

(6) If the O_2 correction factor is less than 0.96 over the normal O_2 range encountered in CVS sampling, see paragraph 3.5.2.

(7) It is recommended that a different detector be obtained if the oxygen correction factor is less than 0.90 for the O_2 range found in CVS samples.

(b) Modal Analysis—Undiluted Exhaust Gas

(1) Set flows as determined in paragraph 3.4.1.1 and ignite the burner. Wait for stabilization. Normally, the burner is operated continuously to avoid the stabilization problem.

(2) Zero the analyzer with N_2.

(3) Determine the oxygen response by introducing propane gas at a concentration of approximately 300 ppmC in the following diluents: 100% N_2, 95% N_2/10% O_2, 85% N_2/15% O_2, and 100% air.

(4) Using the propane in N_2 (0% O_2) as the baseline for no O_2 correction, plot a curve of the oxygen correction factor versus the percent O_2 in the sample, where:

$$O_2 \text{ corr factor} = \frac{\text{HC response with propane in } 100\%\ N_2}{\text{HC response with propane in } O_2 \text{ blends}}$$

(5) If the O_2 correction factor is greater than 1.05 over the range of 0-10% O_2, see paragraph 3.5.2.

(6) It is recommended that a different detector be obtained if the oxygen correction factor is greater than 1.10 for the O_2 range found in the undiluted exhaust gas samples.

3.4.1.3 *Determine Linearity of FID Response*

(a) Set up the FID as determined in paragraphs 3.4.1.1 and 3.4.1.2. Set the sample flow rate at a low value (approximately 5 ml/min) consistent with good signal to noise ratio.

(b) Using propane in air, or N_2, vary the concentration of HC over the expected HC range. If the response is linear, a sample linear calibration factor can be used. If the response is not linear, prepare a calibration curve.

3.4.1.4 *Optimize Performance of NDIR*—After adjusting the analyzers for optimum performance using the manufacturer's recommended procedures, a calibration curve must be generated for the ranges of the instrument that will be used. All emission measuring instruments are comparative devices. The generation of the calibration curves using standard gases (paragraph 3.5.1) should be as accurate as possible. Since many analyzers are connected to computers, a variety of curve-fitting techniques are being used. No specific technique will be recommended here. Polynomial and Lagrangian curve fitting techniques are widely used. It is recommended to examine carefully an accurate plot of the calibration curve to verify that a smooth curve was generated, rather than a curve that has only high correlation at the data points.

3.4.1.5 *Optimize Performance of Chemiluminescence NO Analyzer*—Using the manufacturer's recommended procedures, adjust the analyzer for optimum performance. In addition, determine the efficiency of the NO_2 to NO converter, at the converter temperature recommended by the manufacturer, using the flow system shown schematically in Fig. 4. A suggested procedure is given in Appendix A.

If the converter efficiency is below 90%, the converter temperature should be increased and the efficiency rechecked. Converter temperature should be set at a minimum required for near 100% conversion efficiency.

Care must be used to prevent condensation due to pressure buildup in the NO_x sample train between the sample pump and the analyzer. This has been found to be a critical area of the NO_x sample train, since condensation causes a lowering of the measured NO_x concentration and, therefore, an incorrect NO_x emission measurement.

3.4.2 Monthly—The following checks are to be made monthly or more frequently if there is any doubt regarding the accuracy of the analyses.

3.4.2.1 Calibrate the NDIR analyzers using the same gas flow rates as when sampling exhaust.

(a) Allow 2 h warmup of analyzers.

(b) Tune analyzer.

(c) Set zero and span using prepurified N_2 and the 100% range calibration gas.

(d) Recheck zero and repeat step 3.4.2.1(c), if necessary.

(e) Calibrate each analyzer with calibrating gases that are approximately 15, 30, 45, 60, 75, and 90% of each range used. The concentration of the standard gases should be known with at least ±2% accuracy. If the analyzer proves to be non-linear, use an eight point calibration with a set of calibration gases spread approximately uniformly over the analyzer range in question.

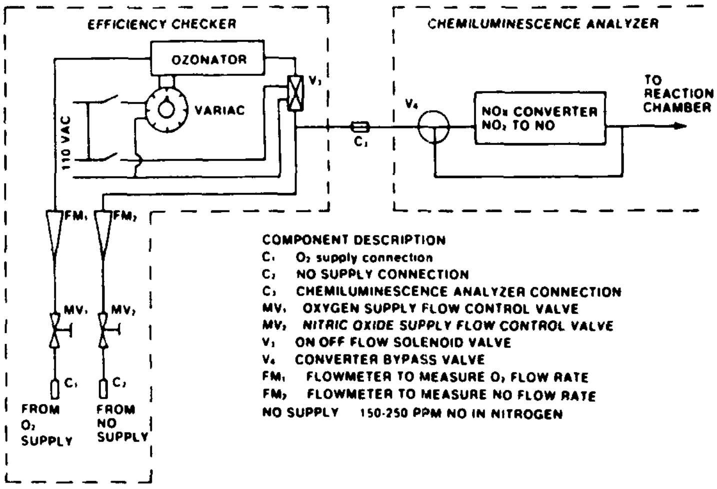

FIG. 4—FLOW SCHEMATIC OF CONVERTER EFFICIENCY ANALYSIS SYSTEM

(f) Compare values with previous curves. Any significant change reflects some problem in the system. Locate and correct the problem and recalibrate.

3.4.2.2 Check FID analyzer O_2 response and HC response.

(a) Ignite the burner and then set the fuel, air, and sample flow rates as determined in paragraphs 3.4.1.1 and 3.4.1.2.

(b) Introduce HC free air zero gas (CVS bag analysis) or N_2 (Modal-undiluted exhaust gas analysis) and zero analyzer.

(c) Check O_2 effect on the response by introducing the calibration gases of propane in air, propane in N_2, and propane in 90% N_2/10% O_2.

(d) Compare the O_2 response values with the previous curves. Any significant change (±10%) indicates a change in the burner operating characteristics. Check the burner system and measure the flows. If the change in the response cannot be resolved, establish a new O_2 response curve as per paragraph 3.4.1.2.

(e) Check the calibration curve or response data as per paragraph 3.4.1.3.

3.4.2.3 Calibrate chemiluminescent analyzer using same flow rates as when sampling exhaust.

(a) Set the sample flow and oxygen flow to the recommended settings.

(b) Turn the ozone generator on and allow a 10 min warmup period.

(c) Using nitrogen, zero the meter on the most sensitive range or the range to be used by means of the dark current suppression adjustment.

(d) Set the span, using 100% range calibration gas on the range to be used.

(e) Calibrate the analyzer with gases blended in N_2 that are approximately 25, 50, 75, and 100% of the range being used.

(f) Check the values with the previous curves. Any significant change reflects some problem in the system. Locate and correct the problem and recalibrate.

(g) Caution. The correct standby position for the NO_x converter is dependent on the converter type. See manufacturer's instructions.

(h) Caution. Some NO_2 to NO converters can be rendered useless for many hours if they are allowed to sample exhaust gas (even momentarily) from over rich vehicles where high levels of CO, low levels of O_2, and free H_2 are produced.

3.4.3 Weekly—Check the converter of the chemiluminescent analyzer using the procedure outlined in paragraph 3.4.1.5.

3.4.4 Daily—Prior to daily testing carry out the following:

3.4.4.1 *NDIR Analyzers*—Normally, power is left on the NDIR analyzers continuously. Only the chopper motors are turned off. In some cases, more dependable performance has been achieved by leaving the chopper motors on.

(a) Zero on prepurified N_2.

(b) Introduce span gas and set the gain to match the calibration curves. Use the same flow rate for calibration, span gas, and exhaust gas to avoid correction for the sample cell pressure change. Use span gas having a concentration of the constituent being measured that will result in 75-95% of full-scale deflection. If the gain has shifted significantly, check the tuning; if necessary, check the calibration.

(c) Check nitrogen zero and repeat steps 3.4.4.1(a) and 3.4.4.1(b), if necessary.

(d) Repeat steps 3.4.4.1(a) through 3.4.4.1(c) prior to each exhaust gas analysis.

(e) Span and zero should be rechecked after bag measurements.

3.4.4.2 *FID Analyzer*

(a) Ignite the burner and then set the fuel, air, and sample flow rates as determined in paragraphs 3.4.1.1 and 3.4.1.2.

(b) Introduce zero gas (HC-free air for CVS analyzers, N_2 for undiluted exhaust gas analyzers) and zero analyzer.

(c) Introduce HC span gas (propane in HC-free air for CVS analyzers, propane in N_2 for undiluted exhaust gas analyzers) of appropriate concentration to result in a response of at least 50% of full-scale on the range anticipated for use. If the calibration curve and span value disagree adjust the span potentiometer of the FID. Sample flow for zero and span must be the same as that used for analyzing exhaust sample.

(d) Repeat steps 3.4.4.2(a) through 3.4.4.3(c) prior to each exhaust gas analysis.

(e) Span and zero should be rechecked after bag measurements.

3.4.4.3 *Chemiluminescent Analyzer*—Normally power is left on continuously. Operate converter in standby mode as recommended by the manufacturer. Vacuum pumps are normally kept on continuously on those model analyzers using vacuum pumps. The ozonator should not be left on continuously for safety reasons. Vacuum pump and ozone problems can be minimized by replacing the pump oil with perfluorinated polyether fluid.

(a) Turn on the sample pumps.

(b) Set O_2 (in some models air is used) and sample flows using nitrogen.

(c) Turn on ozone generator and allow a 10 min warmup.

(d) With the converter in the NO mode, adjust the dark current suppression to zero the meter on the most sensitive range or the range to be used, using prepurified N_2.

(e) Introduce span gas and set gain to match the calibration curves. Use a span gas having an NO concentration that will result in 75-95% of full-scale deflection.

(f) Check dark current suppression and repeat steps 3.4.4.3(d) and 3.4.4.3(e) if necessary.

(g) Span and zero should be rechecked after bag measurements.

3.4.4.4 *Oxygen Analyzer*

(a) Introduce oxygen-free nitrogen and set zero.

(b) Introduce air and set O_2 span. This is usually done concurrently when setting the zero on the FID analyzer.

(c) Sample flow for zero and span must be the same as that used when analyzing exhaust gas samples.

3.5 Supplementary Discussion

3.5.1 Calibration Gases—There are several suppliers of calibration gases in the ranges used in this procedure. These can be obtained with an analysis accuracy of ±2% or better. Stated gas analysis accuracies should be explicitly defined in terms of traceability to NBS standard reference gases or applicable gravimetric standards. It is recommended that all working gases be renamed using NBS standard reference gases or in-house primary reference gases. If a reference gas cylinder value does not fall on a smooth calibration curve, then that cylinder must not be used.

The CO and CO_2 gas can be purchased as a mixture in nitrogen. NO calibrating gas should be diluted with oxygen-free nitrogen and must not be mixed either with CO or CO_2. Propane calibrating gases are purchased with HC-free air as the diluent for use in CVS bag analysis and with N_2 as the diluent for use in undiluted exhaust gas analysis.

Zero gas impurity concentration should not exceed 1 ppm for HC, 1 ppm for CO, 0.1 ppm for NO, 400 ppm (0.04%) for CO_2, and 3 ppm for H_2O.

3.5.2 Reducing the Oxygen Effect on Response—The oxygen correction for FID should be reduced to attain the limits described in paragraph 3.4.1.2. The oxygen effect on response for a particular FID burner design may depend upon (a) the type of burner fuel used, for example H_2, 40% H_2/60% N_2, or 40% H_2/60% He; (b) on the sample flow rate into the burner; and (c) the air and fuel rate to the burner.

3.6 Tailpipe Connections—To obtain a good constant volume sample of exhaust gas it is imperative that no leakage, either into or out of the sampling system, occur at the tailpipe connection between the vehicle and the CVS sampler. The CVS sampler must be provided with dual inlets to accommodate vehicles with dual exhaust systems. When a vehicle with a single exhaust is being tested, the second sampler inlet must be tightly capped to prevent leakage.

Piping between the sampler and the vehicle should be kept to a minimum length and be of adequate diameter. (See Section 4 for more detail on this subject.) The actual connection between the vehicle tailpipe and the flexible tubing of the CVS can be made in one of two ways:

(a) A flanged fitting such as a Marmon coupling. One end of this coupling is welded to the flexible piping from the CVS and a mating section is welded to the exhaust pipe(s) of each vehicle to be tested.

(b) A silicone rubber boot clamped to the exhaust pipe and inlet plumbing to the CVS.

The first method, a flanged fitting, should be used whenever possible. However, when fittings cannot be welded to each vehicle to be tested, the silicon boot alternative has to be used. The main drawback of the silicone boot is that the hot exhaust gas causes rapid deterioration of the silicone. When vehicles with advanced control devices are tested, the very hot exhaust gases produced by these systems may cause the boot to crack internally after a single test.

3.7 Chassis Dynamometer

3.7.1 Procedure for Dynamometer Absorbed Horsepower Calibration—The following procedure describes one method for determining the absorbed horsepower of a chassis dynamometer. The measured absorbed horsepower includes the dynamometer frictional horsepower as well as the power absorbed by the power absorption unit. The dynamometer is driven above the test speed range to 60 mph (96 km/h). The device used to drive the dynamometer (in most cases a vehicle) is then disengaged from the dynamometer and the roll(s) allowed to coast down. The kinetic energy of the system is dissipated by the dynamometer friction and absorption unit. This method neglects the variations in roll bearing friction due to the drive axle weight of the vehicle and also neglects the variations in friction due to different inertia weights. The difference in coastdown time of the free (rear) roll relative to the drive (front) roll may be neglected in the case of dynamometers with paired rolls.

3.7.1.1 *Equipment*

(a) Fifth wheel, tachometer generator, or other device to measure the speed of the front roll.

(b) Hydraulic jack or other equipment to lift vehicle's drive wheels from the rolls.

(c) Stop watch or other timing device to measure the time it takes the rolls speed to decrease from 55 to 45 mph (88.5 to 72.4 km/h).

(d) Pair of chocks, vehicle tie-downs, and other safety devices used to assure safe operation of a vehicle on the rolls.

3.7.1.2 *Preparation*

(a) Place the vehicle on the dynamometer rolls and set chocks against the front wheels. Tie-downs should be slack enough to allow the vehicle to be lifted from the rolls.

(b) Verify the calibration of the fifth wheel, tach generator, or other speed monitoring equipment.

(c) Position the lifting device at the rear of vehicle.

(d) Place the lift pads under the rear bumper, adjacent to the bumper brackets.

(e) Practice lift technique in disengaging the rear wheels to develop a familiarity with the lifting device's response.

(f) When satisfied, raise the lift pads until they are in contact with the bumpers so that there is sufficient tension to keep the lift pads in place until ready to use.

(g) Set dynamometer inertia to 4000 lb (1816 kg) or to the more common weight class to be tested.

3.7.1.3 *Test Procedure*

(a) Drive the dynamometer with the test vehicle to 50 mph (80.5 km/h).

(b) Adjust the dynamometer power absorption unit to an indicated 2.5 hp (1.9 kW).

(c) Accelerate the dynamometer test vehicle to 60 mph (96 km/h). At this point, disengage the drive wheels from the rolls by means of the lifting device.

(d) Record the time for the dynamometer to coast down from 55 to 45 mph (88.5 to 72.4 km/h).

(e) Repeat steps 3.7.1.3(c) and 3.7.1.3(d) two more times.

(f) Calculate an average from the three coastdown times.

(g) Repeat steps 3.7.1.3(a) through 3.7.1.3(f) for 5.0, 7.5, and 10.0 indicated hp (3.7, 5.6, and 7.4 kW) and calculate the average coastdown times for each.

3.7.1.4 *Calculations*—Calculate actual absorbed road horsepower from:

$$HP_{act} = \frac{1}{2}\,\frac{W_i}{32.2}\,\frac{(V_1^2 - V_2^2)}{550t} \approx \frac{0.06073\,W_i}{t}$$

where: W_i = equivalent inertia, lb
V_1 = initial velocity, ft/s (55 mph = 80.67 ft/s)
V_2 = final velocity, ft/s (45 mph = 66.00 ft/s)
t = elapsed time for rolls to coast down from 55 to 45 mph (88 to 72 km/h)

3.7.1.5 *Belt Drive Dynamometers*—The procedure outlined above has been applied extensively to belt drive dynamometers. The next step is to plot the indicated road load horsepower at 50 mph (80 km/h) versus the actual road horsepower at 50 mph (80 km/h). Fig. 5.

The Federal Register advises running coastdowns at the inertia weight most frequently used. Common practice is to run coastdowns at either all inertia weight settings of a dynamometer or at least all inertia weights that are used for testing.

3.7.1.6 *Direct-Drive Dynamometers*—The same procedure can be used for direct-drive dynamometers as for belt drive dynamometers and should be used for manual loading calibration of these units. However, automatic loading

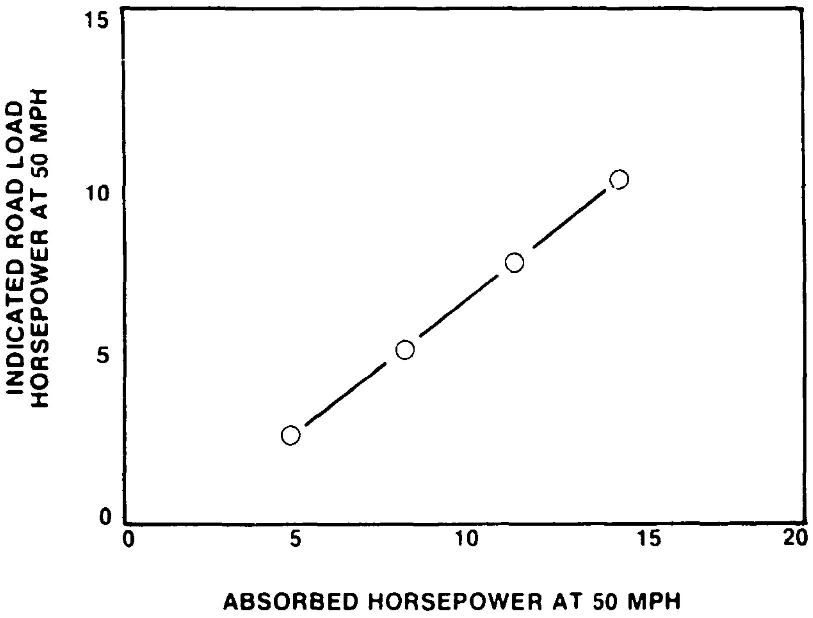

FIG. 5—DYNAMOMETER CALIBRATION CURVE

features of the new direct-drive dynamometers can improve the coastdown procedure. An outline of a direct-drive dynamometer procedure is given in Appendix C.

The direct-drive dynamometer procedure sets up the dynamometer for operation at the desired operating points rather than finding a linear range for each inertia weight. This procedure is rapid and reproducible in both running coastdowns and in operation. It is recommended that a plot of frictional horsepower versus inertia weight be made for each set of coastdown data. These plots can aid in determination that the coastdown data is valid.

In Fig. 6, the frictional power is plotted as a function of inertia weight for nine automatic loading direct-drive dynamometers. The data show that the frictional powers are confined to an approximate 1 hp (745 W) band. On these plots, the "over 5500" values are plotted at 6000 for convenience.

An example of the effect of recalibration is shown in the frictional power versus inertia weight plot in Fig. 7. A dynamometer recalibration indicated a shift of over 0.5 hp (0.3 kW) friction. A recalibration showed that a speed calibration error had been made. After correction, a typical shift of less than 0.5 hp (0.3 kW) was observed.

3.7.2 DYNAMOMETER PROCEDURE

3.7.2.1 The vehicle shall be tested from a cold start. Engine startup and operation over the driving schedule make a complete test run. Exhaust emissions are diluted with air to a constant volume and a portion is sampled continuously during each of the three test phases. The composite samples, collected in three bags, are analyzed for HC, CO, NO_x, and CO_2. Three parallel samples of dilution air are similarly analyzed. CO_2 is measured because it is needed in determining the carbon balance fuel economy.

3.7.2.2 A fixed-speed cooling fan with a nominal capacity of 5300 ft^3/min (150 m^3/min) is positioned during dynamometer operation so as to direct cooling air to the vehicle in an appropriate manner with the engine compartment cover open. In the case of vehicles with front engine compartments, the fan is squarely positioned between 8 and 12 in (200 and 300 mm) in front of the cooling air inlets (grill). In the case of vehicles with rear engine compartments (or if special designs make the above impractical), the cooling fan or fans should be placed such that engine/vehicle temperatures normally encountered during road operation are approximated. The vehicle should be nearly level when tested in order to prevent abnormal fuel distribution.

