EPA-AA-EOD-84/2

Non-Proportional Sample Rates in a Critical Flow Venturi Constant Volume Sampler:

Effects on Federal Emission Test Fuel Economy

Performed by

Engineering Operations Division

Written By

Carl Paulina

January, 1982

Correlation Group
Testing Programs Branch
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Office of Mobile Source Air Pollution Control
Ann Arbor, Michigan 48105

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Executive Summary

Background

The Constant Volume Sampler (CVS) is used in conjunction with gas analyzers to measure automobile exhaust gas constituents emitted during a Federal Test Procedure (FTP) driving sequence. The raw automobile exhaust gases are mixed with dilution air, sampled, and collected in evacuated airtight bags. The bagged samples are then analyzed for percent or parts per million (PPM) composition.

Critical flow venturi (CFV) constant volume samplers (CVS) are used by the Environmental Protection Agency. A detailed explanation of CFV properties and theories is contained in Attachment H. If the analysis bag sample flow rate remains constantly proportional to the total dilute exhaust flow rate, the bagged sample represents average emission concentrations for that portion of the test. This value is then applied to the total calculated volume of dilute exhaust to calculate the total quantity of emission emitted by the vehicle during that portion of the test. The purpose of this study is to examine the possible effects on test results (primarily fuel economy) when sample flow is not constantly proportional to dilute vehicle exhaust bulkstream flow rate in a CFV, CVS.

Test Types

Two separate test programs were used in this study. The first program used one vehicle and one sampling system. Half the tests were run with the sample rate remaining constantly proportional to the total vehicle dilute exhaust flow. The other half were run with a sample rate which did not remain constantly proportional to the total dilute exhaust flow. The test results were then analyzed as two-sample unpaired test groups.

The second program was run on two separate vehicles. Each vehicle test was run using two separate sampling systems, sampling the same dilute exhaust stream. One of the sampling systems operated with the sample rate constantly proportional to the total dilute exhaust flow while the other did not. The sample system which was operating at a flow remaining constantly proportional to the total dilute exhaust flow was randomized throughout the testing sequence. The test results were then analyzed as two-sample paired test groups. The second program's vehicles and CVS operating parameters were chosen to assess the scope of possible effects. Both test programs used modified Federal Emission Test Procedure tests (2 bag hot city) and highway fuel economy tests (HWFET). Hot tests were used to both minimize vehicle test to test variability and to generate a population large enough to insure statistical confidence within a reasonable length of time.

Results

The results of the study indicate that slightly higher fuel economy values were generally achieved when the sample probe flow rates remained constantly proportional to the total dilute exhaust flow rate. Overall, the measured mean differences appeared to be 2% or less. The second test program, with manufacturer-supplied vehicles, exhibited a 0.6% to 1.2% mean difference depending on the vehicle and test type (2 bag hot city, or HWFET). Although the observed offsets are statistically significant, extreme care had to be taken to minimize or eliminate all possible vehicle/site variabilities and inaccuracies. The magnitude of the observed offsets could be masked by Federal Register acceptable tolerances on test parameters. This study used vehicle engine size, loading, and CVS sample probe outlet/inlet operating pressure ratio to try to characterize minimum/maximum possible fuel economy effects. However, the test results indicate that the complex inter-dependent relationships occurring in vehicle emission testing prevent mathematical prediction of results by these aforementioned parameters.

Recommendations

It is recommended that sample probe pressures be monitored to ensure the sample probes are operating at a flow rate which remains constantly proportional to the total dilute exhaust flow.

Non-Proportional Sample Rates in a Critical Flow Venturi Constant Volume Sampler:

Effects on Federal Emission Test Fuel Economy

Background

The Constant Volume Sampler (CVS) is used in conjunction with gas analyzers to measure automobile exhaust gas constituents emitted during a Federal Test Procedure (FTP) driving sequence. The raw automobile exhaust gases are mixed with dilution air, sampled, and collected in evacuated airtight bags. The samples are then analyzed for percent or parts per million (PPM) composition. These measured concentrations are then applied to the calculated total volume of dilute exhaust flow for that portion of the test sequence.

The critical flow venturi (CFV) constant volume samplers (CVS), used by the Environmental Protection Agency, employ two CFV's each. The main or bulkstream CFV is used as a flow metering device to quantify the total volume of vehicle exhaust/dilution (dilute exhaust) air mixture passed through a CVS during a Federal Register city or highway test sequence. The second or sample CFV is used to insure that the analysis bag sample flow during a test is in a constant volumetric proportion to the total exhaust volume throughout the test sequence. A detailed explanation of CFV properties and theories are contained in Attachment H. If the analysis bag sample flow rate remains constantly proportional to the total dilute exhaust flow rate; the bag can be collected, analyzed, and used as average emission concentrations for that portion of the test. This value is then applied to the total calculated volume of dilute exhaust to calculate the total quantity of emission emitted by the vehicle during that portion of the test. The purpose of this study is to examine the possible effects, if any, on test results (primarily fuel economy) caused by the sample probe flow not being constantly proportional to dilute vehicle exhaust bulkstream flow rate.

Initial Investigations

Flow curves for two sample probes contained in EPA CVS's were characterized 1/. The graph of flow rate versus the ratio of the outlet to inlet pressure is contained in Attachment A. The sample probes graphed reached an "in choke" flow condition at a ratio of P_{out}/P_{in} of approximately 0.60. A numerically higher ratio will cause the sample probe to drop out of choke flow, resulting in fluctuation of sample flow with fluctuation of sample conditions. Once a CFV drops to an "out of choke" flow condition, it is beyond the scope of this report to predict what operating parameter will affect the flow rate or by how much.

Actual pressure measurement of the CVS sample probes were recorded to set outlet to inlet pressure ratios P_{out}/P_{in} were numerically higher than the 0.60 ratio discussed above. The values were measured using both a u-tube manometer and strain gauge pressure transducers. The pressure transducers were then used to monitor sample probe CFV inlet and outlet pressures during a vehicle test.

1/ Unpublished Study performed by C. Ryan and B. Harbowy of EOD, Calibration & Maintenance.

Sample probe outlet pressure was recorded on two vehicle tests and fluctuated 0.6 inch of mercury (Hg) on one and 0.9 inch Hg on the other while inlet pressures remained constant. As a result the P_{out}/P_{in} fluctuated during the emission test sequence. The observed fluctuations suggested a possible increase of sample flow rate during high acceleration portions of a test and lower flow rates during idle and lower accelerations. Vehicle emission maps with respect to vehicle speed are potentially variable from vehicle to vehicle. CVS dilution ratio variation will change with engine size. Finally, the pressure ratio fluctuations were not exactly synchronized with vehicle accelerations. Consequently, it is not possible to state in which direction the sample flow rate changed during higher and lower vehicle emission output.

Test Plan One Design

To establish what emission measurement effects are caused by the non-proportional flow rate fluctuations in the CVS sample probe CFV, a sequence of tests were run on a repeatable vehicle used at EPA for site-to-site comparisons. A series of ten highways and ten 2-bag hot city tests were run on the EOD repeatable vehicle. In each test sequence, five tests were run with the sample probe operating "in choke" flow and five were run with the probe operating "out of choke" flow. For the "out of choke" flow tests, a P_{out}/P_{in} equivalent to a ratio of 0.83 was used. An "in choke" ratio of approximately 0.55 was used. In order to minimize possible sequential results, all tests were run using two consecutive tests in one condition followed by two consecutive tests in the opposite condition for eight tests. On the final two tests, probe conditions were alternated. The sequence for the two test types and the pertinent vehicle parameters are listed as Test Plan 1.

Test Plan 1

Vehicle Parameters:

Inertia Weight	3500 Pounds
Actual Horsepower	12.8 Horsepower
Fuel System	Fuel Injection
Drive System	Rear Wheel

Test Sequence:

HWFET	Hot City, 2-Bag Tests
1 In choke	1 Out of choke
2 In choke	2 Out of choke
3 Out of choke	3 In choke
4 Out of choke	4 In choke
5 In choke	5 Out of choke
6 In choke	6 Out of choke
7 Out of choke	7 In choke
8 Out of choke	8 In choke
9 In choke	9 Out of choke
10 Out of choke	10 In choke

In Choke $P_{out}/P_{in} \sim 0.55$

Out of Choke $P_{out}/P_{in} \sim 0.83$

Test Plan One Results

The results were compared as two test groups in each test sequence (2 bag hot city, HWFET). Comparisons of the "in choke" and "out of choke" probe test results are contained in Attachment B. A two-tailed Student's t-Distribution test was used to calculate a confidence interval for the offset between the means at the 0.90 confidence level with 5 tests in each configuration. The assumptions are independent, normally distributed populations and pooled variances.

The calculated intervals for % difference $\frac{\text{unchoked} - \text{choked}}{\text{choked}} \times 100$ between means are:

Hot tests 1.5% ± 1.1% higher fuel economy "in choke" than "out of choke".

HWFET 2.0% ± 1.6% higher fuel economy "in choke" than "out of choke".

A sequential graph of test fuel economy is contained in Attachment C. Attachment D is a comparison graph of the mean and standard deviations of fuel economy for the two samples in each test sequence.