3.7.2.3 Flywheels, electrical, or other means of simulating inertia as shown in Table 2 should be used. If the equivalent inertia specified is not available on the dynamometer being used, the next higher equivalent inertia available, not exceeding 250 lb (113 kg), should be used.

3.7.2.4 *Power Absorption Unit Adjustment*

(a) The power absorption unit is adjusted to reproduce absorbed horsepower at 50 mph (80 km/h) road load. The relationship between absorbed power and indicated power for a particular dynamometer should be determined by the procedure previously outlined.

(b) The absorbed power listed in Table 2 is used or the vehicle manufac-

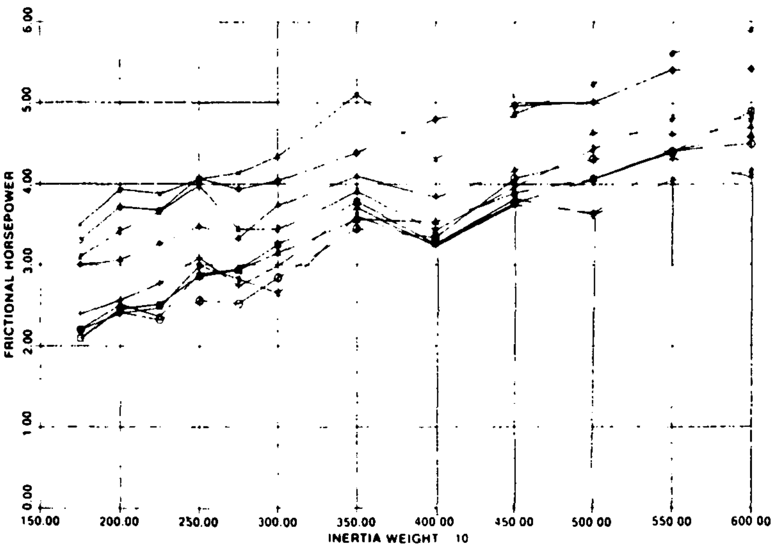

FIG. 6—TYPICAL FRICTIONAL HORSEPOWERS

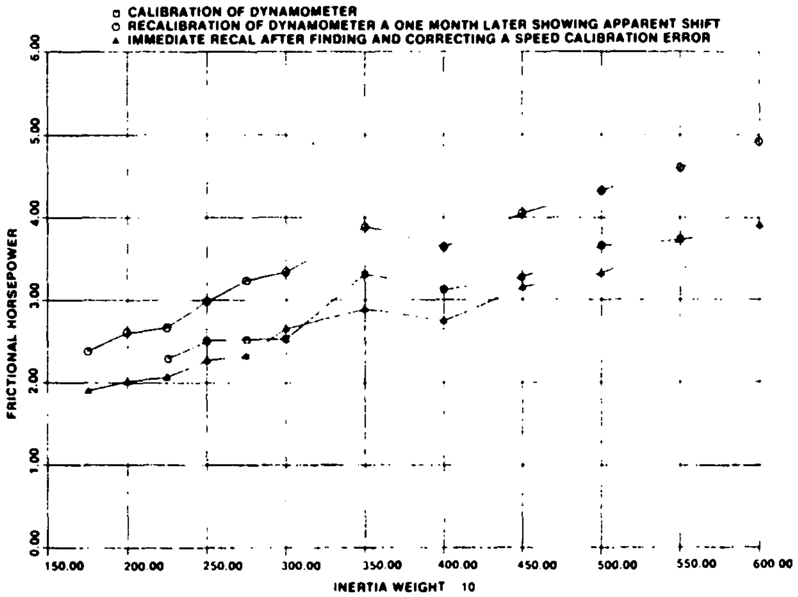

FIG. 7—EFFECT OF RECALIBRATION

turer may determine the absorbed power by the following procedure and request its use:

(i) Measure the absolute manifold vacuum of a representative vehicle of the same equivalent inertia weight, when operated on a level road under balanced wind conditions at a true speed of 50 mph (80 km/h).

(ii) Note the dynamometer indicated power setting required to reproduce the manifold vacuum, when the same vehicle is operated on the dynamometer at a true speed of 50 mph (80 km/h). The tests on the road and on the dynamometer should be performed with the same vehicle ambient absolute pressure (usually barometric), that is, within ±5 mm of Hg.

(iii) The absorbed power values are listed in Table 2.

3.7.2.5 The vehicle speed must be measured by a tachometer generator installed on the rear (or idler) roll. A tachometer generator installed on the front (or drive) roll is used to measure coastdown speed. Even though most tests conducted integrating front and rear tachometer generator speeds over the test cycle have shown only small differences in total distance, the rear (or idler) roll must be used to measure vehicle speed because of tire distortions that occur on accelerations which change the rolling radius.

3.7.2.6 The Federal Register recommends that minimum throttle action should be used to maintain the proper speed-time relationship. When using a two-roll dynamometer, a truer speed-time trace may be obtained by minimizing the rocking of the vehicle in the rolls. The rocking of the vehicle changes the tire rolling radius on each roll. The rocking may be minimized by restraining the vehicle horizontally (or nearly so) by using a cable and winch. Care must be used to prevent tightening this cable too much as this could cause vehicle to be pulled off rolls.

TABLE 2—EQUIVALENT INERTIA WEIGHT AND ABSORBED POWER

Loaded Vehicle Weight		Equivalent Inertia Weight		Absorbed Power at 50 mph (80 km/h) Without and With Air Conditioning Load Simulation			
				Without		With	
lb	kg	lb	kg	hp	kw	hp	kw
Up to 1125	Up to 511	1000	454	5.9	4.4	6.5	4.8
1126 to 1375	512 to 624	1250	568	6.5	4.8	7.2	5.4
1376 to 1625	625 to 738	1500	681	7.1	5.3	7.8	5.8
1626 to 1875	739 to 851	1750	895	7.7	5.7	8.5	6.3
1876 to 2125	852 to 975	2000	908	8.3	6.2	9.1	6.8
2126 to 2375	976 to 1085	2250	1022	8.8	6.6	9.7	7.2
2376 to 2625	1086 to 1195	2500	1135	9.4	7.0	10.3	7.7
2626 to 2875	1196 to 1306	2750	1250	9.9	7.4	10.9	8.1
2876 to 3250	1307 to 1475	3000	1362	10.3	7.7	11.3	8.4
3251 to 3750	1476 to 1700	3500	1590	11.2	8.4	12.3	9.2
3751 to 4250	1701 to 1930	4000	1816	12.0	8.9	13.2	9.8
4251 to 4750	1931 to 2150	4500	2045	12.7	9.5	14.0	10.4
4751 to 5250	2151 to 2380	5000	2270	13.4	10.0	14.7	11.0
5251 to 5750	2381 to 2610	5500	2500	13.9	10.4	15.3	11.4
5751 or more	2611 or more	5500	2500	14.4	10.7	15.8	11.8

3.7.2.7 Drive wheel tires must be inflated to a cold gage pressure of 40 psi (280 kPa). This recommended practice acknowledges that all is not fully understood regarding the rolls-tire interaction. Recent tests using vehicles having engines of 100-450 in^3 (1.6-7.4 × 10^{-3} m^3) displacement show that the average drive wheel tire pressure increased from gage pressure of 40 psi (280 kPa) to 47 ± 3 psi (320 ± 21 kPa) after running the 1975 Federal Test Procedure. When the 75 FTP was immediately followed by a Highway Driving Cycle, the average gage pressure at the end of the test was 50 ± 3 psi (340 ± 20 kPa). These observed tire pressure increases are approximately twice those observed when vehicles are run on the road, confirming that the tire deflections on rolls probably generate more heat and thereby increase the tire pressure. Further study is needed in this area. The cold gage pressure recommended above is an initial step to minimize tire variations.

3.7.2.8 *Warmup of Dynamometer*—If the dynamometer has not been operated during the 2 h period immediately preceding the test, it should be warmed up for 15 min by operating it at 30 mph (48 km/h) using a nontest vehicle.

4. *Calibrating and Operating Procedure*

4.1 Calibration Procedure—The purpose of this procedure is to provide a reliable method for calibrating CVS systems.

A detailed discussion of the major requirements for conducting an accurate CVS calibration follows. The individual sections are arranged in proper sequential order and provide detailed instructions for conducting the necessary checks that must be performed for satisfactory results.

4.1.1 PREPARATION OF CVS SYSTEM FOR CALIBRATION

4.1.1.1 *Installation of Sampling Taps and Lines*—For measurement of the pressure differential across the CVS pump, install static pressure taps of the type shown in Fig. 8 at the top and bottom of the CVS pump drive head plate, centering on the inlet and outlet pump cavities. The same static pressure taps used for CVS calibration should be used for vehicle emission testing. The location should provide at least one diameter of straight pipe up and downstream from the tap to minimize flow disturbances. If a straight length of pipe is not available, a piezometer ring from which a single gage connection is led may be used.

4.1.1.2 If the straight section of pipe is vertical, the static tap can be installed anywhere around the periphery. If the pipe is horizontal, the tap should be located in the periphery of the upper half (above the pipe centerline). The pump inlet pressure tap should be located downstream from the gas sample probes.

The diameter and hole edge rounding of the pressure tap should conform with the recommendations shown in Table 3.

NOTE: It is realized that it will seldom be practical and, generally, it will be impossible actually to measure the radius of the hole-edge rounding. However, if any dulling or rounding is done, the values in Table 3 offer a guide for estimating the maximum desirable degree of edge rounding.[3]

All burrs and irregularities should be removed from the inner wall surface near the static tap.

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[3] *"Static Pressure Cups and Fluid Meters—Theory and Application,"* Fifth Chapter, Section A3, pp. 18-19. American Society of Mechanical Engineers, 345 East 47th Street, New York, New York 10017.

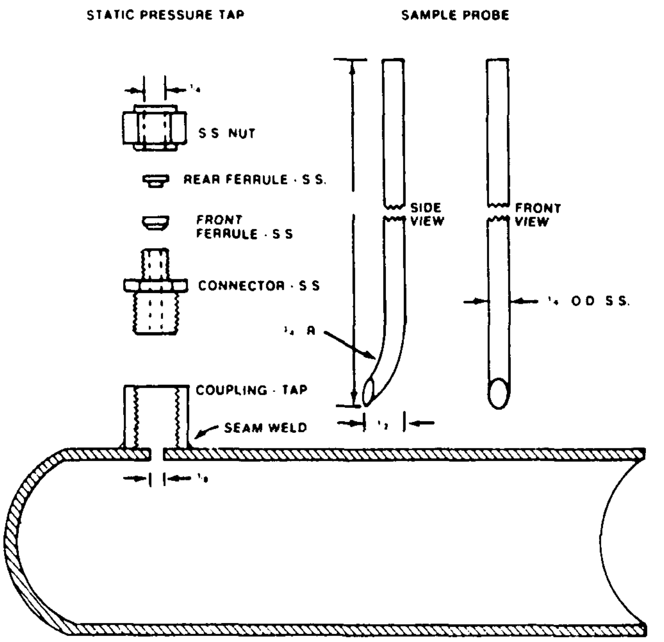

FIG. 8—STATIC PRESSURE TAP FITTINGS AND PROBE DESIGN

4.1.1.3 The sample probes should be made of stainless steel and be of the design shown in Fig. 7. They should be faced upstream directly into the flow. All sample lines leading from the probes should be routed upward. This will allow any water which may condense to drain out of the lines and thereby prevent hydraulic blockage. (Similar precautions should be taken when installing static pressure lines.)

4.1.2 Flange Gaskets—When installing the plumbing on the inlet side of the pump, compression of the gasket may cause a decrease in its inside diameter. If this occurs, it will affect the restriction on the pump and may affect the accuracy of the static pressure reading if the gasket protrusion is upstream of the static tap. Therefore, when assembling the plumbing insure that the gasket ID as installed is not smaller than the pipe ID.

The placement of modal analysis probes relative to the bag sample probe can also disrupt sampling. It has been shown that the backflushing of a modal analysis cart through a probe can significantly affect the bag sampling probe sample during a CVS calibration verification with propane injection.

4.1.3 Primary CVS Calibration with Laminar Flow Element

4.1.3.1 This procedure utilizes a laminar flow element and a variable restriction device to generate a pump performance curve (flow rate as a function of pressure differential). Fig. 9 is a schematic of the test layout and instruments required to perform this calibration. The volumetric flow is determined by a laminar flow element (LFE) placed upstream of the CVS pump (as shown in Fig. 9) to avoid introducing flow disturbances in the LFE. A straightener section of 10 times the exit diameter is added to the outlet of the LFE. This is followed by an adjustable restriction valve. Since the LFE and the pump are in series, it is necessary that all connections between these two items be free of leakage. It is advisable to plug all openings and pressure test the system to insure that the system is free of leaks.

Some LFE have straightener sections built into the device. This obviates the use of a straightener section. However, these LFEs are subject to calibration shifts if they are disassembled for cleaning. If these units are cleaned, they should be recalibrated.

When conducting calibration, the restriction device should be used to generate data points above and below the normal CVS system operating pressure. Data should be obtained beginning with the pump inlet depression corresponding to LFE as the only restriction. Pump inlet depression should be increased by increments of 2-5 in H_2O (500-1250 Pa) until 6-8 data points are determined. Usually, it is difficult to get points below the normal CVS system operating pressure unless the heat exchanger is removed from the system. Most calibrations are done with the heat exchanger in the system.

TABLE 3—PRESSURE TAP HOLES

Nominal Inside Pipe Dia		Pressure Hole Dia		Hole-Edge Rounding Radius	
in	cm	in	mm	in	mm
Under 2	Under 5	1/4 ± 1/8	6.4 ± 3.2	About 1/64	About 0.4
2 to 3	5 to 7.5	3/8 ± 1/8	9.5 ± 3.2	Less 1/32	Less 0.8
4 to 8	10 to 20	1/2 − 1/8 + 1/4	12.7 − 3.2 + 6.4	Less 1/32	Less 0.8
10+	25+	3/4 ± 1/4	19.0 ± 6.4	Less 1/16	Less 1.6

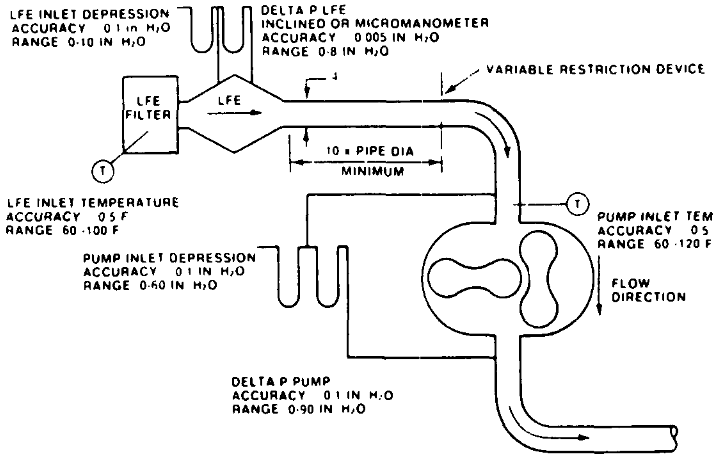

FIG. 9—CVS CALIBRATION WITH LAMINAR FLOW ELEMENT—SCHEMATIC

The following listing of the data to be recorded, unit conversions, and calculations will be followed by a sample calculation and a computer printout.

4.1.3.2 *Data Recorded*

(a) LFE inlet depression, in H_2O (Pa).
(b) Delta *P* LFE, in H_2O (Pa).
(c) LFE inlet temperature, °F (°C).
(d) Pump inlet depression, in H_2O (Pa).
(e) Pump inlet temperature, °F (°C).
(f) Delta *P* pump, in H_2O (Pa).
(g) Barometric pressure, in Hg (Pa).
(h) Pump rpm.

4.1.3.3 *Conversion of Units*

(a) Convert in H_2O to in Hg pressure:

$$\text{LFE inlet depression (in Hg)} = \text{LFE inlet depression (in } H_2O) \times 0.07355 \text{ in Hg/in } H_2O$$

$$\text{Pump inlet depression (in Hg)} = \text{Pump inlet depression (in Hg)} \times 0.07355 \text{ in Hg/in } H_2O$$

(b) Convert from degrees Fahrenheit to degrees Rankine:

$$\text{LFE inlet temperature (R)} = \text{LFE inlet temperature (°F)} + 460$$

$$\text{Pump inlet temperature (R)} = \text{pump inlet temperature (°F)} + 460$$

(c) Conversion to absolute pressure:

$$\text{Absolute pressure (in Hg) at LFE inlet} = \text{barometric pressure (in Hg)} - \text{LFE inlet depression (in Hg)}$$

$$\text{Absolute pressure (in Hg) at pump inlet} = \text{barometric pressure (in Hg)} - \text{pump inlet depression (in Hg)}$$

4.1.3.4 *Calculations*

(a) Determine air viscosity correction factor for LFE inlet air temperature from LFE correction curve obtained from LFE manufacturer.

(b) Determine pressure correction factor for LFE inlet pressure from LFE correction table obtained from LFE manufacturer.

(c) Determine uncorrected volume flow rate from curve supplied by LFE manufacturer and pressure drop. Then determine corrected volume flow rate by multiplying uncorrected volume flow rate × air viscosity correction factor × pressure correction factor.

(d) Using Ideal Gas Law, convert the volume flow rate at LFE standard conditions (530 R, 29.92 in Hg) to the volume flow rate at the pump inlet temperature and pressure:

$$\text{Pump ft}^3\text{/min} = \text{LFE ft}^3\text{/min} \times \frac{29.92}{\text{pump abs inlet pressure (in Hg)}} \times \frac{\text{pump inlet temperature (R)}}{530}$$

(e) Determine pump ft^3/rev by dividing ft^3/min by the pump rpm.

(f) Plot pump ft^3/rev versus the square root of pump delta *P*. Determine the first degree equation of the line by the least squares method.

4.1.3.5 *Example of Calculations* for LFE CVS calibration, using typical data from a 400 ft^3/min LFE.

Data Recorded

(a) LFE inlet depression = 1.00 in H_2O.

(b) Delta P of LFE = 6.520 in H_2O.

(c) LFE inlet temperature = 75.5°F.

(d) Pump inlet depression = 37.8 in H_2O.

(e) Pump inlet temperature = 78.0°F.

(f) Delta P pump = 60.0 in H_2O.

(g) Barometric pressure = 29.34 in Hg.

(h) Pump rpm = 1421.

Conversion of Units:

(a) LFE inlet depression = 0.07355 in Hg.

(b) Pump inlet depression = 2.78 in Hg.

(c) LFE inlet temperature = 535.5 R.

(d) Pump inlet temperature = 538 R.

(e) LFE inlet, absolute pressure = 29.27 in Hg.

(f) Pump inlet, absolute pressure = 26.56 in Hg.

Calculations:

(a) Air viscosity correction factor at 75.5°F (from LFE manufacturer's curve) = 1.006.

(b) Pressure correction factor $= \frac{29.27}{29.92} = 0.9783$.

(c) Uncorrected flow rate (from LFE manufacturer's curve) = 342.8 ft^3/min.

(d) Corrected volume flow rate = 342.8 × 1.006 × 0.9783 = 337.4.

(e) Pump ft^3/min $= 337.4 \times \frac{29.92}{26.56} \times \frac{538}{530} = 385.8$.

(f) Pump ft^3/rev $= \frac{385.8}{1421} = 0.2715$.

4.1.4 GAS STRATIFICATION CHECK

4.1.4.1 With the CVS operating in its testing configuration, introduce a tracer gas, such as 100% propane, into the vehicle exhaust inlet of the CVS system as shown in Fig. 10. The tracer gas should be introduced at a rate that will give a bag sample which produces at least a $^3/_4$ full-scale deflection on the HC range normally used for reading bags. The use of a continuous HC analyzer on the dilute continuous sampling probe makes this rate determination simple. The continuous analyzer is needed for the profile determination of paragraph 4.1.4.2.

4.1.4.2 Starting with the sample probe inlet opening at one side of the dilute stream, run a cross-sectional profile of the pipe, sampling at 0.5 in (13 mm) intervals (wall to wall). Record the concentration at each sampling point location. Conduct a second cross-sectional profile at 90 deg to the first profile. If concentrations from wall to wall vary more than 1%, there is incomplete mixing.