Test Plan Two Design

To further minimize the chance of vehicle test-to-test influences, a sequence of tests were run using two separate probes and sample trains sampling in the same CVS bulkstream on individual vehicle tests. Two separate vehicles were used for the Test Plan Two sequence. The samples of each individual vehicle's exhaust were then processed as two tests using the same analyzer. In the "out of choke" flow tests, a P_{out}/P_{in} of approximately 0.90 was used. This was numerically higher than the ratio used in test plan one. An "in choke" ratio of approximately 0.50 was used for that portion of the tests. The two sample probes were altered in and out of "choke flow" randomly. One test was run with both probes in an "in choke" condition at the start of each sequence (2-bag hot city and HWFET) to quantify possible sample train offsets. If a difference was found, additional tests were run to come up with a mean offset to subtract from subsequent "in" and "out" of choke flow pairs. The test sequences and pertinent vehicle parameters are listed under Test Plan 2.

Test Plan 2

Vehicle 1 Parameters:

Inertia Weight	2500 Pounds
Actual Horsepower	6.0
Fuel System	Carburetor
Drive System	Front Wheel

Test Sequence:

HWFET		Hot City 2-Bag Tests	
Probe 1	Probe 2	Probe 1	Probe 2
1 In Choke	In Choke	1 In Choke	In Choke
2 In Choke	Out of Choke	2 Out of Choke	In Choke
3 Out of Choke	In Choke	3 In Choke	Out of Choke
4 In Choke	Out of Choke	4 In Choke	Out of Choke
5 In Choke	Out of Choke	5 In Choke	Out of Choke
6 Out of Choke	In Choke	6 In Choke	Out of Choke

In Choke $P_{out}/P_{in} \sim 0.50$
Out of Choke $P_{out}/P_{in} \sim 0.90$

Vehicle 2 Parameters:

Inertia Weight	4500 Pounds
Actual Horsepower	13.0
Fuel System	Carburetor
Drive System	Rear Wheel

Test Sequence:

HWFET		Hot City 2-Bag Tests	
Probe 1	Probe 2	Probe 1	Probe 2
1 In Choke	In Choke	1 In Choke	In Choke
2 In Choke	Out of Choke	2 Out of Choke	In Choke
3 Out of Choke	In Choke	3 In Choke	In Choke
4 In Choke	In Choke	4 Out of Choke	In Choke
5 In Choke	Out of Choke	5 In Choke	Out of Choke
6 In Choke	Out of Choke	6 In Choke	Out of Choke
7 Out Choke	In Choke	7 Out of Choke	In Choke
8 In of Choke	In Choke	8 Out of Choke	In Choke

In Choke $P_{out}/P_{in} \sim 0.50$
Out of Choke $P_{out}/P_{in} \sim 0.90$

We used these test sequences both on a "large" and a "small" engine vehicle to bracket maximum and minimum expectable offsets. At least five pairs of "in choke" to "out of choke" comparisons were generated for each car and test sequence.

Test Plan Two Results

The results are listed in Attachment E. Time sequence plots of paired differences in fuel economy are contained in Attachment F. Attachment G is a tabular representation of the means, 0.90 confidence intervals, and confidence that a difference exists.

A student's t-distribution test for paired data was used to calculate a 0.90 confidence interval that the expectable mean offset will fall within on the pairs in each configuration. The assumptions are that the differences are from a random, normally distributed population.

The calculated intervals for the mean percent offset between "in choke" and "out of choke" are:

	(4500 lbs, 13.0 Actual Horsepower)
2 bag hot city	0.6% ± 0.4% higher fuel economy "in choke" than "out of choke".
HWFET	1.2% ± 0.9% higher fuel economy "in choke" than "out of choke".
	(2500 lb, 6.0 Actual Horse Power)
2 bag hot city	0.6% ± 0.4% higher fuel economy "in choke" than "out of choke".
HWFET	0.8% ± 0.5% higher fuel economy "in choke" than "out of choke".

Conclusions and Recommendations

Non-proportional CFV-CVS sample flow can affect vehicle calculated fuel economy. We are unable to discern a mathematically predictable pattern to the effect on calculated fuel economy based on parameters monitored in this study (i.e. engine size, loading, and sample probe outlet/inlet operating pressure ratios). It is recommended that CFV sample probe parameters be monitored to ensure that sample probes remain in a "choke" flow condition. This will ensure a sample flow rate which remains constantly proportional to total dilute exhaust flow.

Attachments

A - CVS, CFV Sample Probe Flow Profile

B - Test Program 1 Results

C - Test Plan 1 Sequential Test Fuel Economies

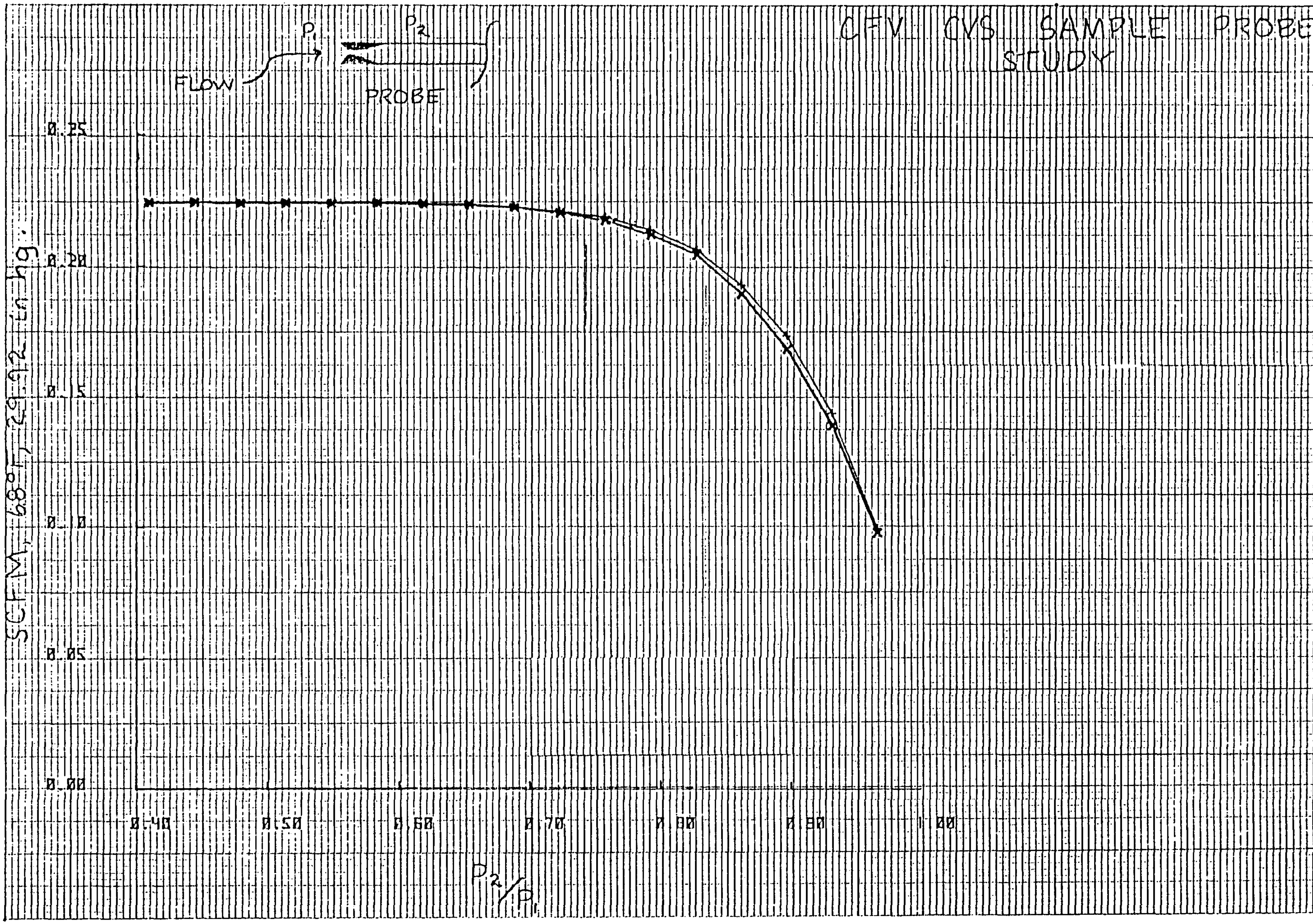
D - Test Plan 1 Fuel Economy Mean and Standard Deviation

E - Test Plan 2 Results

F - Test Plan 2 Sequential Test Absolute Fuel Economies and Percent Differences

G - Test Plan 2 Fuel Economy Results and Statistics

H - CFV Theoretical Analysis



ATTACHMENT A

ATTACHMENT B

LAB CORRELATION SUMMARY　　PROCESSED: NOV 18, 1981

VOLVO PROBE HOTS　　VIN VOLVO REPCA　　INERTIA WT 3500　　ACTUAL HP 12.8

LAB	N		HC	CO	NOX	CO2	FE	BARO	HUM	NXFC	DBL	HSL	TLOSS
			|<------G/MI-------			>|	(MPG)	(IN-HG)	(GRAINS /LB)		|<---(GRAMS)		--->|
SAMPLE CFV CHOKED	5	MEAN	0.606	4.72	2.29	423.	20.5	29.15	49.56	0.89			
		STANDARD DEV.	.0152	0.887	.083	4.	0.1	0.042	4.072	.015			
		C.V.%	2.5	18.8	3.6	0.9	0.7	0.14	8.22	1.71			
SAMPLE CFV UNCHOKED	5	MEAN	0.614	4.52	2.26	430.	20.2	29.03	49.30	0.89			
		STANDARD DEV.	.0195	0.438	.047	5.	0.2	0.182	9.033	.036			
		C.V.%	3.2	9.7	2.1	1.1	1.1	0.63	18.32	3.98			
		DIFF. %	1.	-4.	-1.	2.	-1.	-0.	-1.	-0.			

C.V.% IS THE COEFFICIENT OF VARIATION. (STD. DEV./MEAN *100).
DIFF.% IS THE DIFFERENCE OF THE MEANS BETWEEN THE MFR AND EPA LABS. (MFR-EPA/EPA *100).

LAB CORRELATION SUMMARY - TEST DATA PROCESSED: NOV 18, 1981

LAB: EPA - Choked VEH: VOLVO PROBE HOTS VIN: VOLVO REPCA INERTIA WT: 3500 ACTUAL HP: 12.8

DATE	TESTNO	TYPE	HC	CO	NOX	CO2	FE	DRIVER	DYNO	ODOM	IHP	BARO	HUM	NXFC	DBL	HSL	TLOSS
10-08-81	810905	HOT	0.590	4.20	2.19	424.	20.5	30898	D004	12475.0	10.8	29.10	44.16	0.87			
10-08-81	810906	HOT	0.600	4.40	2.21	422.	20.6	30898	D004	12490.0	10.8	29.10	47.62	0.89			
10-09-81	810909	HOT	0.610	4.40	2.36	428.	20.3	30898	D004	12540.0	10.8	29.18	54.88	0.91			
10-09-81	810910	HOT	0.600	4.30	2.35	424.	20.5	30898	D004	12555.0	10.8	29.18	51.81	0.90			
10-16-81	810912	HOT	0.630	6.30	2.34	417.	20.7	30898	D004	12650.0	10.8	29.21	49.35	0.89			
			|<-----(G/MI)----->|				(MPG)					(IN-HG)	(GRAINS /LB)		|<---(GRAMS)--->|		
MEAN			0.606	4.72	2.29	423.	20.5					29.15	49.56	0.89			
STANDARD DEV.			.0152	0.887	.083	4.	0.1					0.042	4.072	.015			
C.V.%			2.5	18.8	3.6	0.9	0.7					0.1	8.2	1.7			

BAG DATA

DATE	TESTNO	TYPE	DYNO	SITE	HC	2	3	CO	2	3	NOX	2	3	CO2	2	3	FE	2	3
10-08-81	810905	HOT	D004	A002	0.591	0.590	0.0	4.34	4.07	0.0	2.81	1.61	0.0	420.	427.	0.	20.7	20.4	0.0
10-08-81	810906	HOT	D004	A002	0.601	0.595	0.0	4.19	4.58	0.0	2.89	1.59	0.0	421.	424.	0.	20.7	20.5	0.0
10-09-81	810909	HOT	D004	A002	0.620	0.595	0.0	4.34	4.55	0.0	3.13	1.64	0.0	431.	426.	0.	20.2	20.4	0.0
10-09-81	810910	HOT	D004	A002	0.613	0.591	0.0	4.22	4.32	0.0	3.14	1.63	0.0	426.	422.	0.	20.4	20.6	0.0
10-16-81	810912	HOT	D004	A002	0.631	0.636	0.0	5.92	6.59	0.0	3.16	1.59	0.0	417.	416.	0.	20.7	20.7	0.0
										(ALL G/MI)							|<--(MPG)--->|		
MEAN					0.611	0.601	0.0	4.60	4.82	0.0	3.03	1.61	0.0	423.	423.	0.	20.5	20.5	0.0
STANDARD DEV.					0.016	0.019	0.0	0.74	1.01	0.0	0.16	0.02	0.0	6.	4.	0.	0.2	0.1	0.0
C.V.%					2.6	3.2	0.0	16.1	20.9	0.0	5.4	1.4	0.0	1.3	1.0	0.0	1.1	0.6	0.0

C.V.% IS THE COEFFICIENT OF VARIATION.(STD. DEV./MEAN *100).
DIFF. % IS THE DIFFERENCE OF THE MEANS BETWEEN THE MFR AND EPA LAB. (MFR-EPA/EPA *100).
NOTE: THE COMMENTS PERTINENT TO THESE TESTS ARE LOCATED IN THE LAST TABLE OF THIS APPENDIX.

LAB CORRELATION SUMMARY - TEST DATA   PROCESSED: NOV 18, 1981

LAB: SAMPLE CFV 'UNCHOKED   VEH: VOLVO PROBE HOTS   VIN: VOLVO REPCA   INERTIA WT: 3500   ACTUAL HP: 12.8

DATE	TESTNO	TYPE	HC	CO	NOX	CO2	FE	DRIVER	DYNO	ODOM	IHP	BARO	HUM	NXFC	DBL	HSL	TLOSS
10-02-81	810903	HOT	0.580	4.00	2.28	423.	20.6	30898	D004	12407.3	10.8	28.97	65.25	0.96			
10-06-81	810904	HOT	0.620	4.40	2.18	433.	20.1	30898	D004	12448.0	10.8	28.74	46.23	0.88			
10-08-81	810907	HOT	0.620	4.60	2.29	435.	20.0	30898	D004	12506.0	10.8	29.12	44.10	0.87			
10-08-81	810908	HOT	0.620	4.40	2.28	431.	20.2	30898	D004	12519.0	10.8	29.08	43.74	0.87			
10-14-81	810911	HOT	0.630	5.20	2.29	429.	20.2	30898	D004	12577.2	10.8	29.22	47.16	0.88			
			|<—— (G/MI)			——>|	(MPG)					(IN-HG)	(GRAINS /LB)		|<—— (GRAMS)		——>|
MEAN			0.614	4.52	2.26	430.	20.2					29.03	49.30	0.89			
STANDARD DEV.			.0195	0.438	.047	5.	0.2					0.182	9.033	.036			
C.V.%			3.2	9.7	2.1	1.1	1.1					0.6	18.3	4.0			
DIFF. %			1.	-4.	-1.	2.	-1.					-0.	-1.	-0.			

BAG DATA

DATE	TESTNO	TYPE	DYNO	SITE	HC	2	3	CO	2	3	NOX	2	3	CO2	2	3	FE	2	3
10-02-81	810903	HOT	D004	A002	0.593	0.559	0.0	4.03	4.04	0.0	3.05	1.56	0.0	423.	423.	0.	20.5	20.6	0.0
10-06-81	810904	HOT	D004	A002	0.648	0.600	0.0	4.53	4.29	0.0	2.93	1.48	0.0	437.	430.	0.	19.9	20.2	0.0
10-08-81	810907	HOT	D004	A002	0.636	0.613	0.0	4.71	4.49	0.0	3.03	1.61	0.0	439.	431.	0.	19.8	20.1	0.0
10-08-81	810908	HOT	D004	A002	0.647	0.598	0.0	4.47	4.39	0.0	3.06	1.56	0.0	433.	429.	0.	20.0	20.3	0.0
10-14-81	810911	HOT	D004	A002	0.637	0.620	0.0	5.50	5.01	0.0	3.04	1.60	0.0	430.	429.	0.	20.1	20.2	0.0
										(ALL G/MI)							|<-- (MPG)		--->|
MEAN					0.632	0.598	0.0	4.65	4.44	0.0	3.02	1.56	0.0	432.	428.	0.	20.1	20.3	0.0
STANDARD DEV.					0.023	0.024	0.0	0.54	0.36	0.0	0.05	0.05	0.0	6.	3.	0.	0.3	0.2	0.0
C.V.%					3.6	4.0	0.0	11.5	8.1	0.0	1.7	3.3	0.0	1.5	0.7	0.0	1.3	0.9	0.0
DIFF. %					3.	-1.	0.	1.	-8.	0.	-0.	-3.	0.	2.	1.	0.	-2.	-1.	0.

C.V.% IS THE COEFFICIENT OF VARIATION.(STD. DEV./MEAN *100).

DIFF. % IS THE DIFFERENCE OF THE MEANS BETWEEN THE MFR AND EPA LAB. (MFR-EPA/EPA *100).

NOTE: THE COMMENTS PERTINENT TO THESE TESTS ARE LOCATED IN THE LAST TABLE OF THIS APPENDIX.

LAB CORRELATION SUMMARY   PROCESSED: NOV 18, 1981

VOLVO PROBE HFET   VIN VOLVO REPCA   INERTIA WT 3500   ACTUAL HP 12.8

LAB	N		HC	CO	NOX	CO2	FE	BARO	HUM	NXFC	DBL	HSL	TLOSS
			|<-----G/MI			----->|	(MPG)	(IN-HG)	(GRAINS /LB)		|<---(GRAMS)		--->|
SAMPLE CFV CHOKED	5	MEAN	0.503	3.86	3.56	364.	23.9	29.09	50.35	0.90			
		STANDARD DEV.	.0084	0.066	.086	5.	0.3	0.207	3.401	.013			
		C.V.%	1.7	1.7	2.4	1.3	1.3	0.71	6.75	1.45			
SAMPLE CFV UNCHOKED	5	MEAN	0.512	3.86	3.70	371.	23.4	28.86	56.47	0.92			
		STANDARD DEV.	.0099	0.073	.208	5.	0.3	0.242	3.935	.016			
		C.V.%	1.9	1.9	5.6	1.4	1.4	0.84	6.97	1.71			
		DIFF. %	2.	-0.	4.	2.	-2.	-1.	12.	3.			