4.1.5 INDEPENDENT CVS SYSTEM VERIFICATION

4.1.5.1 *Introduction*—The system verification technique involves the introduction of a measured quantity of a tracer such as propane (or CO) at the tailpipe sampling location. If all components of the system are functioning properly, the quantity of tracer calculated from that collected in the sample bag should agree closely with the quantity which was injected. A measured amount of tracer gas partially diluted with air from a small auxiliary blower (Fig. 11) is then mixed with dilution air in the main stream of the CVS. To avoid possible leakage, the tracer gas should be introduced downstream of the auxiliary blower. The auxiliary blower is needed to aid mixing of the 0.02 ft^3 (0.56 L) of propane that is used in a test. When propane is used as the tracer gas, it may be necessary to remove the charcoal filter from the CVS. This will equalize the HC background in the two dilution air streams.

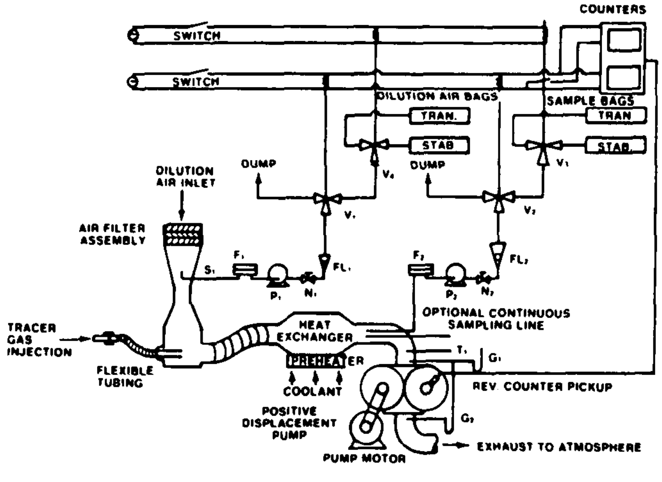

FIG. 10—EXHAUST GAS SAMPLING SYSTEM

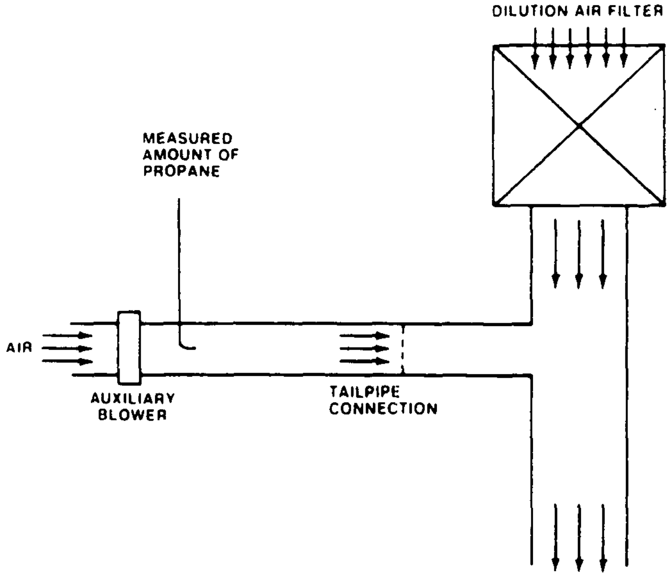

FIG. 11—CVS SYSTEM VERIFICATION

4.1.5.2 *Equipment*

(a) CVS system to be checked.

(b) A container of instrument grade tracer gas.

(c) Analytical balance with a capacity to weigh the charged gas container and flow regulator with a resolution of 0.01 g.

Instead of the weighing technique, flow measurement techniques can be used to determine the amount of tracer gas injected into the CVS. These include: wet test meter, rotometer, and critical flow orifice.

(d) A tracer gas flow regulator which is capable of adjustment to yield bag concentrations which are normally encountered during testing.

(e) An auxiliary blower of 10-30 ft^3/min (0.005-0.014 m^3/s) capacity.

(f) Analyzers to measure tracer gas.

4.1.5.3 *Procedure*

(a) Turn on CVS and allow stream pressure and temperature to stabilize.

(b) Weigh gas container with the flow regulator connected and record weight.

(c) Purge the gas sample bags with dilution air.

(d) Simultaneously, activate CVS mixture and dilution air bag sampling and the positive displacement pump revolution counter.

(e) After 30 s, begin injecting tracer gas into the CVS. Set tracer gas flow rate to yield sample stream concentrations approximating those encountered during vehicle testing.

(f) Record CVS data during tracer gas injection:

Average pump inlet temperature, °F (°C).
Average pump inlet pressure, in H_2O (Pa).
Average pump differential pressure, in H_2O (Pa).

(g) After 14 min 30 s total elapsed time, stop the tracer gas injection.

(h) After 15 min total elapsed time, stop the CVS mixture and dilution air bag samples and the pump revolution counter simultaneously. Record total CVS pump revolutions.

(i) Analyze gases in the CVS mixture and dilution air sample bags. Record concentrations.

(j) Weigh tracer gas container and record weight.

(k) Determine the injected weight of tracer gas by subtracting weight measured in step 4.1.5.3(j) from weight measured in step 4.1.5.3(b). Record difference.

4.1.5.4 *Calculations*

(a) Determine the mass of injected tracer gas indicated by the CVS using the following formula:

$$\text{Calculated mass} = V_{mix} \times \text{density} \times \text{conc}$$

where: $V_{mix} = K_1 \times V_0 \times N \times \frac{P_p}{T_p}$

$$K_1 = \frac{528\ \text{R}}{29.92\ \text{in Hg}}$$

V_0 = volume of gas pumped by the positive displacement pump, ft^3/rev at ambient conditions. This volume is dependent on the pressure differential across the positive displacement pump
N = number of revolutions of the positive displacement pump during the test while samples are being collected
P_p = absolute pressure of the dilute exhaust entering the positive displacement pump, that is, barometric pressure minus the pressure depression below atmospheric of the mixture entering the positive displacement pump
T_p = average temperature of dilute exhaust entering positive displacement pump during test while samples are being collected, R
Density = density of tracer gas, g/ft^3 at 68°F and 29.92 in Hg pressure.
Example: Propane = 51.91 g/ft^3
CO = 32.97 g/ft^3
Conc = concentration of gas in sample bag minus concentration of gas in background bag.

(b) Compare the measured tracer gas weight to the calculated tracer gas weight and determine the percent difference, based upon the measured weight.

(c) If the difference is greater than ±2% investigate possible sources of error and repeat the verification.

4.1.5.5 *Critical Flow Orifice*—A simpler alternative to the gravimetric procedure described above for CVS system verification is the use of a critical flow orifice (CFO). The advantage of a calibrated CFO is that the weighing steps are replaced by a single determination of a high pressure level reading. Appendix D is an example of a data and calculation sheet for use with a CFO. The CVS measurement is compared to the CFO measurement using the CFO measurement as the standard. Again, if the percent difference is greater than ±2%, investigate possible sources of error and repeat the verification.

4.2 Operating Procedure—A wide variety of CVS configurations are currently available. The detailed operating procedure for each configuration will be unique, and will depend upon the nature of the test being performed. Requirements for hot and cold. weighting and inclusion of multiple background bags all necessitate changes in the detailed operating procedure. Furthermore, the required degree of operator attention to the CVS console during performance of an emission test varies from installation to installation. Fully automated systems require almost no attention to detail. Once the test is initiated, all functions including the diverting of exhaust gas into the appropriate sample bags at the correct times and even changing of the paper filters are all accomplished automatically. Other units may require the operator to perform each of these operations manually. As a result of these many factors (configuration of equipment, interfacing equipment for automatic control, and test procedure), no attempt will be made here to provide a detailed step-by-step procedure. Any such procedure would be specific for a particular unit and test objective, rather than of universal value. Each operator should, of course, follow the instructions of the CVS manufacturer and/or system designer as well as the test procedure outlined in the appropriate governmental regulations. The remainder of this section will be devoted to items which may be best described as "good operating practice" and are more universally applicable.

First, it should be pointed out that the concept of CVS sampling is still evolving. Areas of uncertainty still exist. Such an area is that of defining the acceptable "tailpipe depression" at idle or positive pressure during modes such as acceleration and cruise, which the CVS may exert upon the vehicle during the performance of an emissions test. The objective of the operator should be to employ his given CVS unit in a way which will minimize its effect upon vehicle operation. Actual CVS design has a large impact on tailpipe depression or pressurization. Above and beyond this the operator can minimize effects by insuring that connections between the vehicle and the CVS are relatively short (5-6 ft (1.5-1.8 m)), of large enough diameter (4 in (100 mm) or larger) and that the inside wall of this flexible connection is relatively smooth (interlock type tubing).

A second area which deserves attention is that of preventing moisture condensation in the CVS or sampling lines. Condensation may remove soluble gas species from the sample stream and interfere with the accuracy of NO_x measurements. The dew point of concentrated exhaust gas is typically 120-130°F (49-54°C). Therefore, it is essential that the exhaust temperature not approach this range before dilution in the CVS mainstream. The use of a short (5-6 ft (1.5-1.8 m)) connection between the vehicle tailpipe and the CVS inlet will help prevent condensation in the connecting line. If the CVS configuration is such that the exhaust gas is cooled prior to mixing with the dilution air, it will be necessary to insure that condensation does not occur before dilution. Dilution of the exhaust gas should be sufficient to preclude condensation of moisture in the main flow stream.

Condensation of the dilute exhaust sample may occur in sample lines, pumps, filters, and meters, particularly when the relative humidity of the dilution air exceeds 50%. Unless bubbles appear in the flow meters, this condensation may be difficult to detect. Dampness in the paper filters in the sample streams is an indication that condensation is occurring. If condensation is a problem, it may be necessary to install drain lines to divert the condensation back into the main flow path of the CVS upstream of the positive displacement pump. Better approaches to avoid the condensation problem are to match the sample pump capacity more closely to the sampling system and to use back-pressure regulated sample pumps to reduce the maximum pressure to which the sample is exposed and thus reduce the tendency for condensation to occur. Usually, humidity is added to the test area so that the relative humidity is maintained near 50%, so that the NO_x correction factor will be near unity.

Deposits will slowly build up in the CVS. These are most likely to occur in the heat exchanger. Good operating practice dictates regularly scheduled cleaning. Increase of depression at the pump inlet is a good indicator of deposit buildup. Even though the CVS flow conditions are corrected for the changing operating conditions, the deposit buildup is not uniform and consequently can cause stratification at the sample probe. Deposit buildup will be a function of the number and type of tests. For a very active testing program, monthly cleaning would be recommended.

CVS pumps have been known to seize. Usually, this is due to deposits and moisture that remain in a CVS after a series of intermittent tests. This problem can be avoided by connecting the CVS outlet to a laboratory exhaust system that has sufficient capacity to rotate the blower slowly when the CVS is off. The laboratory exhaust is effective in removing the moisture.

Foreign objects can enter the CVS inlet and effectively destroy mixing or cause severe stratification. Large mesh screens have been used effectively to prevent foreign objects from reaching the mixing area and the heat exchanger.

The dilution air filter is not intended to remove all hydrocarbons from the inlet air, but rather to stabilize their level. Precautions should be taken to insure that the dilution air is not contaminated with excessive HC vapor from spilled gasoline, etc. The dilution air filter package is normally a set of three 24 x 24 in (600 x 600 mm) filters. The first is a dust filter, the second a charcoal filter, and the third filter to remove charcoal particles from the dilution air stream. These filters can become loaded with dirt. An acceptable method for determining the useful life of these filters is to monitor the pressure drop across the filter when the CVS blower is operating at high speed. When the pressure drop across the three filters reaches 0.5 in H_2O (125 Pa), the filter set should be changed. If desired the charcoal could be reactivated and reused.

A detailed calibrating procedure appears in another section. It should be noted that, while this procedure is intended to uncover mechanical and flow problems which may exist, it is not a cure-all. Actual operating conditions are somewhat different from calibrating conditions. For example, the temperature and flow rate entering the CVS during calibration is different than the temperature and flow rate of exhaust entering during vehicle emission testing. The degree of stratification under actual test conditions could differ from that observed during calibration. Mixing difficulties at other than calibrating conditions will lead to a situation where, even though a CVS checks out during the calibration, during actual operation the mass obtained by integrating the continuous diluted exhaust stream concentration does not agree with that collected in the bags. When a situation like this is observed, it will be necessary to repeat the stratification check outlined in the calibrating procedure with exhaust gas supplied by a vehicle operating at 50, 40, and 30 mph (80.5, 64, and 48 km/h) steady-states. If mixing is not complete it may be necessary to experiment with unique mixing devices to aid or replace those supplied with the CVS unit. Considerations such as those outlined above emphasize the importance of paying careful attention to each step of CVS operation even when the unit is completely automated. Each configuration has its unique advantages and problems. Furthermore, changes in a given unit may occur from time to time, so that what is not a problem at one moment may become one later.

*5. **Data Analysis***—Two types of data analysis are possible, bag and modal. Bag analysis will yield emission values which are the composite for a complete test. This kind of analysis is simpler to perform, and is satisfactory for determining whether a vehicle will pass a given test. Therefore, bag analysis is used for surveillance or compliance testing. For development of emission control systems, modal analysis is necessary to determine the relationships between emissions and driving mode.

5.1 Bag Analysis—The HC, CO, NO_x ($NO + NO_2$), and CO_2 concentrations are measured in the diluted exhaust and the background bags. Depending upon the specific cycle used, more than one exhaust and one background bag may be needed. For the 1975 Federal Test Procedure, separate exhaust bags are needed for the cold transient, cold stabilized, and hot transient phases of the driving cycle, thus allowing weighting factors to be applied to the cold and hot transient phases of the test. It is good practice to use a separate background bag for each sample bag used, in case the background concentrations change during a test.

5.1.1 EXHAUST EMISSION CALCULATIONS—One diluted exhaust sample bag and one background bag are required for each test phase. The concentrations of HC, CO, NO_X, and CO_2 in the bags are determined by passing the gases through the analyzers described in paragraph 3.2.

5.1.1.1 The final reported test results are computed as follows:

$$Y_{wm} = (X_1Y_1 + X_2Y_2 + X_3Y_3)/7.5 \text{ miles}$$

where: Y_{wm} = weighted mass emissions of each pollutant, that is, HC, CO, and NO_x, g/vehicle mile

X_1, X_2, X_3 = 0.43, 1.0, 0.57, respective weighting factors for each test phase

Y_1, Y_2, Y_3 = mass emissions for each phase, g/phase

1 = cold transient test phase

2 = cold stabilized test phase

3 = hot transient test phase

5.1.1.2 The mass of each pollutant for each phase of the test is determined from the following:

(a) HC mass:

$$HC_{mass} = V_{mix} \times density_{HC} \times \frac{HC_{conc}}{1\,000\,000}$$

(b) CO mass:

$$CO_{mass} = V_{mix} \times density_{CO} \times \frac{CO_{conc}}{1\,000\,000}$$

(c) NO_x mass:

$$NO_{x_{mass}} = V_{mix} \times density_{NO_2} \times \frac{NO_{x_{conc}}}{1\,000\,000} \times Kh$$

(d) CO_2 mass:

$$CO_{2_{mass}} = V_{mix} \times density_{CO_2} \times \frac{CO_{2_{conc}}}{100}$$

5.1.1.3 *Meaning of Symbols*

HC_{mass} = hydrocarbon emission, g/test phase

$Density_{HC}$ = density of hydrocarbons in the exhaust gas, assuming an average carbon-to-hydrogen ratio of 1:1.85 g/ft³ at 68°F (20°C) and 29.92 in Hg (101 kPa) pressure (16.33 g/ft³)[4]

HC_{conc} = hydrocarbon concentration of the dilute exhaust sample corrected for background, ppm carbon equivalent, that is equivalent propane × 3

$HC_{conc} = HC_e - HC_d(1 - 1/DF)$

HC_e = hydrocarbon concentration of the dilute exhaust sample as measured, ppm carbon equivalent

HC_d = hydrocarbon concentration of the background as measured, ppm carbon equivalent

CO_{mass} = carbon monoxide emissions, g/test phase

$Density_{CO}$ = density of carbon monoxide g/ft³ at 68°F (20°C) and 29.92 in Hg (101 kPa) pressure (32.97 g/ft³)

CO_{conc} = carbon monoxide concentration of the dilute exhaust sample corrected for background, water vapor, and CO_2 extraction, ppm

$CO_{conc} = CO_e - CO_d(1 - 1/DF)$

CO_e = carbon monoxide concentration of the dilute exhaust sample corrected for water vapor and carbon dioxide extraction, ppm. The calculation assumes the hydrogen-carbon ratio of the fuel is 1.85:1

$CO_e = (1 - 0.01925\, CO_{2_e} - 0.000323\, R)CO_{e_m}$

$(CO_e = CO_{e_m}$, if instrument has no CO_2 or H_2O response)

CO_{e_m} = carbon monoxide concentration of the dilute exhaust sample as measured, ppm

CO_{2_e} = carbon dioxide concentration of the dilute exhaust sample, mol %

R = relative humidity of the dilution air, %

CO_d = carbon monoxide concentration of the background air corrected for water vapor extraction, ppm

$CO_d = (1 - 0.000323\, R)CO_{d_m}$

$(CO_d = CO_{d_m}$, if instrument has no H_2O response)

CO_{d_m} = carbon monoxide concentration of the background air sample as measured, ppm

$NO_{x_{mass}}$ = oxides of nitrogen emissions, g/test phase

$Density_{NO_2}$ = density of oxides of nitrogen in the exhaust gas, assuming they are in the form of nitrogen dioxide, g/ft³ at 68°F (20°C) and 29.92 in Hg (101 kPa) pressure (54.16 g/ft³)

$NO_{x_{conc}}$ = oxides of nitrogen concentration of the dilute exhaust sample corrected for background, ppm

$NO_{x_{conc}} = NO_{x_e} - NO_{x_d}(1 - 1/DF)$

NO_{x_e} = oxides of nitrogen concentration of the dilute exhaust sample as measured, ppm

NO_{x_d} = oxides of nitrogen concentration of the background as measured, ppm

$CO_{2_{mass}}$ = carbon dioxide emissions, g/test phase

$Density_{CO_2}$ = density of carbon dioxide g/ft³ at 68°F (20°C) and 29.92 in Hg (101 kPa) pressure (51.81 g/ft³)

$CO_{2_{conc}}$ = carbon dioxide concentration of the dilute exhaust sample corrected for background, %

$CO_{2_{conc}} = CO_{2_e} - CO_{2_d}(1 - 1/DF)$

CO_{2_e} = carbon dioxide concentration of the dilute exhaust sample as measured, %

CO_{2_d} = carbon dioxide concentration of the background as measured, %

$$DF = \frac{13.4}{CO_{2_e} + (HC_e + CO_e)\,10^{-4}}$$

V_{mix} = total dilute exhaust volume, ft³/test phase corrected to standard conditions (68°F, 29.92 in Hg) (528 R, 101 kPa)

$V_{mix} = V_0 \times N \times (P_p/29.92)(528/T_p)$

V_0 = volume of gas pumped by the positive displacement pump, ft³/rev. This volume is dependent upon the pressure differential across the positive displacement pump

N = number of revolutions of the positive displacement pump during the test phase while samples are being collected

P_p = absolute pressure of the dilute exhaust entering the positive displacement pump, in Hg, that is, barometric pressure minus the pressure depression below atmospheric of the mixture entering the positive displacement pump

T_p = average temperature of dilute exhaust entering the positive displacement pump during test while samples are being collected

P_b = barometric pressure, in Hg

T_w = wet bulb temperature, °F

T_d = dry bulb temperature, °F

P_w = saturation water vapor pressure, in Hg at wet bulb temperature

$P_w = -4.14438\,10^{-3} + 5.76645\,10^{-3}T_w - 6.32788\,10^{-5}T_w^2 + 2.12294\,10^{-6}T_w^3 - 7.85415\,10^{-9}T_w^4 + 6.55263\,10^{-11}T_w^5.$ This equation is a least squares fit of the Keenan and Keyes "steam table". It reproduces steam table values within ±0.001 in Hg for temperatures of 20-110°F.

P_d = saturation water vapor pressure in Hg at dry bulb temperature. Same equation as for P_w except T_d is used instead of T_w

A = experimentally derived constant for use in Ferrel's equation as recommended by NBS

$A = 3.67\,10^{-4}\,(1 + 0.00064)\,(T_w - 32)$

P_v = partial pressure of water vapor, in Hg (found from Ferrel's equation)

$P_v = P_w - A\,P_b\,(T_d - T_w)$, Ferrel's equation

H = absolute humidity, grains H_2O/lb dry air

$$H = \frac{4347.8\,P_v}{P_b - P_v}$$

K_h = humidity correction factor

$$K_h = \frac{1}{1 - 0.0047(H - 75)}$$

R = relative humidity, %

$$R = \frac{P_v}{P_d} \times 100$$

5.1.1.4 *Calculation of Mass Emission Values*—Computers are generally used to determine the mass emission values. To verify computer programs, Appendix E detailing hand calculations can be used.