C.V.% IS THE COEFFICIENT OF VARIATION. (STD. DEV./MEAN *100).
DIFF.% IS THE DIFFERENCE OF THE MEANS BETWEEN THE MFR AND EPA LABS. (MFR-EPA/EPA *100).

LAB: EPA - Choked | VEH: VOLVO PROBE HFET | VIN: VOLVO REPCA | INERTIA WT: 3500 | ACTUAL HP: 12.8

DATE	TESTNO	TYPE	HC	CO	NOX	CO2	FE	DRIVER	DYNO	ODOM	IHP	BARO	HUM	NXFC	DBL	HSL	TLOSS
09-29-81	810893-1	HFET	0.512	3.87	3.50	364.	23.9	30898	D004	12169.0	10.8	29.25	51.10	0.90			
09-29-81	810894-1	HFET	0.491	3.79	3.48	359.	24.2	30898	D004	12180.0	10.8	29.25	50.52	0.90			
09-30-81	810897-1	HFET	0.499	3.86	3.56	359.	24.2	17282	D004	12247.5	10.8	29.11	46.78	0.88			
09-30-81	810898-1	HFET	0.509	3.82	3.70	370.	23.5	17282	D004	12275.0	10.8	29.11	47.84	0.89			
10-01-81	810901-1	HFET	0.505	3.96	3.57	366.	23.7	30898	D004	12355.8	10.8	28.74	55.51	0.92			
			|<------(G/MI)-----			->|	(MPG)					(IN-HG)	(GRAINS /LB)		|<---(GRAMS)		--->|

		HC	CO	NOX	CO2	FE	BARO	HUM	NXFC
MEAN		0.503	3.86	3.56	364.	23.9	29.09	50.35	0.90
STANDARD DEV.		.0084	0.066	.086	5.	0.3	0.207	3.401	.013
C.V.%		1.7	1.7	2.4	1.3	1.3	0.7	6.8	1.4

LAB CORRELATION SUMMARY - TEST DATA   PROCESSED: NOV 18, 1981

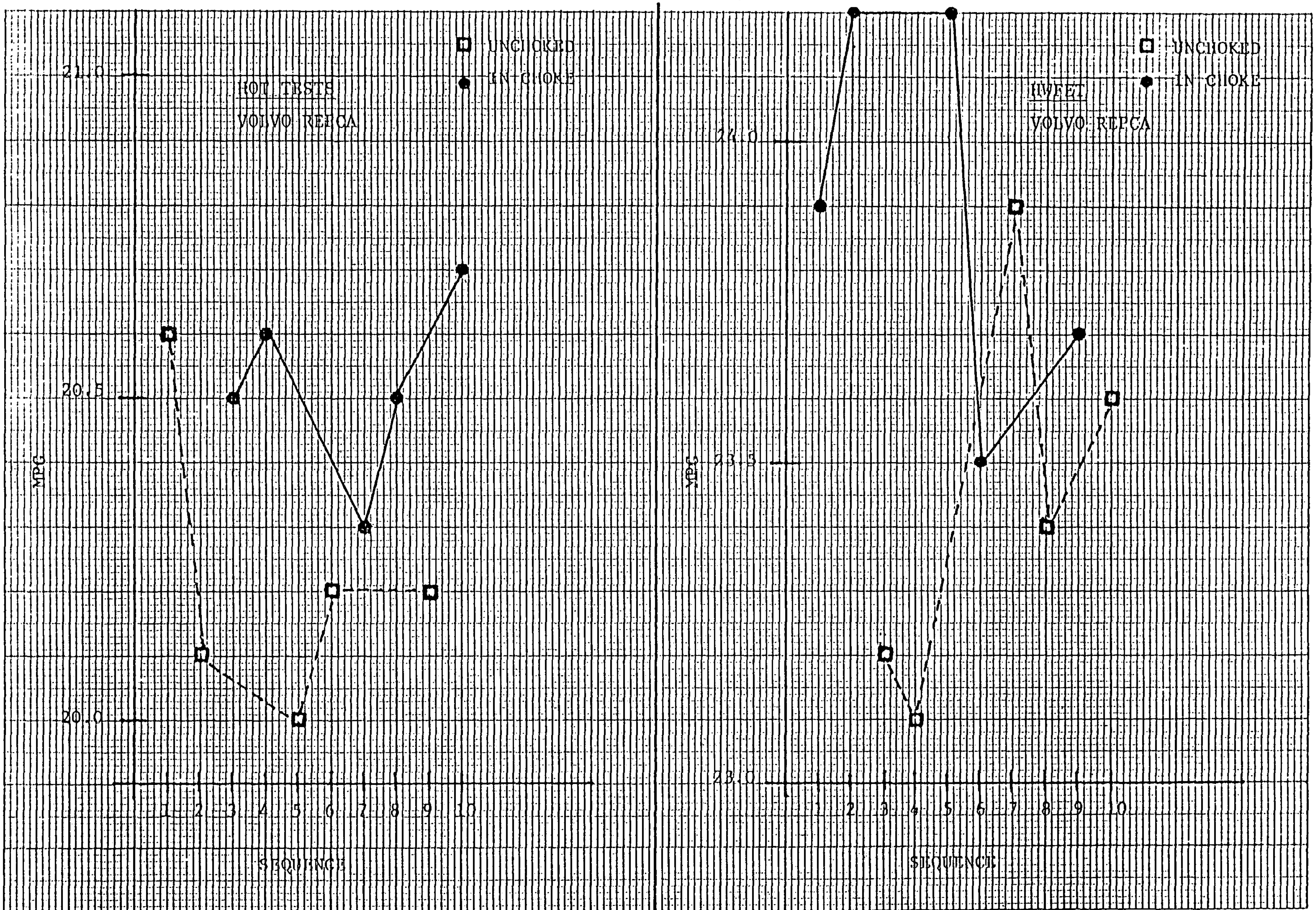
LAB: SAMPLE CFV 'UNCHOKED | VEH: VOLVO PROBE HFET | VIN: VOLVO REPCA | INERTIA WT: 3500 | ACTUAL HP: 12.8

DATE	TESTNO	TYPE	HC	CO	NOX	CO2	FE	DRIVER	DYNO	ODOM	IHP	BARO	HUM	NXFC	DBL	HSL	TLOSS
09-30-81	810895-1	HFET	0.517	3.95	3.73	374.	23.2	17282	D004	12198.5	10.8	29.12	56.05	0.92			
09-30-81	810896-1	HFET	0.517	3.92	4.01	377.	23.1	30898	D004	12223.0	10.8	29.11	53.16	0.91			
10-01-81	810899-1	HFET	0.502	3.85	3.53	363.	23.9	17282	D004	12318.0	10.8	28.63	58.32	0.93			
10-01-81	810900-1	HFET	0.522	3.78	3.75	372.	23.4	17282	D004	12327.1	10.8	28.64	62.19	0.94			
10-01-81	810902-1	HFET	0.500	3.80	3.49	369.	23.6	30898	D004	12376.0	10.8	28.78	52.64	0.90			
			|<------(G/MI)-----			->|	(MPG)					(IN-HG)	(GRAINS /LB)		|<---(GRAMS)		--->|

		HC	CO	NOX	CO2	FE	BARO	HUM	NXFC
MEAN		0.512	3.86	3.70	371.	23.4	28.86	56.47	0.92
STANDARD DEV.		.0099	0.073	.208	5.	0.3	0.242	3.935	.016
C.V.%		1.9	1.9	5.6	1.4	1.4	0.8	7.0	1.7
DIFF. %		2.	-0.	4.	2.	-2.	-1.	12.	3.

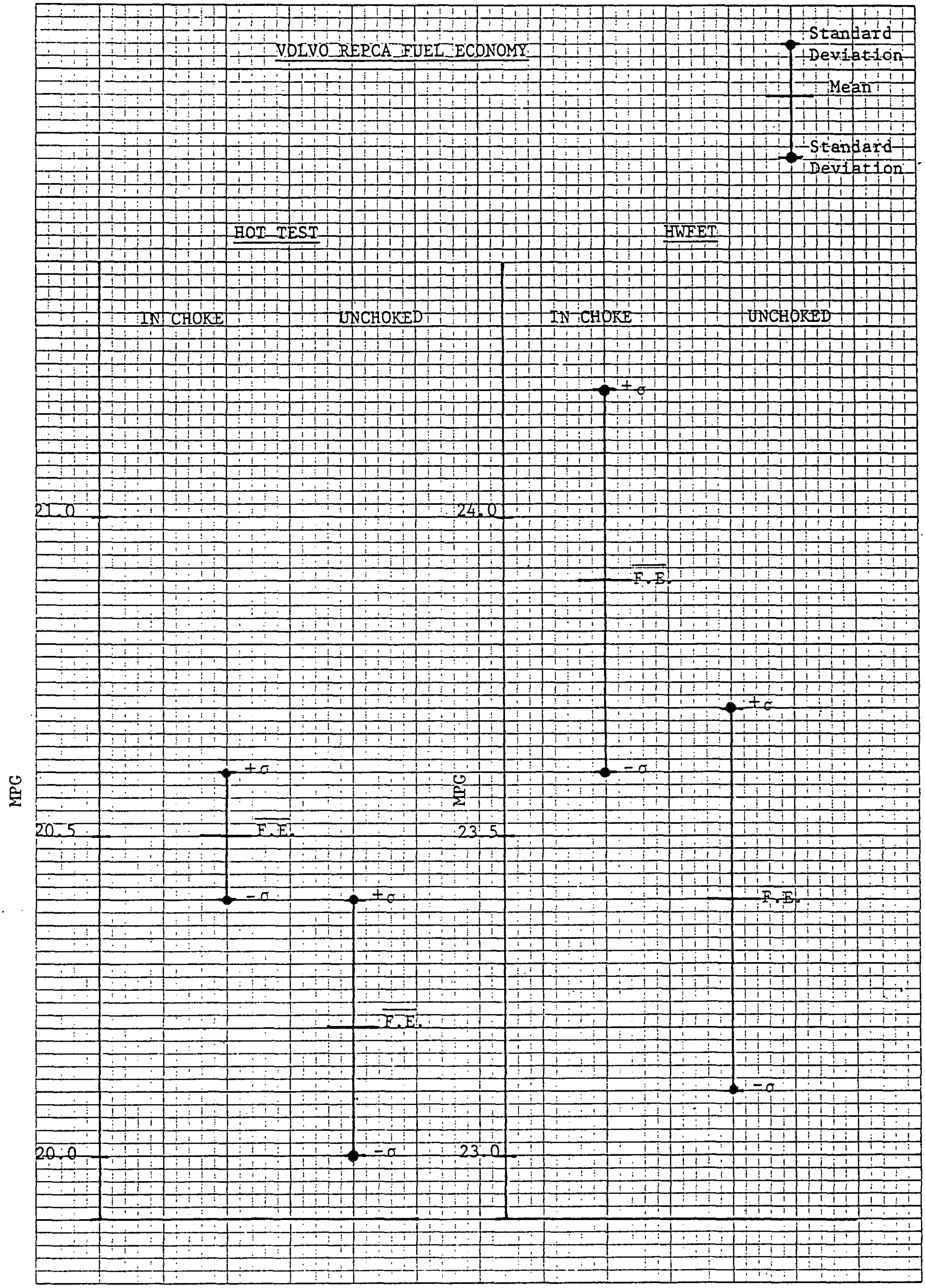
DFE 20x20 TO INCH

VOLVO REPCA FUEL ECONOMY - SEQUENTIAL TESTS



ATTACHMENT C

ATTACHMENT D



LAB CORRELATION SUMMARY - TEST DATA PROCESSED: NOV 19, 1981

3: EPA - PAIRED TESTS VEH: COUGAR HOTS VIN: 106T084 INERTIA WT: 4500 ACTUAL HP: 13.0

DATE	TESTNO	TYPE	HC	CO	NOX	CO2	FE	DRIVER	DYNO	ODOM	IHP	BARO	HUM	NXFC	DBL	HSL	TLOSS
-28-81	811327	HOT	0.162	0.61	0.99	546.	16.2	17282	D003	7195.1	10.8	29.29	48.81	0.89	●		
-28-81	811328	HOT	0.161	0.60	0.99	546.	16.2	17282	D004	7195.1	10.8	29.29	48.81	0.89	●		
-28-81	811329	HOT	0.148	0.43	0.96	544.	16.3	17282	D003	7207.0	10.8	29.29	50.46	0.90	●		
-28-81	811330	HOT	0.147	0.43	0.96	548.	16.1	17282	D004	7207.0	10.8	29.29	50.46	0.90			
-13-81	811331	HOT	0.254	1.13	1.02	542.	16.3	22118	D003	7390.1	10.8	29.39	49.93	0.89	●		
-13-81	811332	HOT	0.250	1.11	1.02	543.	16.3	22118	D004	7390.1	10.8	29.39	49.93	0.89	●		
-13-81	811333	HOT	0.234	0.80	1.09	535.	16.5	22118	D003	7400.5	10.8	29.40	47.38	0.89	●		
-13-81	811334	HOT	0.237	0.80	1.10	536.	16.5	22118	D004	7400.5	10.8	29.40	47.38	0.89			
-13-81	811335	HOT	0.214	0.91	1.05	529.	16.7	22118	D003	7414.5	10.8	29.36	46.97	0.88			
-13-81	811336	HOT	0.214	0.90	1.04	522.	16.9	22118	D004	7414.5	10.8	29.36	46.97	0.88	●		
-13-81	811388	HOT	0.209	1.01	1.02	532.	16.6	23118	D004	7425.8	10.8	29.34	41.91	0.87	●		
-13-81	811389	HOT	0.209	1.02	1.02	535.	16.5	23118	D003	7425.8	10.8	29.34	41.91	0.87			
-13-81	811591	HOT	0.199	0.65	1.06	533.	16.6	22118	D003	7432.1	10.8	29.34	42.73	0.87	●		
-13-81	811592	HOT	0.199	0.66	1.06	537.	16.5	22118	D004	7432.1	10.8	29.34	42.73	0.87			
-13-81	811593	HOT	0.211	0.54	1.05	536.	16.5	22118	D003	7437.0	10.8	29.34	43.12	0.87	●		
-13-81	811594	HOT	0.205	0.53	1.05	537.	16.5	22118	D004	7437.0	10.8	29.34	43.12	0.87			
			<------(G/MI)----->				(MPG)					(IN-HG)	(GRAINS /LB)		<---(GRAMS)--->		
MEAN			0.203	0.76	1.03	538.	16.4					29.34	46.41	0.88			
STANDARD DEV.			.0336	0.234	.041	7.	0.2					0.065	3.275	.012			
C.V.%			16.5	30.9	4.0	1.3	1.3					0.2	7.1	1.4			

D003 = Probe 2

D004 = Probe 1

● Test with probe in "choke" flow

Test Pair

ATTACHMENT E

2 BAG HOT CITY TESTS

4500 lb. 13.0 AHP

LAB CORRELATION SUMMARY - BAG DATA

31 EPA | VEH: COUGAR HOTS | VIN: 106T084 | INERTIA WT: 4500 | ACTUAL HP: 13.0

DATE	TESTNO	TYPE	DYNO	SITE	HC	2	3	CO	2	3	NOX	2	3	CO2	2	3	FE	2	3
-28-81	811327	HOT	D003	A002	0.159	0.166	0.0	1.09	0.17	0.0	1.13	0.86	0.0	522.	560.	0.	16.9	15.6	0.0
-28-81	811328	HOT	D004	A002	0.157	0.166	0.0	1.08	0.16	0.0	1.13	0.87	0.0	522.	569.	0.	16.9	15.6	0.0
-28-81	811329	HOT	D003	A002	0.126	0.169	0.0	0.80	0.09	0.0	1.08	0.86	0.0	521.	565.	0.	17.0	15.7	0.0
-28-81	811330	HOT	D004	A002	0.126	0.166	0.0	0.81	0.09	0.0	1.07	0.85	0.0	527.	567.	0.	16.8	15.6	0.0
-13-81	811331	HOT	D003	A002	0.363	0.155	0.0	2.03	0.32	0.0	1.20	0.86	0.0	535.	549.	0.	16.4	16.1	0.0
-13-81	811332	HOT	D004	A002	0.355	0.155	0.0	1.99	0.32	0.0	1.20	0.86	0.0	536.	549.	0.	16.4	16.1	0.0
-13-81	811333	HOT	D003	A002	0.319	0.156	0.0	1.41	0.23	0.0	1.29	0.91	0.0	523.	546.	0.	16.9	16.2	0.0
-13-81	811334	HOT	D004	A002	0.329	0.153	0.0	1.42	0.23	0.0	1.30	0.91	0.0	525.	546.	0.	16.8	16.2	0.0
-13-81	811335	HOT	D003	A002	0.268	0.165	0.0	1.52	0.36	0.0	1.23	0.88	0.0	516.	541.	0.	17.1	16.4	0.0
-13-81	811336	HOT	D004	A002	0.268	0.165	0.0	1.50	0.35	0.0	1.22	0.87	0.0	512.	532.	0.	17.2	16.6	0.0
-13-81	811388	HOT	D004	A002	0.254	0.167	0.0	1.55	0.51	0.0	1.18	0.87	0.0	516.	548.	0.	17.1	16.1	0.0
-13-81	811389	HOT	D003	A002	0.252	0.170	0.0	1.56	0.52	0.0	1.18	0.87	0.0	519.	551.	0.	17.0	16.1	0.0
-13-81	811591	HOT	D003	A002	0.230	0.171	0.0	1.00	0.34	0.0	1.22	0.90	0.0	509.	555.	0.	17.3	16.0	0.0
-13-81	811592	HOT	D004	A002	0.230	0.171	0.0	1.00	0.34	0.0	1.22	0.90	0.0	510.	561.	0.	17.3	15.8	0.0
-13-81	811593	HOT	D003	A002	0.257	0.169	0.0	0.93	0.19	0.0	1.21	0.91	0.0	521.	550.	0.	16.9	16.1	0.0
-13-81	811594	HOT	D004	A002	0.247	0.166	0.0	0.91	0.18	0.0	1.22	0.90	0.0	525.	547.	0.	16.8	16.2	0.0
											(ALL G/MI)						<--(MPG)--->		
MEAN					0.246	0.164	0.0	1.29	0.27	0.0	1.19	0.88	0.0	521.	553.	0.	16.9	16.0	0.0
STANDARD DEV.					0.075	0.006	0.0	0.39	0.13	0.0	0.06	0.02	0.0	8.	11.	0.	0.3	0.3	0.0
C.V.%					30.3	3.7	0.0	30.5	47.5	0.0	5.4	2.4	0.0	1.5	1.9	0.0	1.6	1.8	0.0

C.V.% IS THE COEFFICIENT OF VARIATION.(STD. DEV./MEAN *100).
DIFF. % IS THE DIFFERENCE OF THE MEANS BETWEEN THE MFR AND EPA LAB. (MFR-EPA/EPA *100).
NOTE: THE COMMENTS PERTINENT TO THESE TESTS ARE LOCATED IN THE LAST TABLE OF THIS APPENDIX.