5.2 Modal Analysis—Modal analysis is necessary for the development of emission controls because it relates cause and effect. The cause is the particular engine system at a specific operating point. The effect is the resulting emissions. Mode of operation can be defined as an idle, cruise, acceleration, and deceleration. The length of a mode could be several minutes or as short as 1 s. At least two methods of modal analysis are available: continuous analysis of diluted vehicle exhaust, and continuous analysis of undiluted exhaust using the CO_2 tracer technique.

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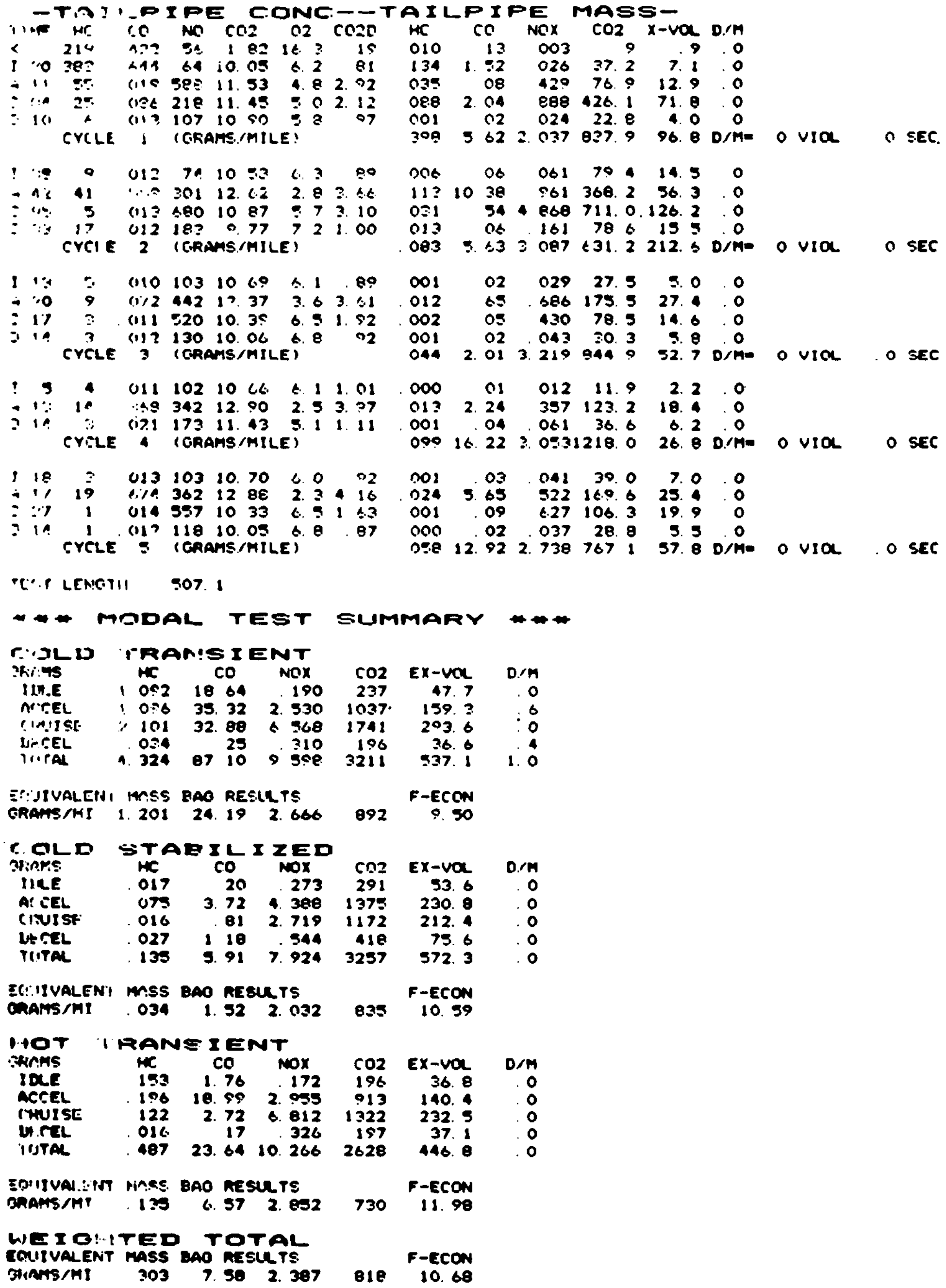
[4] Density of emissions are based on Ideal Gas Law. Density is equal to 1.17714 times the molecular weight.

5.2.1 Continuous Analysis Using Diluted Vehicle Exhaust—Any driving schedule can be broken down into arbitrary modes such as idle, acceleration, cruise, and deceleration. For each mode, the mass emission of each pollutant can be computed using the equations of paragraph 5.1.1.2 modified slightly. The modifications are: The HC, CO, and NO_x masses will be in grams per mode. Generally, a computer will be advantageous for performing the large amount of calculation required for continuous modal analysis.

5.2.1.1 *Calculation of* V_{mix} *for One Mode*—The diluted exhaust volume, ft^3/mode, can be calculated as in paragraph 5.1.1.3, except that N should be taken as the number of pump revolutions for the individual mode being calculated. The number of pump revolutions can be sensed with magnetic or photocell pickups and fed into the computer. For short modes, it may be necessary to measure partial pump revolutions in order to obtain sufficient accuracy.

5.2.1.2 *Calculation of* HC_{conc}, CO_{conc}, *and* $NO_{x_{conc}}$—These quantities have the same meaning as in paragraph 5.1.1.2, except that they now are the average concentrations for each mode. The output of the HC, CO, NO_x, and CO_2 analyzers can be continuously monitored by a computer, with suitable provisions for time delays between the vehicle driver's mode changes and the corresponding analyzer output change. The computer can be programmed to time average the concentrations for the specified intervals corresponding to the individual modes, and make the required corrections. However, it is difficult to measure the background HC, CO, NO_x, and CO_2 concentrations continuously in the dilution air unless separate analyzers are available, which is not usually the case. Therefore, some approximation may be necessary, such as measuring the background before and after the test and assuming a linear relation in between, or collecting an average background dilution air sample for the entire test.

5.2.2 Modal Analysis Using CO_2 Tracer Method—There are many inherent difficulties in continuously analyzing diluted vehicle exhaust, primarily because of the very low diluted concentrations obtained for some modes. These problems can be avoided by continuously measuring the undiluted exhaust concentrations of HC, CO, NO_x, and CO_2. If the undiluted exhaust CO_2 concentration is also measured continuously, it is possible to calculate the vehicle exhaust volume for each mode. From the exhaust volume and the undiluted exhaust concentrations, the modal mass of each pollutant can be calculated. Actually, any constituent of the exhaust can be used as the tracer, but CO_2 is a good choice because it occurs in the largest and most



```
 -TAILPIPE CONC--TAILPIPE MASS-
TIME  HC   CO  NO   CO2   O2 CO2D   HC    CO   NOX   CO2 X-VOL D/M
<     219  477  56  1 82 16 3   19  010    13   003     9    .9  .0
1 20  382  444  64 10.05  6.2   81  134  1.52   026  37.2   7.1  .0
4 11   55  019 582 11.53  4.8 2.92  035    08   429  76.9  12.9  .0
2 04   25  026 218 11.45  5.0 2.12  088  2.04   888 426.1  71.8  .0
3 10    6  013 107 10 90  5 8   97  001    02   024  22.8   4.0   0
    CYCLE 1  (GRAMS/MILE)           398  5 62 2.037 837.9  96.8 D/M=  0 VIOL    0 SEC.

1 39    9  012  74 10 53  6.3   89  006    06   061  79 4  14.5   0
4 42   41  049 301 12.62  2.8 3.66  113 10 38   961 368.2  56.3  .0
2 05    5  013 680 10 87  5 7 3.10  031    54 4 868 711.0.126.2  .0
3 33   17  012 183  9.77  7 2 1.00  013    06  .161  78 6  15 5  .0
    CYCLE 2  (GRAMS/MILE)          .083  5.63 3 087 631.2 212.6 D/M=  0 VIOL    0 SEC

1 13    5  010 103 10 69  6.1  .89  001    02   029  27.5   5.0  .0
4 20    9  072 442 12.37  3.6 3.61 .012    65  .686 175.5  27.4  .0
2 17    3 .011 520 10.39  6.5 1.92 .002    05   430  78.5  14.6  .0
3 14    3  012 130 10.06  6.8   92  001    02  .043  30.3   5.8  .0
    CYCLE 3  (GRAMS/MILE)           044  2.01 3.219 944 9  52.7 D/M=  0 VIOL   .0 SEC

1  5    4  011 102 10 66  6 1 1.01 .000    01   012  11.9   2.2  .0
4 12   14  069 342 12.90  2.5 3.97  013  2.24   357 123.2  18.4  .0
3 14    3  021 173 11.43  5.1 1.11 .001   .04  .061  36.6   6.2  .0
    CYCLE 4  (GRAMS/MILE)           099 16.22 3.0531218.0  26.8 D/M=  0 VIOL    0 SEC

1 18    2  013 103 10.70  6.0   92  001   .03  .041  39.0   7.0  .0
4 17   19  674 362 12 88  2.3 4 16 .024  5.65   522 169.6  25.4  .0
2 27    1  014 557 10 33  6.5 1 63  001   .09   627 106.3  19.9   0
3 14    1 .017 118 10.05  6.8  .87  000   .02  .037  28.8   5.5  .0
    CYCLE 5  (GRAMS/MILE)           058 12.92 2.738 767 1  57.8 D/M=  0 VIOL   .0 SEC

TEST LENGTH    507.1

*** MODAL TEST SUMMARY ***

COLD TRANSIENT
GRAMS       HC     CO     NOX   CO2  EX-VOL   D/M
 IDLE    1 092  18 64    .190   237    47.7    .0
 ACCEL   1 096  35.32   2.530  1037   159.3    .6
 CRUISE  2 101  32.88   6 568  1741   293.6    .0
 DECEL    .034     25    .310   196    36.6    .4
 TOTAL   4.324  87 10   9 598  3211   537.1   1.0

EQUIVALENT MASS BAG RESULTS           F-ECON
GRAMS/MI 1.201  24.19   2.666   892    9.50

COLD STABILIZED
GRAMS       HC     CO     NOX   CO2  EX-VOL   D/M
 IDLE     .017     20    .273   291    53.6    .0
 ACCEL     075   3.72   4.388  1375   230.8    .0
 CRUISE   .016    .81   2.719  1172   212.4    .0
 DECEL    .027   1 18    .544   418    75.6    .0
 TOTAL    .135   5.91   7.924  3257   572.3    .0

EQUIVALENT MASS BAG RESULTS           F-ECON
GRAMS/MI  .034   1.52   2.032   835   10.59

HOT TRANSIENT
GRAMS       HC     CO     NOX   CO2  EX-VOL   D/M
 IDLE      153   1.76    .172   196    36.8    .0
 ACCEL    .196  18.99   2.955   913   140.4    .0
 CRUISE    122   2.72   6.812  1322   232.5    .0
 DECEL    .016     17    .326   197    37.1    .0
 TOTAL    .487  23.64  10.266  2628   446.8    .0

EQUIVALENT MASS BAG RESULTS           F-ECON
GRAMS/MI  .135   6.57   2.852   730   11.98

WEIGHTED TOTAL
EQUIVALENT MASS BAG RESULTS           F-ECON
GRAMS/MI   303   7.58   2.387   818   10.68
```

FIG. 12—EXAMPLE OF HOT TRANSIENT MODAL DATA AND MODAL TEST SUMMARY

constant concentration and, therefore, is easiest to measure accurately even after dilution.

5.2.2.1 *Exhaust Modal Mass Flow Calculations Using CO_2 Tracer Method*—Assume that the modal average undiluted exhaust HC, CO, NO_x, and CO_2 concentrations are measured, and that the modal average CO_2 concentrations are measured in the diluted exhaust stream. The diluted exhaust volume ft^3/mode, V_{mix}, can be calculated as described in paragraph 5.2.1.1. Assuming a constant for background CO_2, the average exhaust dilution ratio for each mode can be calculated as follows:

$$DR = \frac{CO_2\ \text{exhaust} - CO_2\ \text{background}}{CO_2\ \text{CVS} - CO_2\ \text{background}}$$

The undiluted exhaust volume, ft^3/mode, is:

$$V_{und} = V_{mix}/DR$$

The modal mass is given by following:

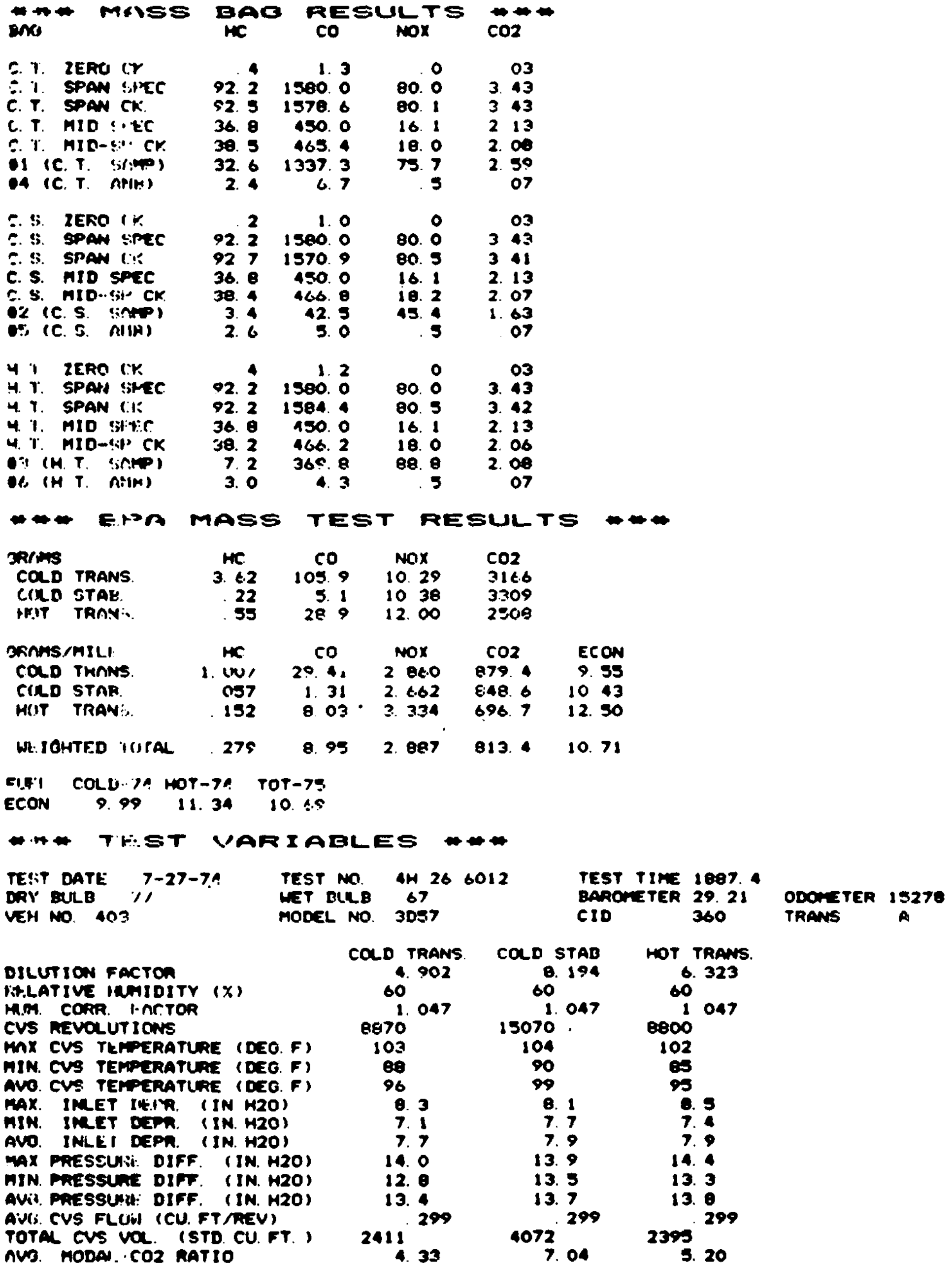
$$HC_{\text{modal mass}} = \frac{HC_{\text{conc und}} \times V_{und} \times \text{density}_{HC}}{10^6}$$

$$CO_{\text{modal mass}} = \frac{CO_{\text{conc und}} \times V_{und} \times \text{density}_{CO}}{10^6}$$

$$NO_{x_{\text{modal mass}}} = \frac{NO_{x_{\text{conc und}}} \times V_{und} \times \text{density}_{NO_2}}{10^6}$$

The upper portion of Fig. 12 shows only a hot transient modal mass output. Several pages may be required for a complete test. The mass emissions for individual modes can then be summed for the complete test, and these values compared with the mass emissions computed from the bags. Theoretically, the total of the modal masses should be equal to the mass emissions calculated from the bag data. In practice, there will not usually be perfect agreement, but the bags should agree with the modal total for each phase within a few percent. Fig. 13 is an example of a computer mass summary. The weighted mass values of Fig. 13 can be compared to the weighted modal data of Fig. 12. Fig. 14 shows the results of the bag versus modal NO_x comparison when the chemiluminescent NO_x analyzer was used.