D003 = Probe 2
D004 = Probe 1

LAB CORRELATION SUMMARY - COMMENTS

COUGAR HOTS VIN 106T084 INERTIA WT 4500 ACTUAL HP 13.0

327	PROBE 2-CVS 23 IN CHOKE	4500 LBS/13.0 ACT.
328	PROBE 1-CVS 24-IN CHOKE	4500/13.0 ACT.
329	PROBE 2-CVS 23-IN CHOKE	
330	PROBE 1-CVS 24-OUT OF CHOKE	1 14.13 2 14.10 3 14.25
331	PROBE 2-CVS 23 IN CHOKE	1 13.57 2 13.78 3 13.87
332	PROBE 1-CVS 24 IN CHOKE	1 13.57 2 13.78 3 13.87
333	PROBE 2-CVS 23-IN CHOKE	1 14.03 2 13.70 3 13.99
334	PROBE 1-CVS 24 -OUT OF CHOKE	1 14.03 2 13.70 3 13.99
335	PROBE 2-CVS 23-OUT OF CHOKE	1 13.60 2 13.91 3 14.09
336	PROBE 1-CVS 24-IN CHOKE	1 13.60 2 13.91 3 14.09
388	PROBE 1-CVS 24-IN CHOKE	
389	PROBE 2-CVS 23-OUT OF CHOKE	
591	PROBE2-CVS 23C - IN CHOKE	1ST BAG SHOOK FOR STRATIFICATION
592	PROBE 1-CVS24C- OUT OF CHOKE	1ST BAG SHOOK FOR STRATIFICATION
593	PROBE 2 CVS 23C -IN CHOKE	
594	PROBE 1 CVS 24C-OUT OF CHOKE	

LAB CORRELATION SUMMARY - TEST DATA PROCESSED: NOV 19, 1981

EPA VEH: COUGAR HFETS VIN: 106T084 INERTIA WT: 4500 ACTUAL HP: 13.0

TE	TESTNO	TYPE	HC	CO	NOX	CO2	FE	DRIVER	DYNO	ODOM	IHP	BARO	HUM	NXFC	DBL	HSL	TLOSS	SEQUENCE
)4-81	811438-1	HFET	0.079	0.09	1.54	383.	23.1	22118	D004	7283.0	10.8	29.25	49.32	0.89	●			1
)4-81	811439-1	HFET	0.078	0.08	1.53	379.	23.4	22118	D003	7283.0	10.8	29.25	49.32	0.89	●			
13-81	811444-1	HFET	0.067	0.05	1.56	373.	23.8	22118	D004	7447.0	10.8	29.34	42.73	0.87	●			4
13-81	811445-1	HFET	0.067	0.05	1.57	375.	23.6	22118	D003	7447.0	10.8	29.34	42.73	0.87	●			
16-81	811606-1	HFET	0.065	0.02	1.47	378.	23.5	34784	D004	7540.0	9.7	28.78	58.89	0.93	●			8
16-81	811607-1	HFET	0.065	0.02	1.46	377.	23.5	34784	D003	7540.0	9.7	28.78	58.89	0.93	●			
)4-81	811440-1	HFET	0.077	0.12	1.52	372.	23.8	22129	D004	7306.0	10.8	29.26	48.08	0.89	●			2
)4-81	811441-1	HFET	0.077	0.12	1.54	381.	23.2	22129	D003	7306.0	10.8	29.26	48.08	0.89				
)4-81	811442-1	HFET	0.077	0.16	1.54	371.	23.9	22118	D004	7329.0	10.8	29.25	51.62	0.90				3
)4-81	811443-1	HFET	0.077	0.15	1.54	371.	23.9	22118	D003	7329.0	10.8	29.25	51.62	0.90	●			
16-81	811446-1	HFET	0.066	0.06	1.49	380.	23.3	34784	D004	7474.0	9.7	28.78	39.47	0.86	●			5
16-81	811447-1	HFET	0.066	0.05	1.49	382.	23.2	34784	D003	7474.0	9.7	28.78	39.47	0.86				
16-81	811448-1	HFET	0.067	0.06	1.46	363.	24.4	34784	D004	7497.0	9.7	28.78	56.40	0.92	●			6
16-81	811450-1	HFET	0.067	0.06	1.47	371.	23.9	34784	D003	7497.0	9.7	28.78	56.40	0.92				
16-81	811604-1	HFET	0.067	0.07	1.47	377.	23.5	34784	D004	7519.0	9.7	28.78	55.21	0.91				7
16-8.1	811605-1	HFET	0.067	0.07	1.47	374.	23.7	34784	D003	7519.0	9.7	28.78	55.21	0.91	●			
			|<------(G/MI)------>|				(MPG)					(IN-HG)	(GRAINS /LB)		|<---(GRAMS)--->|			

	HC	CO	NOX	CO2	FE	BARO	HUM	NXFC
MEAN	0.071	0.08	1.51	375.	23.6	29.03	50.21	0.90
STANDARD DEV.	.0056	0.041	.039	5.	0.3	0.265	6.505	.024
C.V.%	7.9	53.0	2.6	1.4	1.4	0.9	13.0	2.7

D003 = Probe 2

D004 = Probe 1

HWFET TESTS

4500 lb. 13.0 AHP

● Test with probe in "choke" flow

Test Pair

LAB CORRELATION SUMMARY - COMMENTS

COUGAR HFETS	VIN 106T084	INERTIA WT 4500	ACTUAL HP 13.0

438	PROBE 1-CVS 24 .8	1 14.42 2 14.49 3 14.55	TEST WGT 4500 POUNDS ACHP 13.0 IHP 10
439	PROBE 2-CVS 23 10.8	1 14.42 2 14.49 3 14.55	TEST WGT 4500 POUNDS ACHP 13.0 IHP
444	PROBE 1-CVS 24-IN CHOKE IHP = 10.8		ACTUAL TEST WEIGHT = 4500 ACHP = 13.0
445	PROBE 2-CVS 23-IN CHOKE IHP = 10.8		ACTUAL TEST WEIGHT = 4500 ACHP =13.0
606	PROBE 1 CVS 24C IN CHOKE AVE. CVS TEMP.- 200 TO 225 F		C.D. 1 14.48 2 14.58 3 14.56
607	PROBE 2 CVS 23C IN CHOKE		C.D. 1 14.48 2 14.58 3 14.56
440	PROBE 1-CVS 24-IN CHOKE	ACTUAL WEIGHT- 4500 ACHP=13.0 IHP=10.8	1 14.55 2 14.57 3 14.61
441	PROBE 2-CVS 23-OUT OF CHOKE	ACTUAL WEIGHT-4500 ACHP=13.0 IHP=10.8	1 14.55 2 14.57 3 14.61
442	PROBE 1-CVS 24 10.8	QC 1 14.37 2 14.52 3 14.50	ACTUAL WEIGHT 4500 ACHP = 13.0 IHP =
443	PROBE 2-CVS 23 10.8	QC 1 14.37 2 14.52 3 14.50	ACTUAL WEIGHT -4500 ACHP = 13.0 IHP =
446	PROBE 1-CVS 24 IN CHOKE		C.D. 1 14.16 2 14.18 3 14.19
447	PROBE 2-CVS 23 OUT OF CHOKE		14.16 14.18 14.19
448	PROBE 1-CVS 24 IN CHOKE		C.D. 1 14.43 2 14.52 3 14.47
450	PROBE 2-CVS 23 (TREAT AS AN ODD TEST NUMBER) OUT OF CHOKE		C.D. 1 14.43 2 14.52 3 14.47
604	PROBE 1-CVS24C OUT OF CHOKE		C.D. 1 14.48 2 14.56 3 14.55
605	PROBE 2 CVS-23C IN CHOKE		C.D. 1 14.48 2 14.56 3 14.55

LAB CORRELATION SUMMARY - TEST DATA PROCESSED: DEC 1, 1981

EPA VEH: ESCORT HOTS VIN: 2G2-1.6-F-076 INERTIA WT: 2500 ACTUAL HP: 6.0

2 BAG HOT CITY TESTS
2500 lb. 6.0 AHP

TE	TESTNO	TYPE	HC	CO	NOX	CO2	FE	DRIVER	DYNO	ODOM	IHP	BARO	HUM	NXFC	DBL	HSL	TLOSS
9-81	811349	HOT	0.350	13.90	0.09	345.	24.1	34783	D003	7667.1	4.6	29.30	55.06	0.91	●		
9-81	811350	HOT	0.350	13.91	0.09	346.	24.0	34783	D004	7667.1	4.6	29.30	55.06	0.91	●		
9-81	811351	HOT	0.559	21.07	0.07	335.	24.0	34783	D003	7681.5	4.6	29.30	54.88	0.91	●		
9-81	811352	HOT	0.561	21.10	0.07	336.	23.9	34783	D004	7681.5	4.6	29.30	54.88	0.91			
9-81	811353	HOT	0.570	21.81	0.08	333.	24.0	34783	D003	7695.1	4.6	29.31	54.67	0.91			
9-81	811354	HOT	0.565	21.71	0.07	332.	24.1	34783	D004	7695.1	4.6	29.31	54.67	0.91	●		
10-81	811355	HOT	0.332	10.11	0.14	360.	23.5	22118	D003	7712.0	4.6	29.40	54.85	0.91			
10-81	811356	HOT	0.331	10.02	0.15	358.	23.7	22118	D004	7712.0	4.6	29.40	54.85	0.91	●		
10-81	811357	HOT	0.319	11.00	0.13	362.	23.3	22118	D003	7731.0	4.6	29.34	55.84	0.92			
10-81	811358	HOT	0.317	10.91	0.13	361.	23.4	22118	D004	7731.0	4.6	29.34	55.84	0.92	●		
10-81	811359	HOT	0.483	16.21	0.11	358.	23.0	22118	D003	7742.0	4.6	29.34	57.20	0.92			
10-81	811360	HOT	0.482	16.11	0.11	356.	23.2	22118	D004	7742.0	4.6	29.34	57.20	0.92	●		
			|<------(G/MI)------>|				(MPG)					(IN-HG)	(GRAINS /LB)		|<---(GRAMS)--->|		
MEAN			0.435	15.65	0.10	349.	23.7					29.33	55.42	0.92			
STANDARD DEV.			.1104	4.737	.029	12.	0.4					0.049	0.924	.004			
C.V.%			25.4	30.3	28.1	3.4	1.6					0.2	1.7	0.4			

D003 = Probe 2
D004 = Probe 1

BAG DATA

TE	TESTNO	TYPE	DYNO	SITE	HC	2	3	CO	2	3	NOX	2	3	CO2	2	3	FE	2	3
9-81	811349	HOT	D003	A002	0.512	0.201	0.0	15.84	12.11	0.0	0.11	0.06	0.0	305.	381.	0.	26.7	22.1	0.0
9-81	811350	HOT	D004	A002	0.512	0.201	0.0	15.83	12.15	0.0	0.11	0.06	0.0	305.	384.	0.	26.8	22.0	0.0
9-81	811351	HOT	D003	A002	0.624	0.499	0.0	19.65	22.39	0.0	0.10	0.04	0.0	299.	368.	0.	26.7	21.9	0.0
9-81	811352	HOT	D004	A002	0.625	0.502	0.0	19.72	22.37	0.0	0.10	0.04	0.0	301.	369.	0.	26.6	21.8	0.0
9-81	811353	HOT	D003	A002	0.531	0.606	0.0	18.20	25.15	0.0	0.11	0.05	0.0	299.	364.	0.	26.9	21.9	0.0
9-81	811354	HOT	D004	A002	0.526	0.600	0.0	18.14	25.01	0.0	0.10	0.04	0.0	297.	364.	0.	27.1	21.9	0.0
10-81	811355	HOT	D003	A002	0.560	0.121	0.0	13.35	7.12	0.0	0.15	0.13	0.0	328.	389.	0.	25.3	22.2	0.0
10-81	811356	HOT	D004	A002	0.558	0.121	0.0	13.23	7.05	0.0	0.17	0.13	0.0	328.	386.	0.	25.3	22.3	0.0
10-81	811357	HOT	D003	A002	0.502	0.151	0.0	13.27	8.92	0.0	0.16	0.11	0.0	327.	395.	0.	25.3	21.7	0.0
10-81	811358	HOT	D004	A002	0.498	0.151	0.0	13.16	8.84	0.0	0.16	0.11	0.0	328.	392.	0.	25.4	21.8	0.0
10-81	811359	HOT	D003	A002	0.748	0.240	0.0	20.12	12.64	0.0	0.16	0.06	0.0	322.	390.	0.	24.9	21.6	0.0
10-81	811360	HOT	D004	A002	0.742	0.243	0.0	19.89	12.64	0.0	0.15	0.06	0.0	320.	389.	0.	25.1	21.7	0.0
											(ALL G/MI)						|<--(MPG)--->|		
MEAN					0.578	0.303	0.0	16.70	14.70	0.0	0.13	0.07	0.0	313.	381.	.0.	26.0	21.9	0.0
STANDARD DEV.					0.089	0.190	0.0	2.91	7.00	0.0	0.03	0.04	0.0	13.	11.	0.	0.8	0.2	0.0
C.V.%					15.4	62.8	0.0	17.4	47.6	0.0	21.7	47.6	0.0	4.2	3.0	0.0	3.3	1.0	0.0

D003 = Probe 2
D004 = Probe 1

● Test with probe in "choke" flow

Test Pair

LAB CORRELATION SUMMARY - COMMENTS

ESCORT HOTS   VIN 2G2-1.6-F-076   INERTIA WT 2500   ACTUAL HP 6.0

349	PROBE 2-CVS 23-IN CHOKE	E.O.T. 5 SECS. AFTER 24C
350	PROBE 1-CVS 24- IN CHOKE	1 14.50 2 14.61 3 14.60
351	PROBE 2-CVS 23-IN CHOKE	
352	PROBE 1-CVS 24-OUT OF CHOKE	1 14.38 2 14.47 3 14.48
353	PROBE 2-CVS 23-OUT OF CHOKE	
354	PROBE 1-CVS 24-IN CHOKE	
355	PROBE 2-CVS 23-OUT OF CHOKE IND. H.P. 2/10 HIGH	
356	PROBE 1-CVS 24-IN CHOKE IND. H.P. 2/10 HIGH	1 14.28 2 14.31 3 14.45
357	PROBE 2-CVS 23-OUT OF CHOKE IND. H.P.=2/10 HIGH	
358	PROBE 1-CVS 24-IN CHOKE IND. H.P.= 2/10 HIGH	1 14.12 2 14.30 3 14.33
359	PROBE 2-CVS 23-OUT OF CHOKE H.P.=2/10 HIGH	450 SECS. OF 1ST BAG TRACE OUT OF SPECS.
360	PROBE 1-CVS 24-IN CHOKE-H.P.=2/10 HIGH 450 SECS. OF 1ST BAG-TRACE OUT OF SPECS.	1 14.31 2 14.33 3 14.33

LAB CORRELATION SUMMARY - TEST DATA PROCESSED: DEC 1, 1981

: EPA VEH: ESCORT HWFETS VIN: 262-1.6-F-076 INERTIA WT: 2500 ACTUAL HP: 6.0

ATE	TESTNO	TYPE	HC	CO	NOX	CO2	FE	DRIVER	DYNO	ODOM	IHP	BARO	HUM	NXFC	DBL	HSL	TLOSS
28-81	811363-1	HFET	0.094	4.13	0.12	237.	36.4	30898	D003	7511.0	4.6	29.30	47.95	0.89	●		
28-81	811364-1	HFET	0.095	4.11	0.12	236.	36.5	30898	D004	7511.0	4.6	29.30	47.95	0.89	●		
28-81	811365-1	HFET	0.126	4.70	0.13	239.	35.9	30898	D003	7522.9	4.6	29.28	53.70	0.91			
28-81	811366-1	HFET	0.126	4.69	0.13	237.	36.2	30898	D004	7522.9	4.6	29.28	53.70	0.91	●		
28-81	811367-1	HFET	0.082	3.80	0.15	237.	36.5	30898	D003	7555.1	4.6	29.29	53.67	0.91	●		
28-81	811368-1	HFET	0.082	3.82	0.15	237.	36.4	30898	D004	7555.1	4.6	29.29	53.67	0.91			
29-81	811369-1	HFET	0.079	2.98	0.21	239.	36.3	17282	D003	7582.2	4.6	29.35	52.20	0.90			
29-81	811370-1	HFET	0.081	2.97	0.21	238.	36.5	17282	D004	7582.2	4.6	29.35	52.20	0.90	●		
29-81	811371-1	HFET	0.071	2.76	0.21	240.	36.2	17282	D003	7610.3	4.6	29.35	57.50	0.92			
29-81	811372-1	HFET	0.075	2.72	0.21	236.	36.8	17282	D004	7610.3	4.6	29.35	57.50	0.92	●		
29-81	811386-1	HFET	0.072	2.82	0.19	238.	36.6	34783	D004	7636.5	4.6	29.34	54.60	0.91			
29-81	811387-1	HFET	0.071	2.81	0.19	236.	36.8	34783	D003	7636.5	4.6	29.34	54.60	0.91	●		
			|<------(G/MI)----->|				(MPG)					(IN-HG)	(GRAINS /LB)		|<---(GRAMS)--->|		

	HC	CO	NOX	CO2	FE	BARO	HUM	NXFC
MEAN	0.088	3.53	0.17	238.	36.4	29.32	53.27	0.91
STANDARD DEV.	.0195	0.764	.038	1.	0.3	0.058	2.999	.012
C.V.%	22.2	21.7	22.8	0.6	0.7	0.2	5.6	1.3