5.3 **Background**—The exhaust dilution inherent in the operation of the constant volume sampler results in low concentrations of pollutants being presented to analyzers. Under some conditions, such as testing vehicles with very low emission levels, the diluted exhaust concentrations are not far above the background level of pollutants found in the dilution air. Therefore, it is important that background levels of pollutants be taken into account when measuring vehicle emissions.



```
*** MASS BAG RESULTS ***
BAG                    HC       CO      NOX       CO2

C. T.  ZERO CK          . 4      1. 3      . 0       03
C. T.  SPAN SPEC      92. 2   1580. 0    80. 0     3. 43
C. T.  SPAN CK.       92. 5   1578. 6    80. 1     3 43
C. T.  MID SPEC       36. 8    450. 0    16. 1     2 13
C. T.  MID-SP CK      38. 5    465. 4    18. 0     2. 08
#1 (C. T.  SAMP)      32. 6   1337. 3    75. 7     2. 59
#4 (C. T.  AMB)        2. 4      6. 7      . 5       07

C. S.  ZERO CK          . 2      1. 0       0        03
C. S.  SPAN SPEC      92. 2   1580. 0    80. 0     3 43
C. S.  SPAN CK        92 7    1570. 9    80. 5     3 41
C. S.  MID SPEC       36. 8    450. 0    16. 1     2. 13
C. S.  MID-SP CK      38. 4    466. 8    18. 2     2. 07
#2 (C. S.  SAMP)       3. 4     42. 5    45. 4     1. 63
#5 (C. S.  AMB)        2. 6      5. 0      . 5       07

H. T.  ZERO CK           4       1. 2       0        03
H. T.  SPAN SPEC      92. 2   1580. 0    80. 0     3. 43
H. T.  SPAN CK        92. 2   1584. 4    80. 5     3. 42
H. T.  MID SPEC       36. 8    450. 0    16. 1     2. 13
H. T.  MID-SP CK      38. 2    466. 2    18. 0     2. 06
#3 (H. T.  SAMP)       7. 2    369. 8    88. 8     2. 08
#6 (H. T.  AMB)        3. 0      4. 3      . 5       07
*** EPA MASS TEST RESULTS ***

GRAMS                  HC       CO      NOX       CO2
 COLD TRANS.          3. 62    105. 9   10. 29     3166
 COLD STAB.            . 22      5. 1   10 38      3309
 HOT  TRANS.           . 55     28 9    12. 00     2508

GRAMS/MILE             HC       CO      NOX       CO2      ECON
 COLD TRANS.         1. 007    29. 41   2 860     879. 4    9. 55
 COLD STAB.            057      1. 31   2. 662    848. 6   10 43
 HOT  TRANS.          . 152     8 03    3. 334    696. 7   12. 50

 WEIGHTED TOTAL       . 279     8. 95   2. 887    813. 4   10. 71

FUEL   COLD-74 HOT-74  TOT-75
ECON     9. 99   11. 34  10. 69
*** TEST VARIABLES ***

TEST DATE   7-27-74      TEST NO.  4H 26 6012       TEST TIME 1887. 4
DRY BULB    77           WET BULB   67              BAROMETER 29. 21   ODOMETER 15278
VEH NO. 403              MODEL NO.  3057            CID       360      TRANS     A

                                COLD TRANS.  COLD STAB    HOT TRANS.
DILUTION FACTOR                    4. 902       8. 194       6. 323
RELATIVE HUMIDITY (%)             60           60           60
HUM. CORR. FACTOR                  1. 047       1. 047       1 047
CVS REVOLUTIONS                 8870        15070 .       8800
MAX CVS TEMPERATURE (DEG. F)     103          104          102
MIN. CVS TEMPERATURE (DEG. F)     88           90           85
AVG. CVS TEMPERATURE (DEG. F)     96           99           95
MAX.  INLET DEPR.  (IN H2O)        8. 3         8. 1         8. 5
MIN.  INLET DEPR.  (IN. H2O)       7. 1         7. 7         7. 4
AVG.  INLET DEPR.  (IN. H2O)       7. 7         7. 9         7. 9
MAX PRESSURE  DIFF.  (IN. H2O)    14. 0        13. 9        14. 4
MIN. PRESSURE DIFF.  (IN. H2O)    12. 8        13. 5        13. 3
AVG. PRESSURE DIFF.  (IN. H2O)    13. 4        13. 7        13. 8
AVG. CVS FLOW (CU. FT/REV)          . 299        . 299        . 299
TOTAL CVS VOL.  (STD. CU. FT. )  2411         4072         2395
AVG. MODAL CO2 RATIO               4. 33        7. 04        5. 20
```

FIG. 13—EXAMPLE OF BAG DATA

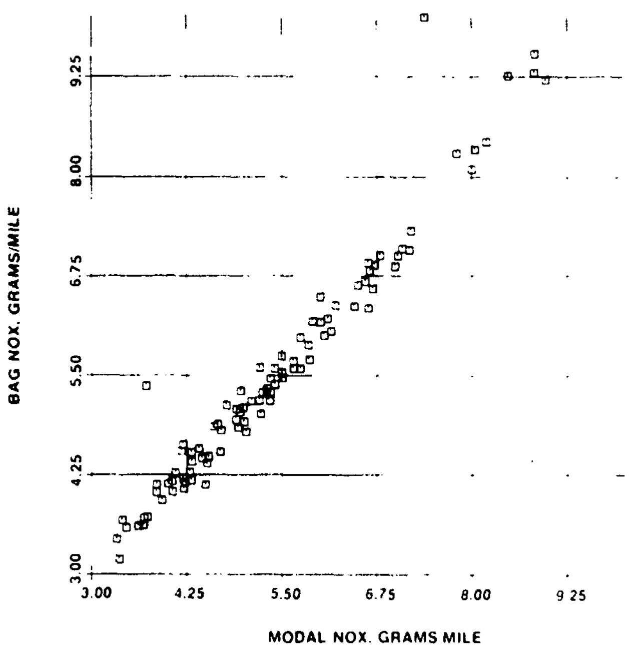


FIG. 14—BAG NO_x VERSUS MODAL NO_x

Fig. 15 is a partial schematic diagram of a constant volume sampler. The following equations apply:

$$V_E + V_D = V_{mix} \qquad (1)$$

where: V_E = volume of vehicle exhaust
V_D = volume of dilution air
V_{mix} = volume of diluted exhaust

$$V_E C_E + V_D C_D = V_{mix} C_{mix} \qquad (2)$$

where: C_E = concentration of a given pollutant in the undiluted exhaust
C_D = concentration of same pollutant in the dilution air (background)
C_{mix} = concentration of the same pollutant in the diluted exhaust

$$V_E C_E = V_{mix} C_{mix} - V_D C_D = V_{mix} C_{mix} - (V_{mix} - V_E) C_D$$

$$V_E C_E = V_{mix}(C_{mix} - C_D) + V_E C_D \qquad (3)$$

Eq. 3 expresses the correct way of calculating the true mass emission of the test vehicle, which is the quantity, $V_E C_E$. However, the application of Eq. 3 requires that V_E be measured, which is not done in practice. An approximation to the correct value of $V_E C_E$ can be obtained by neglecting the $V_E C_D$ *term in the right-hand side of* Eq. 3. *The background concentration* is merely substracted from the diluted exhaust concentration of the same pollutant. This method may be satisfactory if the background concentration and/or V_E is small compared to V_{mix}. However, for very low emitting vehicles whose diluted exhaust concentrations approach the background concentrations, it is necessary to apply Eq. 3 more rigorously, which requires the determination of either vehicle exhaust or the dilution air flow. The procedure of paragraph 5.1.1 may be used, wherein the exhaust dilution factor is estimated by means of the empirical equation:

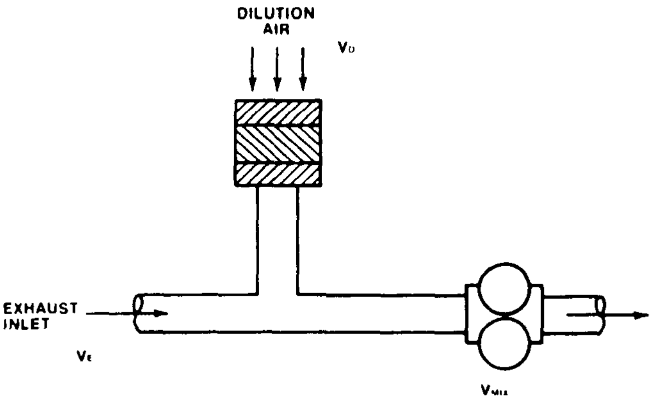


FIG. 15—CONSTANT VOLUME SAMPLER SCHEMATIC

$$DF = \frac{13.4}{CO_{2_e} + (HC_e + CO_e)\,10^{-4}}$$

Then V_E is approximately equal to V_{mix} divided by DF. With V_E known, Eq. 3 can be used. This technique avoids the need to measure either the exhaust flow or the dilution air flow, and may be satisfactory for all but the most rigorous testing. Eq. 3 is applicable to continuous modal analysis as well as to bag samples.

5.4 ***Fuel Economy Calculation from Exhaust Emissions***—*It is possible to* calculate fuel economy from a vehicle's exhaust emissions using a form of carbon balance. The carbon in the fuel can be calculated as follows:

Fuel density, g/gal = 8.331 × 0.7404 × 453.6 = 2798

8.331 lb/gal = density of water
0.7404 = specific gravity of typical gasoline
453.6 g/lb = conversion factor

Weight fraction of carbon in fuel, assuming fuel of composition $CH_{1.85}$ = 12.011/(12.011 + (1.85 × 1.008)) = 0.866

12.011 = atomic weight of carbon
1.008 = atomic weight of hydrogen

Grams of carbon per gallon of fuel = (fuel density, g/gal)(wt% C in fuel) = 2798 × 0.866 = 2423

The carbon in the exhaust can be calculated as follows:

Mass C in HC = (HC g/mile)(wt% C in HC molecule, assume $CH_{1.85}$)
= (HC g/mile)(0.866)
Mass C in CO = (CO g/mile)(wt% C in CO molecule)
= (CO g/mile)(12.011/12.011 + 16)
= (CO g/mile)(0.429)
Mass C in CO_2 = (CO_2 g/mile)(wt% C in CO_2 molecule)
= (CO_2 g/mile)(12.011)/(12.011 + (2 × 16))
= (CO_2 g/mile)(0.273)

Total mass of C in the exhaust, g/mile = 0.866 HC g/mile + 0.429 CO g/mile + 0.273 CO_2 g/mile

The vehicle fuel economy can be calculated as follows:

$$\text{miles/gal} = (\text{g C/gal fuel})/(\text{g/mile C in exhaust})$$

$$= \frac{2423}{0.866\ HC + 0.429\ CO + 0.273\ CO_2}$$

$$= \frac{2798}{HC + 0.495\ CO + 0.315\ CO_2}$$

where HC, CO, and CO_2 represent the grams/mile of these respective exhaust emissions for the vehicle.

Different values for fuel density and/or fuel H/C ratio will yield a slightly different equation.

5.4.1 WEIGHTED FUEL ECONOMY—"Weighted" fuel economy is the carbon balance fuel economy based on weighted emission values found from the 1975 Federal Test Procedure. This weighted fuel economy is identical to the fuel economy that would be obtained if the fuel economies were calculated for each *of the three phases of the 75 FTP, and then weighted in the same manner* as the emissions. The proof follows: Subscript *w* refers to the 75 FTP weighted emissions, subscript 1, 2, and 3, refer to the 75 FTP phase. The distance for phase 1 and phase 3 is 3.59 miles, and the distance for phase 2 is 3.91 miles. The weighting factor for phase 1 is 0.43 and for phase 3 is 0.57.

$$FE_w = \frac{2423}{0.866\ HC_w + 0.429\ CO_w + 0.273\ CO_{2_w}} \qquad (1)$$

$$HC_w = \frac{0.43(3.59)\ HC_1 + 3.91\ HC_2 + 0.57(3.59)\ HC_3}{7.5} \qquad (2)$$

$$CO_w = \frac{0.43(3.59)\ CO_1 + 3.91\ CO_2 + 0.57(3.59)\ CO_3}{7.5} \qquad (3)$$

$$CO_{2_w} = \frac{0.43(3.59)\ CO_{21} + 3.91\ CO_{22} + 0.57(3.59)\ CO_{23}}{7.5} \qquad (4)$$

Substituting Eqs. 2, 3, and 4 into Eq. 1 and rearranging terms gives:

$$FE_w = \frac{2423(7.5)}{\begin{array}{c}0.43(3.59)(0.866\ HC_1 + 0.429\ CO_1 + 0.273\ CO_{21}) + \\ (3.91)(0.866\ HC_2 + 0.429\ CO_2 + 0.273\ CO_{22}) + \\ 0.57(3.59)(0.866\ HC_3 + 0.429\ CO_3 + 0.273\ CO_{23})\end{array}} \qquad (5)$$

The carbon balance formula applied to the emissions for each test phase is given by:

$$FE_n = \frac{2423}{0.866\ HC_n + 0.429\ CO_n + 0.273\ CO_{2_n}} \qquad (6)$$

where: *n* indicates the test phase. Substituting Eq. 6 into Eq. 5 gives

$$FE_w = \frac{7.5}{0.43\frac{3.59}{FE_1} + \frac{3.91}{FE_2} + 0.57\frac{3.59}{FE_3}} \qquad (7)$$

The denominator is simply the gallons for each test phase weighted in the same manner as emissions.

5.4.2 FUEL ECONOMY CYCLE—The carbon balance fuel economy can be determined from any cycle, where emissions have been measured and are expressed in grams/mile. Recently EPA has developed a Highway Driving Cycle for fuel economy measurements. The driving sequence for this cycle is shown in Appendix F. This 12.75 min cycle has an average speed of 48.20 mph (77.6 km/h) and covers 10.24 miles (16.5 km).

6. *Safety Recommendations*

6.1 Dynamometer—The test vehicle should be restrained on the dynamometer by using tie-downs or other suitable means. The maximum speed and acceleration/deceleration rates of the dynamometer must not be exceeded.

6.2 Calibration Gas Cylinders

6.2.1 HANDLING—Gas cylinders must not be moved unless the safety cap is securely screwed on the cylinder. Gas cylinders must always be supported by chains or other suitable means when in use, transported, or in storage.

6.2.2 TOXIC OR DANGEROUS GASES—Gases such as CO and NO_x must be used in an area with adequate ventilation. An ambient CO monitor for the emissions laboratory area is suggested.

6.3 Vehicle Fuel (Gasoline)—Vehicle fuel must always be contained in safety containers.

APPENDIX A
NO_x CONVERTER EFFICIENCY CHECK
(See Fig. 4)

1. Attach NO/N_2 supply to NO inlet on NO_x generator at C2 (NO concentration approximately 95% of full-scale), O_2 or air supply at C1 and efficiency checker to analyzer at C3.

2. With ozonator of NO_x generator off, oxygen or air supply off, and analyzer in bypass mode, adjust NO/N_2 flow to analyzer. Zero analyzer and adjust span calibration to indicate approximately 100% of full-scale while flowing NO from NO_x generator.
   Record actual reading ______________________________

3. Turn oxygen or air supply of NO_x generator and adjust MV1 to obtain analyzer reading of approximately 90% of full-scale.
   Record actual reading ____________________

4. Turn on ozonator power and adjust variac to obtain approximate 20% full-scale reading.
   Record actual reading ____________________

5. Place analyzer in converter mode.
   Record actual reading ____________________

6. Turn off ozonator.
   Record actual reading ____________________

7. Repeat steps 4 through 6 as necessary.

8. Calculate efficiency as follows:

$$\%\ \text{Efficiency} = \frac{5-4}{6-4} \times 100\%$$

% Efficiency = ____________________

Note: Converter efficiency must be greater than 90% and should be greater than 95%.
Check efficiency weekly.
Record Test Cell, Analyzer, Date and Operator

APPENDIX B
STANDARD REFERENCE GASES FOR AUTOMOTIVE EMISSIONS ANALYSIS

The NBS Office of Standard Reference Materials announces the availability of Nitric Oxide in Nitrogen SRMs as its fourth series of SRMs for mobile source emission analysis. These SRMs are individually certified, and are available at the following *nominal* concentrations:

SRM 1683—Nitric Oxide in Nitrogen, 50 ppm
SRM 1684—Nitric Oxide in Nitrogen, 100 ppm
SRM 1685—Nitric Oxide in Nitrogen, 250 ppm
SRM 1686—Nitric Oxide in Nitrogen, 500 ppm
SRM 1687—Nitric Oxide in Nitrogen, 1000 ppm

The availability of the first two series, Propane in Air and Carbon Dioxide in Nitrogen, were announced in February 1973, and consist of the following *nominal* concentrations:

SRM 1665—Propane in Air, 2.8 ppm
SRM 1666—Propane in Air, 9.5 ppm
SRM 1667—Propane in Air, 48 ppm
SRM 1668—Propane in Air, 95 ppm
SRM 1669—Propane in Air, 475 ppm
SRM 1673—Carbon Dioxide in Nitrogen, 0.95%
SRM 1674—Carbon Dioxide in Nitrogen, 7.2%
SRM 1675—Carbon Dioxide in Nitrogen, 14.2%

The availability of the third series, Carbon Monoxide in Nitrogen, was announced in January 1974, and consists of:

SRM 1677—Carbon Monoxide in Nitrogen, 9.74 ppm
SRM 1678—Carbon Monoxide in Nitrogen, 47.1 ppm
SRM 1679—Carbon Monoxide in Nitrogen, 94.7 ppm
SRM 1680—Carbon Monoxide in Nitrogen, 484 ppm
SRM 1681—Carbon Monoxide in Nitrogen, 957 ppm

The development of these SRMs is a cooperative effort by National Bureau of Standards and the Environmental Protection Agency to provide standards that are needed to monitor compliance with automotive emission laws.

These standard reference gases are not to be considered as daily working standards, but rather as *primary* standards to be used in the calibration of daily working standards obtained from commercial sources, and by gas manufacturers to help control the quality of the working standards during processing. Thus, they provide a traceability of all gas standards used in mobile-source emission analysis back to a central reference point, the National Bureau of Standards.

These gases are supplied in cylinders with a delivered volume of 31 ft^3 at STP. The cylinders conform to the DOT 3AA-2015 specification.

The certified concentration of gas in each cylinder is given on the certificates issued at the time of purchase. For propane, carbon dioxide, and nitric oxide, cylinder labels list only the *nominal* concentration and these SRMs should be used only in conjunction with the printed Certificate of Analysis. Because the Certificate of Analysis may not accompany the cylinders, purchasers are requested to list the name of the actual user on the purchase order so that the Certificate of Analysis can be mailed directly to the user.

The cost of these SRMs includes the cost of the cylinder: for Propane in Air (SRMs 1665-1669) and Carbon Dioxide in Nitrogen (SRMs 1673-1675) the cost is $280 per cylinder; for Carbon Monoxide in Nitrogen (SRMs 1677-1681) the cost is $303 per cylinder; and for Nitric Oxide in Nitrogen (SRMs 1683-1687) the cost is $303 per cylinder. Purchase orders for these SRMs should be sent to the Office of Standard Reference Materials, B311 Chemistry, National Bureau of Standards, Washington, DC 20234.

APPENDIX C
PROCEDURE FOR AUTOMATIC LOADING DIRECT-DRIVE DYNAMOMETER

Procedure:

1. Verify dynamometer speed and indicated horsepower calibrations.
2. *Use typical weight car to run coastdowns after verifying speed calculation*
3. Set inertia weight to 1750, horsepower to 7.7 (indicated about 6 hp)
4. Run coastdown recording time between 55 mph and 45 mph
   (a) Read horsepower directly with computer if available, or
   (b) Determine coastdown time between 55 and 45;
5. If necessary adjust internal pot. on auto. dyno. Repeat coastdowns until horsepower or time (depending upon your system) is within 0.1 hp or 0.1.
6. *Repeat coastdown without further pot. adjustment.*
7. Record FINAL repeated HORSEPOWER or TIME value.
8. Drive vehicle at 50 mph. Record INDICATED HORSEPOWER as observed on meter.
9. Repeat above for all inertia weights.
10. Check 1 or 2 coastdowns W/AC set point. Friction should be the same at each inertia weight.
11. Find friction horsepower at each inertia weight, plot and compare with previous coastdown results.

LOCATION ______________________ ROLLS ______________________ ENGINEER ______________________

ROLLS S/N ______________________ COASTDOWN DATE ______________________

INERTIA WEIGHT, lb	ABS HP AT 50 MPH WO/AC	COAST DOWN TIME S	FINAL HP FROM Comp.	FINAL TIME OF COAST DOWN	INDICATED HP AT 50 MPH	FRICTION HP AT 50 MPH	ABS HP AT 50 MPH W/AC
1750	7.7	13.80	—	—	—	—	8.47
2000	8.3	14.63	—	—	—	—	9.13
2250	8.8	15.53	—	—	—	—	9.68
2500	9.4	16.15	—	—	—	—	10.34
2750	9.9	16.87	—	—	—	—	10.89
3000	10.3	17.86	—	—	—	—	11.33
3500	11.2	18.98	—	—	—	—	12.32
4000	12.0	20.24	—	—	—	—	13.20
4500	12.7	21.52	—	—	—	—	13.97
5000	13.4	22.66	—	—	—	—	14.74
5500	13.9	24.03	—	—	—	—	15.29
over 5500	14.4	23.20	—	—	—	—	15.84

Run a sufficient number of coastdowns to verify that W/AC switch is increasing horsepower by 10%, as indicated in Table 2.

—		—	—	—	—	—	—
—		—	—	—	—	—	—

APPENDIX D
CRITICAL FLOW ORIFICE (CFO) PROPANE INJECTION DATA AND CALCULATION SHEET

CVS (MANF.-NUMBER) = ____________________ DATE __________

ENGINEER ____________________ REMARKS ____________________

Barometer = ______________ in Hg

CVS Inlet Depression (pressure) = $\frac{\_\_\_\_\_\_}{13.596}$ in H_2O = ______________ in Hg
Enter Dif. of above in STD. CVS FLOW equation

CVS Delta P = ________ in H_2O: CVS Flow at Operating Conditions found from LFE Calibration Curve

STD. CVS FLOW = ________ × $\frac{\_\_\_\_\_\_}{29.92}$ × $\frac{528}{460 + \_\_\_\_\_\_\ {}^{\circ}F}$

Sample ________ ppm
− Bkg. ________ ppm

CVS G = ______ ft^3/rev × 51.908 × ______ × 10^{-6} ______ rev

CVS G = ______________

- -

Barometer = ____________ in Hg

CFO Gage − ________ PSIG
0.4912 × Barometer = ________

P_a = ________

A, B, and C below are constants for a particular CFO. Each CFO would have its own constants.

A = 0.004 105 79
BP_a = 0.006 811 90 P_a = 0. __________
CP_a^2 = 0.000 004 652 42 P_a^2 = 0. __________
SUM = 0. __________

CFO GRAMS = 51.908 × $\frac{\_\_\_\_\_\_}{60}$ × ____________________

CFO Temperature = ____________ °F: $(460 + T_0)^{1/2}$ = ____________ from Table

CFO G = ____________________

- -

TEST ERROR = $\frac{\text{CVS CALCULATED G} \_\_\_\_\_\_ - \text{CFO CALCULATED G} \_\_\_\_\_\_}{\text{CFO CALCULATED G}} \times 10^{-2}$

= ______________ % POSITIVE ERROR or NEGATIVE ERROR (circle)

APPENDIX E
HAND CALCULATION FORM—1975 FEDERAL TEST PROCEDURE

AMBIENT CONDITIONS

Corrected Barometric Pressure (P_b) = ________ in Hg
Wet Bulb Temperature (T_w) = ________ °F
Dry Bulb Temperature (T_d) = ________ °F

CONSTANT VOLUME SAMPLER PARAMETERS

	Phase 1	Phase 2	Phase 3
Average Delta P, in H_2O			
Average Flow, ft^3/rev			
Average P_{in}, in H_2O			
Average T_{in}, °F			
T_{obs}, T_{in} + 460, R			
Dilution Air Temp, Dry Bulb			
Dilution Air Temp, Wet Bulb			
Dilution Air Relative Humidity (R), %			
CVS Revolutions, rev			

BAG CONCENTRATIONS

	Phase 1	Phase 2	Phase 3
Dilution Bag			
HC_d, ppm			
CO_{d_m}, ppm			
NO_{xd}, ppm			
CO_{2_d}, %			
Sample Bag			
HC_e, ppm			
CO_{e_m}, ppm			
NO_{xe}, ppm			
CO_{2_e}, %			

Facility ------------------ Date ----------------

CORRECTED BAG CONCENTRATIONS

Dilution Bag $CO_d = (1 - 0.000323\ R)\ CO_{d_m}$

R	Phase 1	Phase 2	Phase 3
0.000323 R			
1 − 0.000323 R			
CO_{d_m}			
CO_d, ppm			

Sample Bag $CO_e = (1 - 0.01925\ CO_{2_e} - 0.000323\ R)\ CO_{e_m}$

CO_{2_e}			
$0.01925\ CO_{2_e}$			
$1 - 0.01925\ CO_{2_e} - 0.000323\ R$			
CO_{e_m}			
CO_e, ppm			

DILUTION FACTORS

$$DF = \frac{13.4}{CO_{2_e} + (HC_e + CO_e)\ 10^{4}}$$

HC_e enters into this equation as ppm carbon equivalent.

HC_e			
CO_e			
$HC_{e_m} + CO_e$			
$CO_{2_e} + (HC_{e_m} + CO_e)\ 10^{4}$			
DF			

Facility ------------------ Date ----------------

TEST PHASE CONCENTRATIONS

$HC_{conc} = HC_e - HC_d\ (1 - 1/DF)$
$CO_{conc} = CO_e - CO_d\ (1 - 1/DF)$
$NO_{x\,conc} = NO^{xe} - NO^{xd}\ (1 - 1/DF)$

	Phase 1	Phase 2	Phase 3
1/DF			
(1 − 1/DF)			
HC_d			
$HC_d(1 - 1/DF)$			
HC_e			
HC_{conc}, ppm			
CO_d			
$CO_d\ (1 - 1/DF)$			
CO_e			
CO_{conc}, ppm			
NO_{xd}			
$NO_{xd}\ (1 - 1/DF)$			
NO_{xe}			
$NO_{x\,conc}$, ppm			
CO_{2_d}			
$CO_{2_d}\ (1 - 1/DF)$			
CO_{2_e}			
$CO_{2_{conc}}$			

Facility ------------------ Date ----------------

NO^x HUMIDITY CORRECTION FACTOR

	Phase 1	Phase 2	Phase 3
P_b			
T_w			
T_d			
P_w			
P_d			
A			
P_v			
4347.8 P_v			
$P_b - P_v$			
H			
0.0047 (H − 75)			
1 − 0.0047 (H − 75)			
K_h			
R			

Facility ------------------ Date ----------------

APPENDIX E

HAND CALCULATION FORM—1975 FEDERAL TEST PROCEDURE (continued)

ABSOLUTE INLET PRESSURE

	Phase 1	Phase 2	Phase 3
P_{in} (absolute) $= P_b - P_{in}/13.596$			
P_{in}			
$P_{in}/13.596$			
P_b			
P_{in} (absolute)			

CORRECTED CVS FLOW PER PHASE

$$\text{CVS Flow } (V_{mix}) = V_0 \times \frac{P_{in}\text{ (abs)}}{29.92} \times \frac{528}{T_{obs}} \times \text{revs}$$

V_0			
P_{in} (abs)/29.92			
$528/T_{obs}$			
revs			
V_{mix}, Std ft^3			

NO_x HUMIDITY CORRECTION FACTOR

$$P_w = -4.14438\ 10^{3} + 5.76645\ 10^{3}\ T_w - 6.32788\ 10^{5}\ T_w^{2} + 2.12294\ 10^{6}\ T_w^{3} - 7.85415\ 10^{9}\ T_w^{4} + 6.55263\ 10^{11}\ T_w^{5}$$

$$A = 3.67\ 10^{4}(1 + 0.00064(T_w - 32))$$

$$P_v = P_w - AP_b(T_d - T_w)$$

$$H = \frac{4347.8\ P_v}{P_b - P_v}$$

$$K_h = \frac{1}{1 - 0.0047(H - 75)}$$

$R = \dfrac{P_v\ 100}{P_d}$ where P_d from first equation above using T_d instead of T_w.

Facility _ Date _ _ _ _ _ _ _ _ _ _ _ _ _ _

PHASE MASS

$HC_{mass} = V_{mix} \times HC_{conc} \times 16.33 \times 10^{6}$

$CO_{mass} = V_{mix} \times CO_{conc} \times 32.97 \times 10^{6}$

$NO_{x\,mass} = V_{mix} \times NO_{x\,conc} \times 54.16 \times 10^{6} \times K_h$

$CO_{2\,mass} = V_{mix} \times CO_{2\,conc} \times 51.81 \times 10^{2}$

	Phase 1	Phase 2	Phase 3
V_{mix}			
HC_{conc}			
HC_{mass}, g			
CO_{conc}			
CO_{mass}, g			
$NO_{x\,conc}$			
K_h			
$NO_{x\,mass}$, g			
$CO_{2\,conc}$			
$CO_{2\,mass}$, g			

WEIGHTED MASS

Weighted Mass = 0.43 Phase 1 Mass + Phase 2 Mass + 0.57 Phase 3 Mass

	HC	CO	NO_x	CO_2
0.43 Phase 1 Mass				
1.00 Phase 2 Mass				
0.57 Phase 3 Mass				
Weighted Mass, g				
Weighted Emissions, grams/mile (Hand Calc)				
Weighted Emissions, grams/mile (Comp Calc)				

$$\%\ \text{Difference} = \frac{\text{(Computer} - \text{Hand Calculation)}}{\text{Hand Calculation}} \times 100$$

% Difference				

Facility _ Date _ _ _ _ _ _ _ _ _ _ _ _ _ _

APPENDIX F
EPA HIGHWAY DRIVING CYCLE
TIME-SPEED TRACE

Time	mph	km/h	Time	mph	km/h	Time	mph	km/h	Time	mph	km/h	Time	mph	km/h	Time	mph	km/h
0	0.0	0.0	90	46.3	74.5	180	43.1	69.4	270	46.7	75.2	360	57.4	92.4	450	58.2	93.7
1	0.0	0.0	91	46.2	74.4	181	42.2	67.9	271	46.2	74.4	361	57.2	92.1	451	58.1	93.5
2	0.0	0.0	92	46.3	74.5	182	41.5	66.8	272	46.0	74.0	362	57.1	91.9	452	58.0	93.3
3	2.0	3.2	93	46.5	74.8	183	41.5	66.8	273	45.8	73.7	363	57.0	91.7	453	58.0	93.3
4	4.9	7.9	94	46.9	75.5	184	42.1	67.8	274	45.6	73.4	364	57.0	91.7	454	58.0	93.3
5	8.1	13.0	95	47.1	75.8	185	42.9	69.0	275	45.4	73.1	365	56.9	91.6	455	58.0	93.3
6	11.3	18.2	96	47.4	76.3	186	43.5	70.0	276	45.2	72.7	366	56.9	91.6	456	58.0	93.3
7	14.5	23.3	97	47.7	76.8	187	43.9	70.7	277	45.0	72.4	367	56.9	91.6	457	58.0	93.3
8	17.3	27.8	98	48.0	77.2	188	43.6	70.2	278	44.7	71.9	368	57.0	91.7	458	57.9	93.2
9	19.6	31.5	99	48.2	77.6	189	43.3	69.7	279	44.5	71.6	369	57.0	91.7	459	57.9	93.2
10	21.8	35.1	100	48.5	78.1	190	43.0	69.2	280	44.2	71.1	370	57.0	91.7	460	58.0	93.3
11	24.0	38.6	101	48.8	78.5	191	43.1	69.4	281	43.5	70.0	371	57.0	91.7	461	58.1	93.5
12	25.8	41.5	102	49.1	79.0	192	43.4	69.8	282	42.8	68.9	372	57.0	91.7	462	58.1	93.5
13	27.1	43.6	103	49.2	79.2	193	43.9	70.7	283	42.0	67.6	373	57.0	91.7	463	58.2	93.7
14	28.0	45.1	104	49.1	79.0	194	44.3	71.3	284	40.1	64.5	374	57.0	91.7	464	58.3	93.8
15	29.0	46.7	105	49.1	79.0	195	44.6	71.8	285	38.6	62.1	375	57.0	91.7	465	58.3	93.8
16	30.0	48.3	106	49.0	78.9	196	44.9	72.3	286	37.5	60.4	376	57.0	91.7	466	58.3	93.8
17	30.7	49.4	107	49.0	78.9	197	44.8	72.1	287	35.8	57.6	377	56.9	91.6	467	58.2	93.7
18	31.5	50.7	108	49.1	79.0	198	44.4	71.5	288	34.7	55.8	378	56.8	91.4	468	58.1	93.5
19	32.2	51.8	109	49.2	79.2	199	43.9	70.7	289	34.0	54.7	379	56.5	90.9	469	58.0	93.3
20	32.9	52.9	110	49.3	79.3	200	43.4	69.8	290	33.3	53.6	380	56.2	90.4	470	57.8	93.0
21	33.5	53.9	111	49.4	79.5	201	43.2	69.5	291	32.5	52.3	381	56.0	90.1	471	57.5	92.5
22	34.1	54.9	112	49.5	79.7	202	43.2	69.5	292	31.7	51.0	382	56.0	90.1	472	57.1	91.9
23	34.6	55.7	113	49.5	79.7	203	43.1	69.4	293	30.6	49.2	383	56.0	90.1	473	57.0	91.7
24	34.9	56.2	114	49.5	79.7	204	43.0	69.2	294	29.6	47.6	384	56.1	90.3	474	56.6	91.1
25	35.1	56.5	115	49.4	79.5	205	43.0	69.2	295	28.8	46.3	385	56.4	90.8	475	56.1	90.3
26	35.7	57.5	116	49.1	79.0	206	43.1	69.4	296	28.4	45.7	386	56.7	91.2	476	56.0	90.1
27	35.9	57.8	117	48.9	78.7	207	43.4	69.8	297	28.6	46.0	387	56.9	91.6	477	55.8	89.8
28	35.8	57.6	118	48.6	78.2	208	43.9	70.7	298	29.5	47.5	388	57.1	91.6	478	55.5	89.3
29	35.3	56.8	119	48.4	77.9	209	44.0	70.8	299	31.4	50.5	389	57.3	92.2	479	55.2	88.8
30	34.9	56.2	120	48.1	77.4	210	43.5	70.0	300	33.4	53.8	390	57.4	92.4	480	55.1	88.7
31	34.5	55.5	121	47.7	76.8	211	42.6	68.6	301	35.6	57.3	391	57.4	92.4	481	55.0	88.5
32	34.6	55.7	122	47.4	76.3	212	41.5	66.8	302	37.5	60.4	392	57.2	92.1	482	54.9	88.4
33	34.8	56.0	123	47.3	76.1	213	40.7	65.5	303	39.1	62.9	393	57.0	91.7	483	54.9	88.4
34	35.1	56.5	124	47.5	76.4	214	40.0	64.4	304	40.2	64.7	394	56.9	91.6	484	54.9	88.4
35	35.7	57.5	125	47.8	76.9	215	40.0	64.4	305	41.1	66.1	395	56.6	91.1	485	54.9	88.4
36	36.1	58.1	126	47.9	77.1	216	40.3	64.9	306	41.8	67.3	396	56.3	90.6	486	54.9	88.4
37	36.2	58.3	127	48.0	77.2	217	41.0	66.0	307	42.4	68.2	397	56.1	90.3	487	54.9	88.4
38	36.5	58.7	128	47.9	77.1	218	42.0	67.6	308	42.8	68.9	398	56.4	90.8	488	55.0	88.5
39	36.7	59.1	129	47.9	77.1	219	42.7	68.7	309	43.3	69.7	399	56.7	91.2	489	55.0	88.5
40	36.9	59.4	130	47.9	77.1	220	43.1	69.4	310	43.8	70.5	400	57.1	91.9	490	55.0	88.5
41	37.0	59.5	131	48.0	77.2	221	43.2	69.5	311	44.3	71.3	401	57.5	92.5	491	55.0	88.5
42	37.0	59.5	132	48.0	77.2	222	43.4	69.8	312	44.7	71.9	402	57.8	93.0	492	55.0	88.5
43	37.0	59.5	133	48.0	77.2	223	43.9	70.7	313	45.0	72.4	403	58.0	93.3	493	55.0	88.5
44	37.0	59.5	134	47.9	77.1	224	44.3	71.3	314	45.2	72.7	404	58.0	93.3	494	55.1	88.7
45	37.0	59.5	135	47.3	76.1	225	44.7	71.9	315	45.4	73.1	405	58.0	93.3	495	55.1	88.7
46	37.0	59.5	136	46.0	74.0	226	45.1	72.6	316	45.5	73.2	406	58.0	93.3	496	55.0	88.5
47	37.1	59.7	137	43.3	69.7	227	45.4	73.1	317	45.8	73.7	407	58.0	93.3	497	54.9	88.4
48	37.3	60.0	138	41.2	66.3	228	45.8	73.7	318	46.0	74.0	408	58.0	93.3	498	54.9	88.4
49	37.8	60.8	139	39.5	63.6	229	46.5	74.8	319	46.1	74.2	409	57.9	93.2	499	54.8	88.2
50	38.6	62.1	140	39.2	63.1	230	46.9	75.5	320	46.5	74.8	410	57.8	93.0	500	54.7	88.0
51	39.3	63.2	141	39.0	62.8	231	47.2	76.0	321	46.8	75.3	411	57.7	92.9	501	54.6	87.9
52	40.0	64.4	142	39.0	62.8	232	47.4	76.3	322	47.1	75.8	412	57.7	92.9	502	54.4	87.5
53	40.7	65.5	143	39.1	62.9	233	47.3	76.1	323	47.7	76.8	413	57.8	93.0	503	54.3	87.4
54	41.4	66.6	144	39.5	63.6	234	47.3	76.1	324	48.3	77.7	414	57.9	93.2	504	54.3	87.4
55	42.2	67.9	145	40.1	64.5	235	47.2	76.0	325	49.0	78.9	415	58.0	93.3	505	54.2	87.2
56	42.9	69.0	146	41.0	66.0	236	47.2	76.0	326	49.7	80.0	416	58.1	93.5	506	54.1	87.1
57	43.5	70.0	147	42.0	67.6	237	47.2	76.0	327	50.3	81.0	417	58.4	94.0	507	54.1	87.1
58	44.0	70.8	148	43.1	69.4	238	47.1	75.8	328	51.0	82.1	418	58.9	94.8	508	54.1	87.1
59	44.3	71.3	149	43.7	70.3	239	47.0	75.6	329	51.7	83.2	419	59.1	95.1	509	54.0	86.9
60	44.5	71.6	150	44.1	71.0	240	47.0	75.6	330	52.4	84.3	420	59.4	95.6	510	54.0	86.9
61	44.8	72.1	151	44.3	71.3	241	46.9	75.5	331	53.1	85.5	421	59.8	96.2	511	54.0	86.9
62	44.9	72.3	152	44.4	71.5	242	46.8	75.3	332	53.8	86.6	422	59.9	96.4	512	54.0	86.9
63	45.0	72.4	153	44.6	71.8	243	46.9	75.5	333	54.5	87.7	423	59.9	96.4	513	54.0	86.9
64	45.1	72.6	154	44.7	71.9	244	47.0	75.6	334	55.2	88.8	424	59.8	96.2	514	54.0	86.9
65	45.4	73.1	155	44.9	72.3	245	47.2	76.0	335	55.8	89.8	425	59.6	95.9	515	54.0	86.9
66	45.7	73.5	156	45.2	72.7	246	47.5	76.4	336	56.4	90.8	426	59.4	95.6	516	54.0	86.9
67	46.0	74.0	157	45.7	73.5	247	47.9	77.1	337	56.9	91.6	427	59.2	95.3	517	54.1	87.1
68	46.3	74.5	158	45.9	73.9	248	48.0	77.2	338	57.0	91.7	428	59.1	95.1	518	54.2	87.2
69	46.5	74.8	159	46.3	74.5	249	48.0	77.2	339	57.1	91.9	429	59.0	95.0	519	54.5	87.7
70	46.8	75.3	160	46.8	75.3	250	48.0	77.2	340	57.3	92.2	430	58.9	94.8	520	54.8	88.2
71	46.9	75.5	161	46.9	75.5	251	48.0	77.2	341	57.6	92.7	431	58.7	94.5	521	54.9	88.4
72	47.0	75.6	162	47.0	75.6	252	48.0	77.2	342	57.8	93.0	432	58.6	94.3	522	55.0	88.5
73	47.1	75.8	163	47.1	75.8	253	48.1	77.4	343	58.0	93.3	433	58.5	94.1	523	55.1	88.7
74	47.2	76.0	164	47.6	76.6	254	48.2	77.6	344	58.1	93.5	434	58.4	94.0	524	55.2	88.8
75	47.3	76.1	165	47.9	77.1	255	48.2	77.6	345	58.4	94.0	435	58.4	94.0	525	55.2	88.8
76	47.2	76.0	166	48.0	77.2	256	48.1	77.4	346	58.7	94.5	436	58.3	93.8	526	55.3	89.0
77	47.1	75.8	167	48.0	77.2	257	48.6	78.2	347	58.8	94.6	437	58.2	93.7	527	55.4	89.2
78	47.0	75.6	168	47.9	77.1	258	48.9	78.7	348	58.9	94.8	438	58.1	93.5	528	55.5	89.3
79	46.9	75.5	169	47.8	76.9	259	49.1	79.0	349	59.0	95.0	439	58.0	93.3	529	55.6	89.5
80	46.9	75.5	170	47.3	76.1	260	49.1	79.0	350	59.0	95.0	440	57.9	93.2	530	55.7	89.6
81	46.9	75.5	171	46.7	75.2	261	49.1	79.0	351	58.9	94.8	441	57.9	93.2	531	55.8	89.8
82	47.0	75.6	172	46.2	74.4	262	49.1	79.0	352	58.8	94.6	442	57.9	93.2	532	55.9	90.0
83	47.1	75.8	173	45.9	73.9	263	49.1	79.0	353	58.6	94.3	443	57.9	93.2	533	56.0	90.1
84	47.1	75.8	174	45.7	73.5	264	49.0	78.9	354	58.4	94.0	444	57.9	93.2	534	56.0	90.1
85	47.2	76.0	175	45.5	73.2	265	48.9	78.7	355	58.2	93.7	445	58.0	93.3	535	56.0	90.1
86	47.1	75.8	176	45.4	73.1	266	48.2	77.6	356	58.1	93.5	446	58.1	93.5	536	56.0	90.1
87	47.0	75.6	177	45.3	72.9	267	47.7	76.8	357	58.0	93.3	447	58.1	93.5	537	56.0	90.1
88	46.9	75.5	178	45.0	72.4	268	47.5	76.4	358	57.9	93.2	448	58.2	93.7	538	56.0	90.1
89	46.5	74.8	179	44.0	70.8	269	47.2	76.0	359	57.6	92.7	449	58.2	93.7	539	56.0	90.1

(Table continued next page)

APPENDIX F
EPA HIGHWAY DRIVING CYCLE
TIME-SPEED TRACE (continued)

Time	mph	km/h	Time	mph	km/h	Time	mph	km/h	Time	mph	km/h	Time	mph	km/h	Time	mph	km/h
540	56.0	90.1	580	51.1	82.2	620	49.7	80.0	660	51.0	82.1	700	54.2	87.2	740	48.5	78.1
541	56.0	90.1	581	50.7	81.6	621	50.6	81.4	661	51.1	82.2	701	54.5	87.7	741	47.6	76.6
542	56.0	90.1	582	50.3	81.0	622	51.5	82.9	662	51.4	82.7	702	54.8	88.2	742	46.8	75.3
543	56.0	90.1	583	49.8	80.1	623	52.2	84.0	663	51.7	83.2	703	55.0	88.5	743	45.6	73.4
544	56.0	90.1	584	49.3	79.3	624	52.7	84.8	664	52.0	83.7	704	55.5	89.3	744	44.2	71.1
545	56.0	90.1	585	48.7	78.4	625	53.0	85.3	665	52.2	84.0	705	55.9	90.0	745	42.5	68.4
546	56.0	90.1	586	48.2	77.6	626	53.6	86.3	666	52.5	84.5	706	56.1	90.3	746	39.2	63.1
547	55.9	90.0	587	48.1	77.4	627	54.0	86.9	667	52.8	85.0	707	56.3	90.6	747	35.9	57.8
548	55.9	90.0	588	48.0	77.2	628	54.1	87.1	668	52.7	84.8	708	56.4	90.8	748	32.6	52.5
549	55.9	90.0	589	48.0	77.2	629	54.4	87.5	669	52.6	84.7	709	56.5	90.9	749	29.3	47.2
550	55.8	89.8	590	48.1	77.4	630	54.7	88.0	670	52.3	84.2	710	56.7	91.2	750	26.8	43.1
551	55.6	89.5	591	48.4	77.9	631	55.1	88.7	671	52.3	84.2	711	56.9	91.6	751	24.5	39.4
552	55.4	89.2	592	48.9	78.7	632	55.4	89.2	672	52.4	84.3	712	57.0	91.7	752	21.5	34.6
553	55.2	88.8	593	49.0	78.9	633	55.4	89.2	673	52.5	84.5	713	57.3	92.2	753	19.5	31.4
554	55.1	88.7	594	49.1	79.0	634	55.0	88.5	674	52.7	84.8	714	57.7	92.9	754	17.4	28.0
555	55.0	88.5	595	49.1	79.0	635	54.5	87.7	675	52.7	84.8	715	58.2	93.7	755	15.1	24.3
556	54.9	88.4	596	49.0	78.9	636	53.6	86.3	676	52.4	84.3	716	58.8	94.6	756	12.4	20.0
557	54.6	87.9	597	49.0	78.9	637	52.5	84.5	677	52.1	83.8	717	59.1	95.1	757	9.7	15.6
558	54.4	87.5	598	48.9	78.7	638	50.2	80.8	678	51.7	83.2	718	59.2	95.3	758	7.0	11.3
559	54.2	87.2	599	48.6	78.2	639	48.2	77.6	679	51.1	82.2	719	59.1	95.1	759	5.0	8.0
560	54.1	87.1	600	48.3	77.7	640	46.5	74.8	680	50.5	81.3	720	58.8	94.6	760	3.3	5.3
561	53.8	86.6	601	48.0	77.2	641	46.2	74.4	681	50.1	80.6	721	58.5	94.1	761	2.0	3.2
562	53.4	85.9	602	47.9	77.1	642	46.0	74.0	682	49.8	80.1	722	58.1	93.5	762	0.7	1.1
563	53.3	85.8	603	47.8	76.9	643	46.0	74.0	683	49.7	80.0	723	57.7	92.9	763	0.0	0.0
564	53.1	85.5	604	47.7	76.8	644	46.3	74.5	684	49.6	79.8	724	57.3	92.2	764	0.0	0.0
565	52.9	85.1	605	47.9	77.1	645	46.8	75.3	685	49.5	79.7	725	57.1	91.9	765	0.0	0.0
566	52.6	84.7	606	48.3	77.7	646	47.5	76.4	686	49.5	79.7	726	56.8	91.4			
567	52.4	84.3	607	49.0	78.9	647	48.2	77.6	687	49.7	80.0	727	56.5	90.9			
568	52.2	84.0	608	49.1	79.0	648	48.8	78.5	688	50.0	80.5	728	56.2	90.4			
569	52.1	83.8	609	49.0	78.9	649	49.5	79.7	689	50.2	80.8	729	55.5	89.3			
570	52.0	83.7	610	48.9	78.7	650	50.2	80.8	690	50.6	81.4	730	54.6	87.9			
571	52.0	83.7	611	48.0	77.2	651	50.7	81.6	691	51.1	82.2	731	54.1	87.1			
572	52.0	83.7	612	47.1	75.8	552	51.1	82.2	692	51.6	83.0	732	53.7	86.4			
573	52.0	83.7	613	46.2	74.4	653	51.7	83.2	693	51.9	83.5	733	53.2	85.6			
574	52.1	83.8	614	46.1	74.2	654	52.2	84.0	694	52.0	83.7	734	52.9	85.1			
575	52.0	83.7	615	46.1	74.2	655	52.5	84.5	695	52.1	83.8	735	52.5	84.5			
576	52.0	83.7	616	46.2	74.4	656	52.1	83.8	696	52.4	84.3	736	52.0	83.7			
577	51.9	83.5	617	46.9	75.5	657	51.6	83.0	697	52.9	85.1	737	51.3	82.6			
578	51.6	83.0	618	47.8	76.9	658	51.1	82.2	698	53.3	85.8	738	50.5	81.3			
579	51.4	82.7	619	49.0	78.9	659	51.0	82.1	699	53.7	86.4	739	49.5	79.7			

INSTRUMENTATION AND TECHNIQUES FOR VEHICLE REFUELING EMISSIONS MEASUREMENT—SAE J1045

SAE Recommended Practice

Report of Automotive Emissions and Air Pollution Committee approved August 1973.

Scope—This SAE Recommended Practice describes a procedure for measuring the hydrocarbon emissions occurring during the refueling of passenger cars and light trucks. It can be used as a method for investigating the effects of temperatures, fuel characteristics, etc., on refueling emissions in the laboratory. It also can be used for determining the reduction in emissions achieved with emission control hardware. For this latter use, standard temperatures, fuel volatility, and fuel quantities are specified.

General Discussion—Refueling losses are made up of the following individual losses:

(a) Displaced fuel tank vapor.
(b) Entrained fuel droplets in the displaced vapor.
(c) Liquid spillage.
(d) Nozzle drip during insertion and removal from the filler neck.

Experience has shown that displaced vapor normally is 90% or more of the total loss. The amount of displaced vapor is known to be affected by a number of factors, particularly dispensed fuel temperature, Reid vapor pressure, and the degree to which dispensed fuel and displaced vapor come into contact.

The measurement facility described in this SAE Recommended Practice includes a sealed enclosure. The enclosure is identical to that described in SAE J171, except for the minimum length specified and that a refueling hose and nozzle has been added. The hydrocarbon measuring instrument is identical to that of SAE J171. This technique is used to measure the total loss for the four sources listed above.

The recommended practice includes the following sections:

1. Test Fuel
2. Test Facilities and Equipment
3. Measurement Method
4. Information and Data to be Recorded.

1. Test Fuel

1.1 The test fuel should have a Reid vapor pressure of 9.0 ± 0.5 psi (62 ± 3 kPa). To describe the fuel being used adequately, it should be inspected for these properties:

Property	ASTM Test Method
Distillation	D 86
IBP	—
5%	—
10%	—
15%	—
20%	—
30%	—
40%	—
50%	—
90%	—
FBP	—
Reid vapor pressure, psi (Pa)	D 323
Hydrogen-carbon ratio[a]	D 1018

[a] The hydrogen-carbon (H/C) ratio is required for the calculation of losses using the enclosure method. The H/C ratio will be different for vapor losses as compared to liquid losses. Therefore, the H/C ratio should be measured for both condensed vapor and for the test fuel. Judgment should be used in interpolating between the two values for individual tests. H/C ratio can alternately be measured by β-ray absorption, which is quick and accurate (see Jacobs, et al., Anal Chem., Vol. 28, March 1956).

tor signal from a gas chromatograph, which shows deflections to indicate, for example, the presence of individual hydrocarbons.

11.14 **Hang-Up**—A term to describe the phenomena whereby higher molecular weight hydrocarbons are retained in the sample train, causing an initial low analyzer reading, followed by higher readings in subsequent tests. Excessive hang-up causes errors in the analysis of the hydrocarbons in exhaust gas.

11.15 **Gas Chromatograph**—An instrument commonly used to detect individual gases in complex gaseous mixtures. NOTE: In automobile exhaust gas analysis such instruments can be used to separate and determine the concentration of individual hydrocarbon species in a complex hydrocarbon mixture.

11.16 **Hexane Equivalent Concentration (ppm hexane)**—The concentration of a propane calibrating gas in terms of its hexane equivalent concentration. For NDIR, hexane equivalent concentration has been established as propane concentration times 0.52. For FID, hexane equivalent concentration equals propane concentration times 0.50.

11.17 **Idle Speed**—The engine's low idle speed as specified by the manufacturer.

11.18 **Inertia Weights**—A series of weights on a chassis dynamometer used to simulate the test weight of a vehicle.

11.19 **Intermediate Speed**—The peak torque speed or 60% of the rated speed, whichever is higher.

11.20 **Mode**—A particular event (for example, acceleration, deceleration, cruise, or idle) of a vehicle test cycle.

11.21 **Nondispersive Infrared (NDIR)**—Electromagnetic radiation used as the light source in NDIR instruments capable of measuring CO, CO_2, NO, and unburned hydrocarbons in exhaust gas.

11.22 **Nondispersive Ultraviolet (NDUV)**—Electromagnetic radiation used as the light source in NDUV instruments capable of measuring NO_2 concentrations in exhaust gas.

11.23 **Non-Methane Hydrocarbons (NMHC)**—All organic hydrocarbon compounds, excluding methane, present in an exhaust sample.

11.24 **Smoke Opacimeter**—An optical instrument designed to measure the opacity of diesel exhaust gases. The full flow of exhaust gases passes through the optical unit. One such smoke opacimeter is described in SAE J255 (June, 1971).

11.25 **Span Gas**—A single calibrating gas blend routinely used in calibration of an instrument such as those used for detecting hydrocarbons, carbon monoxide, and nitric oxide.

11.26 **Steady-State Condition**—An engine operating condition at a constant speed and load and at stabilized temperatures and pressures.

11.27 **Opacity**—The fraction of light transmitted from a source which is prevented from reaching the observer or instrument receiver, in percent (Opacity = |1 − Transmittance| × 100).

11.28 **Photographic Smoke Measurement**—A measurement technique which relies upon an instrumental or visual comparison of the photographic image of a smoke plume with an established scale of blackness or opacity to determine the opacity of the original smoke plume.

11.29 **Probe**—A device inserted into some portion of an engine or vehicle system in order to obtain a representative gas or liquid sample.

11.30 **Proportional Sampling**—A method of obtaining a composite sample of exhaust gas representative of all driving modes in a test cycle. This sample, when analyzed, will represent the average molar concentration of a constituent properly weighted for mass flow rates.

11.31 **Rated Power**—The maximum brake power output of an engine, in horsepower or kilowatts, as stated by the manufacturer.

11.32 **Rated Speed**—The engine speed at which the manufacturer specifies the rated brake power of an engine.

11.33 **Rated Torque**—The maximum torque produced by an engine, as stated by the manufacturer.

11.34 **Reid Vapor Pressure**—The vapor pressure of gasoline at 100°F (37.8°C) determined in a special bomb in the presence of a volume of air which occupies four times the volume of liquid fuel (ASTM procedure D 323).

11.35 **Reference Cell**—That portion of the NDIR instrument which provides the reference signal to the detector.

11.36 **Resolution**—The minimum distinguishable reading, for a given trace width and scale combination, expressed as a percent of full-scale.

11.37 **Sample Cell**—That portion of the NDIR instrument which contains the sample gas being analyzed.

11.38 **Sampling**—The technique of obtaining an accurate sample of exhaust gas for analysis. Sampling may be grab, continuous, or proportional.

11.39 **Test Cycle**—A sequence of an engine or vehicle operating modes, usually designed to simulate road usage of the vehicle.

11.40 **Test Fuel**—A fuel for use in a given test and having specific chemical and physical properties required for that test.

11.41 **Transmittance**—That fraction of light transmitted from a source, through a smoke-obscured path, which reaches the observer or instrument receiver.

$$\left(\text{Transmittance} = 1 - \frac{\text{Opacity}}{100}\right)$$

11.42 **Variable Dilution Sampling**—Use Constant Volume Sampling.

11.43 **Variable Rate Sampling**—A technique to obtain an exhaust sample which takes a specific and constant fraction (for example, $\frac{1}{1000}$) of the total exhaust stream at each mode so that when the aggregate sample is analyzed for its molar constituents, it is weighted in proportion to the average flow rate through the cycle.

11.44 **Visual Smoke Measurement**—A measurement technique which relies upon human observation of an engine's smoke plume to rate that plume's appearance against an established scale of blackness or opacity (usually a gray scale on either a transparent or opaque white base).

METHANE MEASUREMENT USING GAS CHROMATOGRAPHY—SAE J1151 OCT88

SAE Recommended Practice

Report of the Automotive Emissions Committee, approved August 1976, completely revised June 1983, and reaffirmed October 1988.

*1. **Purpose***—This SAE Recommended Practice provides a means for a batch measurement of the methane concentration in light-duty vehicle exhaust samples. Nonmethane hydrocarbon concentration can be obtained by subtracting the methane concentration from the total hydrocarbon concentration obtained by a separate measurement made in accordance with accepted practices such as SAE J1094, J254, or a current Federal Test Procedure.[1]

*2. **Scope***—This SAE Recommended Practice describes instrumentation for determining the amount of methane in air and exhaust gas.

*3. **Sections***—The remainder of this practice is divided into the following sections:

4. Definitions of Terms and Abbreviations.
5. Equipment.
6. Principle of Operation.
7. Instrument Operating Procedure.
8. Instrument Performance Specifications.
9. Maintenance.

*4. **Definitions of Terms and Abbreviations***

4.1 Terms Used

4.1.1 Vehicle emission terms are defined in SAE J1145.

4.1.2 CARRIER GAS—A gas that acts as a passive vehicle to transport the sample through a gas chromatograph column.

4.1.3 GAS CHROMATOGRAPHY—A separation technique in which a sample in the gaseous state is carried by a flowing gas (carrier gas) through a tube (column) containing stationary material. The stationary material performs the separation by means of its differential affinity for the components of the sample.

4.2 Abbreviations and Symbols

°C	—degree(s) Celsius
CH_4	—methane
CO	—carbon monoxide
CO_2	—carbon dioxide
cm	—centimeter(s)
CVS	—constant volume sampler
FID	—flame ionization detector
Fig.	—figure
g	—gram
GC	—gas chromatograph(ic)
h	—hour(s)

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[1] See Code of Federal Regulations, Title 40 Protection of Environment, Part 86, Subpart B, Emission Regulations for 1977 and Later Model Year New Light-Duty Vehicles and New Light-Duty Trucks: Test Procedures (40 CFR 86.101 et seq.) (as possibly amended by the Federal Register).

HC	—hydrocarbon(s)
ID	—inside diameter
in	—inch
kPa	—kilopascal
NMHC	—nonmethane hydrocarbon(s)
min	—minute(s)
m	—meter
mm	—millimeter(s)
µm	—micrometer(s)
O_2	—oxygen
OD	—outside diameter
ppm	—parts per million
ppm C	—parts per million carbon
psig	—pound(s) per square inch, gage
s	—second(s)
scfh	—standard cubic foot per hour
SAE	—Society of Automotive Engineers, Inc.
SS	—stainless steel
%	—percent

5. Equipment

5.1 Safety Precautions—Flammable FID fuel (containing hydrogen) and potentially toxic 2% CO in exhaust gas are vented from this instrument at low flow rates of approximately 80 cm^3/min (0.2 scfh). At these low flow rates, there should not normally be a hazard from these gases, but precautions should be observed to insure dilution of these potentially hazardous vented gas streams.

The instrument uses flammable fuel and the precautions specified by the manufacturer should be observed.

The sample bypass line in the instrument has a flow of about 2000 cm^3/min (4 scfh) of automotive exhaust gas. This flow should be discharged outside of the building or into an adequately ventilated area.

5.2 Instrument—A gas chromatograph is used to separate the methane from the other constituents of an exhaust gas sample. The concentration of methane is determined with a FID. A typical suitable gas chromatograph is described in this section.

5.3 Component Description—*The schematic diagram in Fig. 1* shows a typical gas chromatograph assembled to routinely determine methane. The following components are typically used.

5.3.1 Valve, V1—Sample injection and switching valve, should be low dead volume, gas tight, and heatable to at least 150°C.

5.3.2 Valve, V2—Used to provide supplementary fuel to the FID burner.

5.3.3 Valve, V3—Used to select span gas, sample, or no flow.

5.3.4 Valve, V4—Used as a restrictor to match the flow resistance of the Porapak N column.

5.3.5 Valve, V5—Used as a restrictor to match the flow resistance of the Molecular Sieve column. This valve allows equalizing backflush and foreflush flow rates through the Porapak column.

5.3.6 Valve, V6—Used as a restrictor for controlling the rate of sample flow to fill the sample loop.

5.3.7 Pressure Regulator, PR1, and Pressure Gage, G1—To control flow rate of the fuel which is also the carrier gas.

5.3.8 Pressure Regulator, PR2, and Pressure Gage, G2—Back-pressure regulator for controlling the rate of sample flow to the sample loop in conjunction with valve V6. Should be adjusted in the pressure range from 7 to 34 kPa (1 to 5 psig).

5.3.9 GC Column—Porapak N, 180/300 µm (equivalent to 50/80 mesh), 610 mm (2 ft) length × 2.16 mm (0.085 in) ID × 3.18 mm (1/8 in) OD SS, to separate air, CH_4, and CO from the other sample constituents. The column is conditioned 12 h or more at 150°C with carrier gas flowing prior to initial use. Valve V1 should be in the fill/backflush position during the conditioning.

5.3.10 GC Column—Molecular Sieve Type 13X, 250/350 µm (equivalent to 45/60 mesh), 1220 mm (4 ft) length ×2.16 mm (0.085 in) ID, 3.18 mm (1/8 in) OD SS, to separate methane from oxygen, nitrogen, and CO. The column is conditioned 12 h or more at 150°C with carrier gas flow prior to initial use. Valve V1 should be in the fill/backflush position during the conditioning.

5.3.11 Sample Loop—A sufficient length of SS tubing to obtain approximately 1 cm^3 volume.

5.3.12 Oven—To maintain columns and valves at a stable temperature for analyzer operation, and to condition columns at 150°C.

5.3.13 Valve Actuator—To actuate sample injection and switching valve.

5.3.14 Valve Programmer—Timing unit to control valve actuator.

5.3.15 Dryer—To remove water and other contaminants which might be present in the carrier gas, a filter dryer containing Molecular Sieve is used. If it is a visual indicating type, the dryer is replaced when the need is indicated. Otherwise, it is replaced or reconditioned monthly. If the dryer has a metal body, it can be reconditioned after removing it from the instrument by flowing approximately 50 cm^3/min of dry nitrogen through the dryer while it is heated to 150°C in an oven for 12 h.

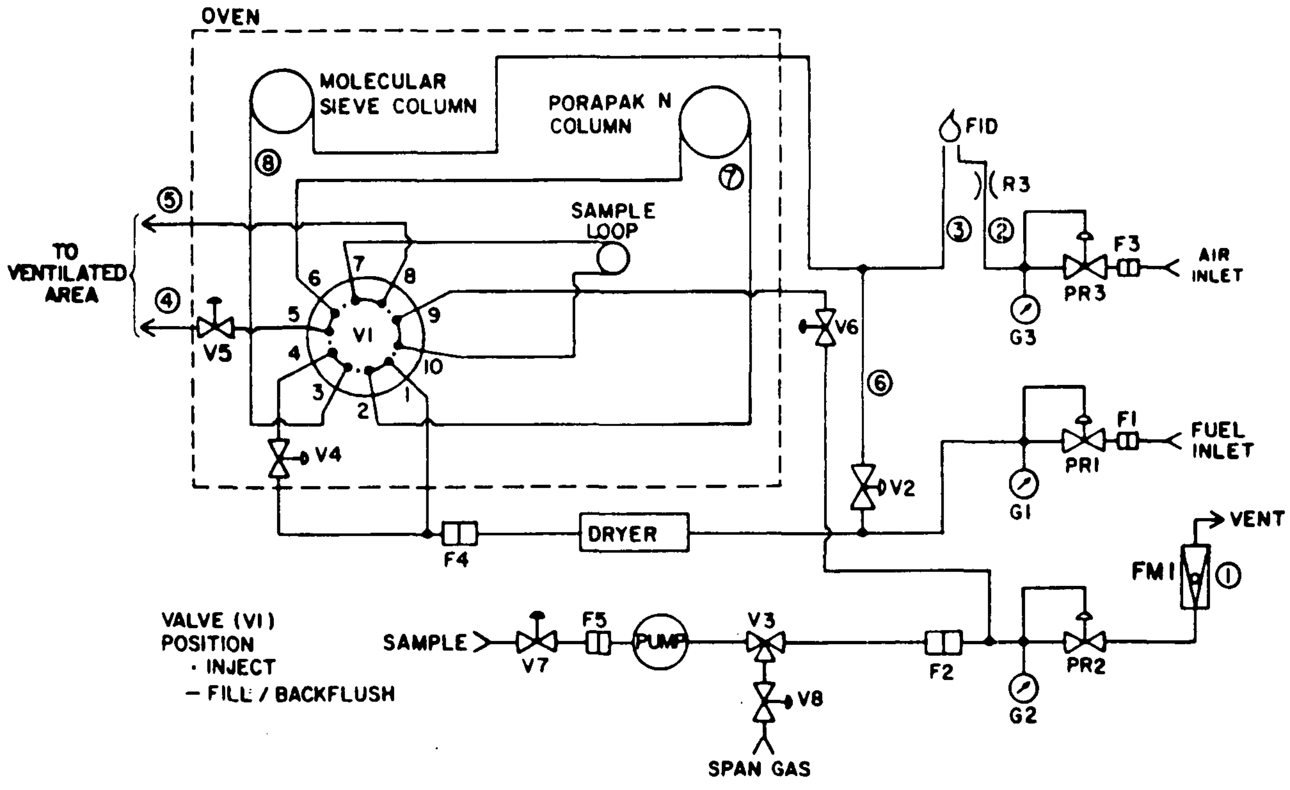

FIG. 1—INSTRUMENT TO MEASURE METHANE

5.3.16 Restrictor, R3—For controlling the rate of air flow to FID.

5.3.17 Pressure Regulator, PR3—Used with pressure gage, G3, and restrictor, R3, to control air flow to FID.

5.3.18 Filters F1, F3, F4—Sintered metal filters to prevent grit from entering the instrument.

5.3.19 Filters F2, F5—Sintered metal filters in the sample stream to prevent grit from entering the pump or instrument. Should be of sufficiently large area to have a pressure drop of less than 15 kPa (2 psi) at the bypass flow rate used of approximately 2000 cm^3/min (4 scfh).

5.3.20 Pump—Used to bring sample to gas chromatograph.

5.3.21 Valve, V7—Used with flowmeter, FM1, to regulate bypass sample flow rate. The bypass sample flow rate should be fast enough to flush out the entire sample line in a time less than the GC analysis time so that while an analysis is being made, the sample loop is filled with the next sample and is ready for the next analysis cycle. A typical bypass flow rate would be 2000 cm^3/min (4 scfh).

5.3.22 Valve, V8—Used with flowmeter, FM1, to equalize bypass flow rates of span gas and sample.

5.3.23 Recorder—The recorder or other readout device should have an input compatible with the FID analyzer output, an accuracy (including the effects of deadband and linearity) of ±0.25% of full scale or better, a span step response time of 0.4 s or less, and a chart speed of approximately 25 mm/min (1 in/min).

5.3.24 FID—The flame ionization detector generates an electrical current proportional to the flow rate of methane through the burner. The associated electrometer amplifier acts as a current to voltage converter and should have an electronic time constant of less than 0.20 s.

6. Principle of Operation—The instrument (Fig. 1) measures the methane concentration in a sample swept from a fixed volume sample loop by a carrier gas stream when the valve (V1) is in the inject position. The carrier gas can be blended FID fuel. The stream enters the Porapak N gas chromatographic column which temporarily retains NMHC, CO_2, and water, and passes air, methane, and CO to the Molecular Sieve column. As soon as all of the methane elutes from the Porapak N column and has passed through valve V1 toward the Molecular Sieve column, the Porapak N column is backflushed to waste by switching the valve (V1) to the fill/backflush position. Switching V1 also starts filling the sample loop with the next sample. The Molecular Sieve column separates the methane from the air and CO before passing it to the FID. The FID produces a signal peak proportional to the methane concentration in the sample. As soon as the methane peak passes through the FID, valve V1 can be switched back to the inject position to inject the next sample. A complete cycle, from injection of one sample to injection of a second, can be made in 30 s. Automation of injection and backflush switching assures reproducible peak times and shapes and is easily accomplished.

7. Instrument Operating Procedure

7.1 In general, the manufacturer's instructions for operation of the instrument or gas chromatograph should be followed.

7.2 **Component Assembly**—The assembly of the components for the instrument is shown in Fig. 1. The sample and switching valve V1, restrictor valves V4 and V5, sample loop, and the two GC columns are installed in the oven. The outlet of valve V5 and the outlet from valve V1, port 8 must discharge directly into an open area at atmospheric pressure where there can be no effluent build-up. The other components are connected outside the oven with all connecting tubing of minimum length. After all of the connections have been made, as indicated in Fig. 1, leak check the fittings and the instrument is ready for adjustment of operating parameters.

7.3 **Initial Adjustment of Operating Parameters**—The timing sequence is determined by the flow rates of the carrier gas, the gas hold-up volume of the system, and the column temperature. Typical flow rates at several instrument locations identified by the encircled numerals in Fig. 1 are given in Table 1. The following procedure would typically be followed to determine satisfactory flow rates of the assembled system and the switching times of the valves.

7.3.1 Set the initial operating parameters. Record oven temperature, gas pressures, and flow rates for later reference.

7.3.1.1 *Sample*—Adjust the flow of span gas or sample with V8 or V7 so that the flow discharged to the vent is about 2000 cm^3/min (4 scfh). Adjust backpressure regulator PR2 so that gage G2 reads from 7 to 34 kPa (1 to 5 psig). Readjust span gas or sample bypass flow to 2000 cm^3/min. With valve V1 in the fill/backflush position, adjust valve V6 so that the flow from port 8 of valve V1 is 80-100 cm^3/min.

7.3.1.2 *Carrier Gas*—Mixed fuel is recommended to minimize the number of gases required for vehicle exhaust measurements since mixed fuel is also used for total hydrocarbon measurements (see SAE J1094). Mixtures from 38 to 55% hydrogen with the diluent being helium or nitrogen have been found to be acceptable. The carrier gas mixture should contain less than 0.5 ppm C HC. (The oxygen peak height (see Fig. 2) is not a direct response to oxygen, but is caused by a synergistic effect of O_2 on the HC impurity in the mixed fuel, therefore it is an approximate indicator of the hydrocarbon concentration in the fuel.)

With sampling and switching valve (V1) in the inject position and valve V2 closed, adjust pressure regulator PR1 so that the carrier flow rate through the columns into the FID burner is about 70 cm^3/min. Typically, the pressure regulator PR1 will be set at approximately 140 kPa (20 psig). The flow is readily measured with a soap bubble flowmeter. The elapsed time from sample injection to the appearance of the oxygen peak (Fig. 2) is primarily a function of the carrier flow rate. Turn valve V1 to the fill/backflush position. Adjust valve V4 so that the carrier flow rate through the Molecular Sieve column and into the FID burner is the same (within 2%) as when valve V1 is in the inject po-

TABLE 1—TYPICAL FLOW RATES

Location (Fig. 1)	Valve V1 Position	
	Inject	Fill/Backflush
	Flow Rate—cm^3/min (room pressure and temperature)	
1. Sample Bypass Vent	2000	2000
2. Burner Air	400	400
3. Total Burner Fuel[a]	100	100
4. Backflush	60	60
5. Sample	95	90
6. Makeup Fuel[a]	30	30
7. Porapak N Column[a]	70[b]	60
8. Molecular Sieve Column[a]	70[b]	70[b]

[a] Fuel: 40% H_2/60% He.

[b] These flow rates were measured at location 3 with valve V2 closed.

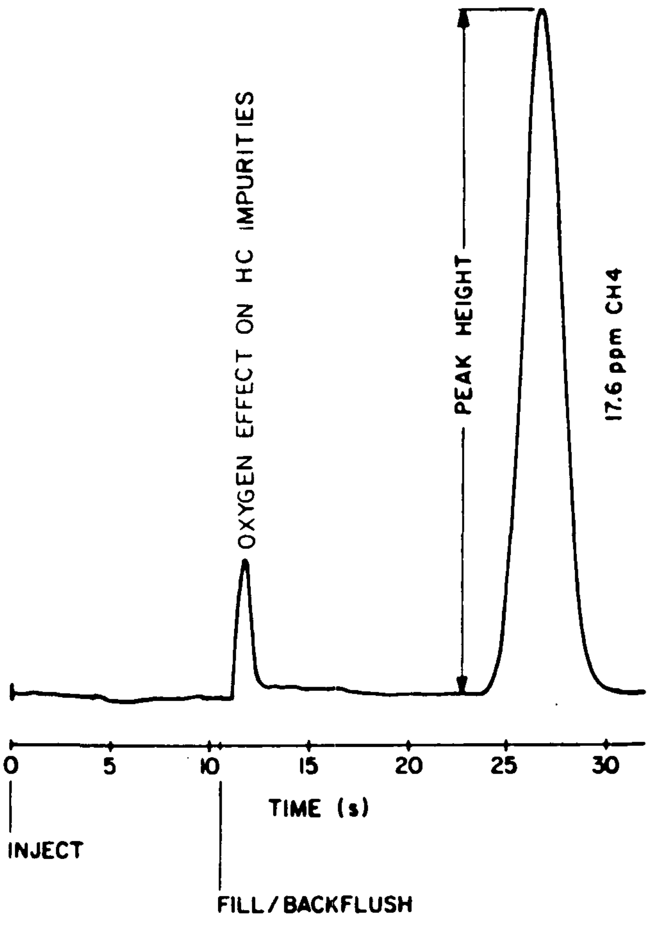

FIG. 2—TYPICAL GAS CHROMATOGRAM

sition. Check the backflush flow rate through valve V5 to confirm that it is approximately equal (within 30%) to the flow rate through the columns into the FID burner.

7.3.1.3 *Column Conditioning*—With valve V1 in fill/backflush position and carrier gas flowing, adjust oven temperature to 150°C and condition columns for a minimum of 12 hours. After conditioning, adjust oven temperature to about 55°C.

7.3.1.4 *Additional Fuel*—Open valve V2 to provide a total hydrogen flow to the FID burner of about 40 cm^3/min (for example, 100 cm^3/min of 40% H_2/60% He fuel).

7.3.1.5 *Air (Should Contain Less Than 0.5 ppm C HC)*—Set the pressure regulator PR3 so that the air flow to the FID burner is approximately ten times the hydrogen flow.

7.3.1.6 *Column Oven Temperature*—The column oven should be maintained at a constant temperature. A temperature of about 55°C will allow an analysis time of 30 seconds. The temperature can be adjusted between 35 and 75°C in order to give a desired analysis time. Allow time for oven temperature to stabilize before making measurements. The temperature control setting that maintains 150°C for use in conditioning the GC columns should be ascertained before column installation.

7.3.2 TIMING SEQUENCE—The analysis starts with valve V1 in the fill/backflush position. In this position, the sample loop is flushed and filled with sample (flow rate 80–100 cm^3/min). With a typical instrument, it was found that if the sample select valve, V3, selected the next sample at least 6 s before sample injection, the sample loop was fully flushed and hence a longer flush and fill time gave the same analytical results. The sample is injected by switching valve V1 into the inject position. The sample passes into the Porapak N column from which air elutes first and then methane. Carbon dioxide, higher hydrocarbons, and water vapor are retained longer in the Porapak N column. It is necessary to leave valve V1 in the inject position only long enough for all the methane to elute from the Porapak N column. If valve V1 is in the inject position too long, CO_2 will also elute from the Porapak N column, pass onto the Molecular Sieve column, be absorbed by and gradually deactivate the Molecular Sieve column. The optimum time for switching is found by determining the minimum time required for maximum methane response to be obtained. With a typical instrument at a column flow rate of 73 cm^3/min, it was found that if valve V1 was manually switched from inject to fill/backflush 6 s after injection, the methane peak height was 53% of its ultimate height measured with a later valve switching. If valve V1 was switched 7 s after injection, the methane peak height was 95% of its ultimate height, and if valve V1 was switched 8 s after injection, the ultimate peak height was reached. For this instrument, valve V1 was programmed to stay in the inject position for 9 seconds. The gases in order of elution from the Molecular Sieve column into the FID are oxygen, which gives a small peak; nitrogen; methane, which gives the peak that is measured; and CO, which elutes well before the next methane peak. The FID does not respond to the nitrogen and carbon monoxide. Fig. 2 shows a gas chromatogram obtained with this system. (In normal use a slower chart speed is used.) With valve V1 in the fill/backflush position, the Porapak N column is backflushed to waste to clean it out for the next sample. Also during this time, the sample loop is flushed and filled with the next sample to be analyzed. After most of the methane peak has eluted into the FID, valve V1 can be switched to inject the next sample. The last traces of methane can finish eluting while the next sample is being injected. In a typical instrument, the cycle time was 30 seconds.

7.4 Calibration—Typically, analyzer response is linear (not necessarily passing through the origin) with the methane content of the sample. However, this should be verified for each analyzer prior to its introduction into service and at monthly intervals thereafter. The linearity should also be verified whenever the FID burner is serviced and whenever the fuel carrier gas supply is changed. A series of four or more calibration gases, containing methane of known concentration in air, covering the range of concentrations within which sample gases may be expected to fall, should be used for calibration. Optionally, a flow blender may be used to blend a single calibration gas with zero grade air to provide a series of intermediate calibration gases. The methane impurity of the zero grade air should be determined and considered in the calculation of the methane concentration of the intermediate gases. Obtain the least-squares straight line regression of the methane concentration in the calibration gas as a function of methane peak height (or, if used, peak area). It is recommended that the datum point obtained with zero grade air should not be included in the regression. The reason is that if the methane concentration in the zero grade air is lower than the methane concentration in the carrier gas, the sample of zero grade air will produce a negative methane peak. Many peak height or peak area measuring schemes cannot correctly determine the height or area of the negative peak. For each range calibrated, if the deviation of the calibration points from the regression line is 2% or less or within 0.1 ppm methane of the value of each data point (excluding zero), then linearity is confirmed and a linear equation may be used to determine the methane concentration. Otherwise, attempt to find and correct the cause of the non-linearity. If necessary, the best fit nonlinear equation which represents the data to within 2% (or 0.1 ppm methane) of each point may be used to determine the concentration.

7.5 Emission Measurement Procedure—Each series of sample and dilution air bags from one vehicle test should be preceded with a measurement of zero gas and span gas. If the instrument output for these gases is not the same as during the last calibration, an electrical or computational correction to the instrument output should be made. Re-check zero. Six methane analyses can be made in 4 minutes. A measurement of zero gas and span gas following the test series which is within 2% of full scale from the initial values will confirm that there was no substantial instrument drift during the measurement of the test samples. The instrument should be located near the CVS in order to minimize the length of tubing. Samples are pumped directly from the bag via a Teflon or stainless steel tube to the sample inlet.

7.6 Data Analysis—The methane peak height is used as a measure of the amount of methane. Peak height is the distance from the peak maximum to the peak baseline. The peak baseline is defined as the plateau immediately preceding the peak. (Alternatively, the methane peak area, as determined with an integrator, can be used as a measure of the amount of methane.) Methane concentrations are measured directly, NMHC concentrations can be determined by the difference between an independent total hydrocarbon concentration measurement and the methane concentration.

7.6.1 METHANE—The following example for a linear analyzer illustrates the method of calculation:

Span—18.9 ppm C methane—50.0 chart divisions
Bag Analysis
  Methane—25.0 chart divisions
Bag Concentration Calculation

$$\text{Methane—}18.9 \times \frac{25.0}{50.0} = 9.45 \text{ ppm C}$$

For calculating the mass of methane by a method analogous to that used in the Federal Test Procedure[1] for hydrocarbons, the methane density at 20°C (68°F) and 101.32 kPa (760 mm Hg) pressure should be taken to be 0.667 kg/m^3 (18.89 g/ft^3).

7.6.2 NONMETHANE HYDROCARBON—NMHC data analysis is accomplished with calculation techniques similar to those used for total HC CVS bag emission data analysis. The following example for a linear analyzer illustrates the method of calculation:

Span—18.9 ppm C methane—50.0 chart divisions
Bag Analysis
  Methane—25.0 chart divisions
  Total HC—82.56 ppm C
Bag Concentration Calculations

$$\text{Methane—}18.9 \times \frac{25.0}{50.0} = 9.45 \text{ ppm C}$$

$$\text{NMHC—(total HC (ppm C) — methane (ppm C))} = 82.56 - 9.45 = 73.11 \text{ ppm C}$$

The exhaust sample and the dilution-air bags should be analyzed and the NMHC concentrations used for calculation of mass emissions as directed in the Federal Test Procedure[1] for hydrocarbon.

It can be noted that, in general, the sum of the methane mass emissions and the calculated NMHC mass emissions will not exactly equal the total calculated HC mass emissions. This is because the FID measures carbon mass and not hydrocarbon mass. The relation between these two masses depends on the hydrogen/carbon ratio of the hydrocarbons in the exhaust gas and this is not determined for each sample. Instead a nominal value for the hydrogen/carbon ratio is assumed in the Federal Register.

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[1] See Code of Federal Regulations, Title 40 Protection of Environment, Part 86, Subpart B, Emission Regulations for 1977 and Later Model Year New Light-Duty Vehicles and New Light-Duty Trucks; Test Procedures (40 CFR 86.101 et seq.) (as possibly amended by the Federal Register).

8. Instrument Performance Specifications

8.1 Baseline Noise—The instrument shall be run for 20 min with valve V1 remaining in the fill/backflush position. The peak-to-peak noise and drift of the baseline shall not exceed the equivalent of 0.16 ppm methane. (With a typical instrument, the peak-to-peak noise and drift was 0.07 ppm methane.)

8.2 Precision—A span gas containing about 20 ppm methane in air shall be read at least 25 times. Wait one cycle period (typically 30 s) between starting the flow of span gas and the first rotation of valve V1 into the inject position. The standard deviation of the series of span gas readings shall not exceed 0.10 ppm methane. (With a typical instrument the standard deviation of a series of span gas readings was 0.02 ppm methane.) Since the first reading of the series is most apt to show an offset, the magnitude of the difference between the first determination of the series and the mean of the series shall be no greater than 0.14 ppm methane or 3.3 standard deviations, whichever is greater.

8.3 Column Resolution—The methane retention time (paragraph 9.2.1) divided by the peak width at half height (paragraph 9.2.2) shall exceed 10.5. (In Fig. 2 this quotient is 11.5.)

9. Maintenance

9.1 Valve V1 Position—Except when actually injecting a sample, valve V1 should be kept in the fill/backflush position so as to minimize possible contamination of the Molecular Sieve column by effluent from the Porapak N column.

9.2 Column Performance

9.2.1 The methane retention time, which is the elapsed time from sample injection (sample injection is when valve V1 rotates from the fill/backflush position to the inject position) to the appearance of the methane peak maximum, should be measured when the instrument is placed in service and at weekly intervals thereafter. A change in the retention time from its initial value gives an indication that the column has deteriorated or that the initial conditions have changed. If the retention time has changed by more than 10%, the cause should be identified and corrected. Check oven temperature. Check or condition the dryer as described in paragraph 5.3.15. Check the carrier gas flow rates against the flow rates initially measured as described in paragraph 7.3.1.2. Check for leaks. Condition the columns as described in paragraphs 5.3.9 and 5.3.10.

9.2.2 Time the width of the methane peak at half of its peak height using a stopwatch or a gas chromatogram obtained with the recorder running at a fast speed of at least 0.3 m/min (1 ft/min). Perform this test when the instrument is first placed in service and at monthly intervals thereafter. A change in the peak width at half height of more than 15% suggests that the cause be identified as in paragraph 9.2.1.

9.3 Dryer Conditioning—If an indicating type dryer is used, it should be checked monthly and replaced if exhaustion is indicated. If a non-indicating type dryer is used, it should be replaced or reconditioned monthly. (See paragraph 5.3.15.)