D003 = Probe 2
D004 = Probe 1

● Test with probe in "choke" flow

Test Pair

HWFET TESTS
2500 lb. 6.0 AHP

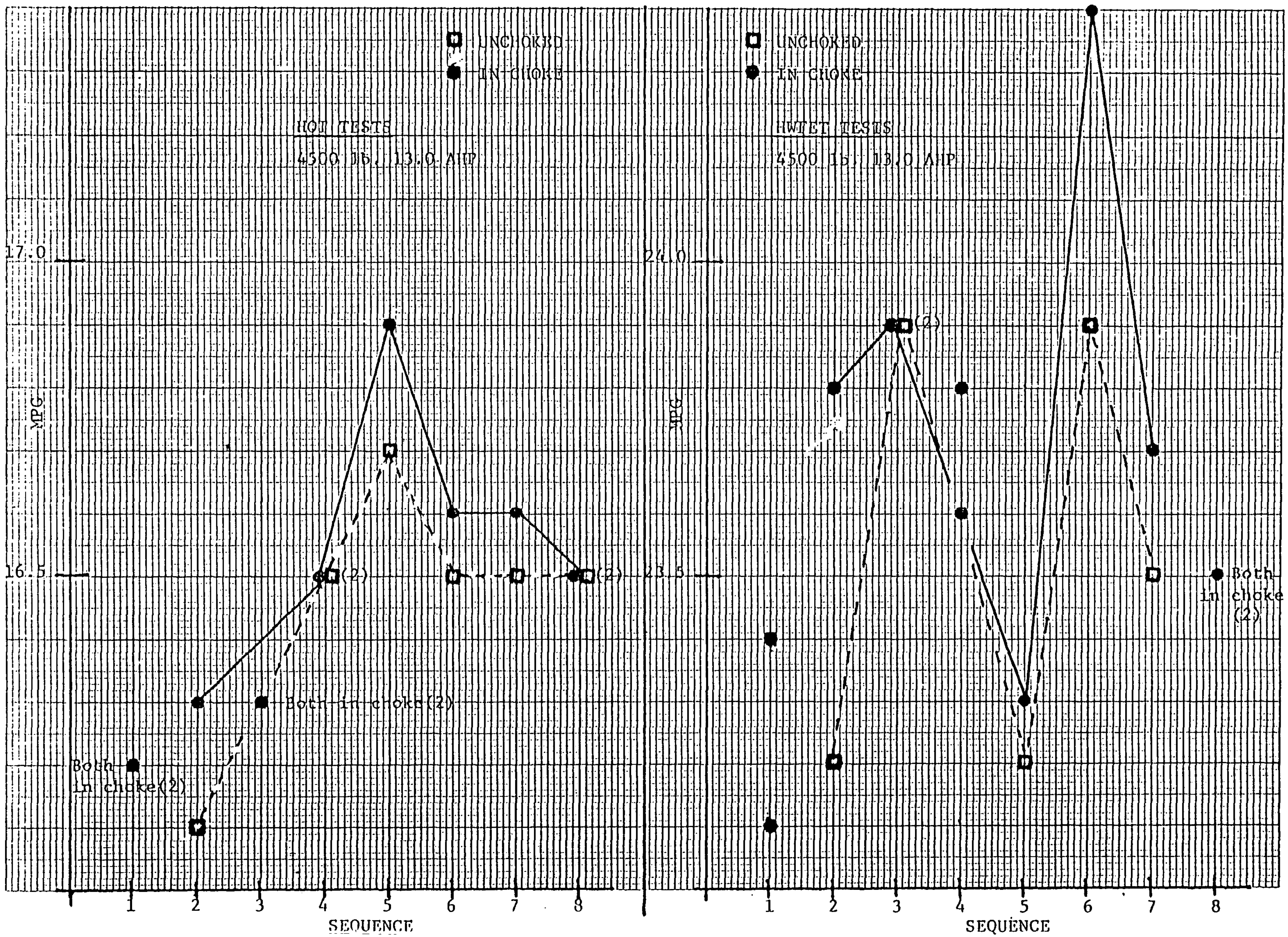
LAB CORRELATION SUMMARY - COMMENTS

ESCORT HWFETS	VIN 262-1.6-F-076	INERTIA WT 2500	ACTUAL HP 6.0

363	PROBE 2-CVS 23-IN CHOKE C.D.15.20,15.16,15.06	
364	PROBE 1-CVS 24-IN CHOKE C.D. 15.20,15.16,15.06	
365	PROBE 2-CVS 23 C.D.15.29,15.21,15.12	
366	PROBE 1-CVS 24 C.D.15.29,15.21,15.12	
367	PROBE 2-CVS 23-IN CHOKE	
368	PROBE 1-CVS 24-OUT OF CHOKE	CD 1 15.34 2 15.37 3 15.22
369	PROBE 2-CVS 23-OUT OF CHOKE	
370	PROBE 1-CVS 24-IN CHOKE	1 15.28 2 15.33 3 15.27
371	PROBE 2-CVS 23	QC'S. 1 15.30 2 15.40 3 15.36
372	PROBE 1-CVS 24	QC'S. 1 15.30 2 15.40 3 15.36
386	PROBE 1-CVS 24-OUT OF CHOKE	1 15.35 2 15.35 3 15.28
387	PROBE 2-CVS 23-IN CHOKE	QC'S. 1 15.35 2 15.35 3 15.28

KEE 20x20 TO INCH

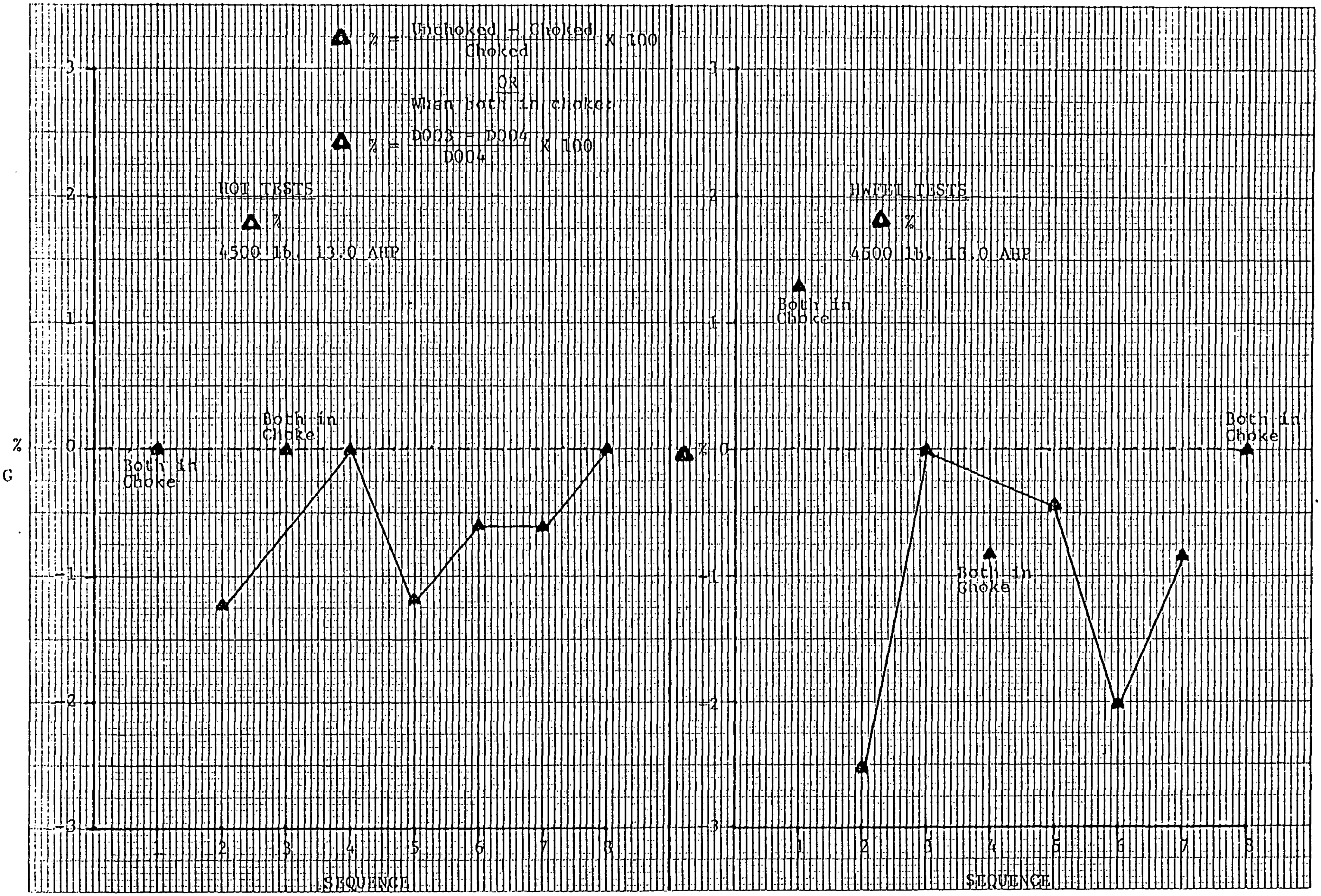
SEQUENTIAL ABSOLUTE FUEL ECONOMY - 4500 lb.



ATTACHMENT F

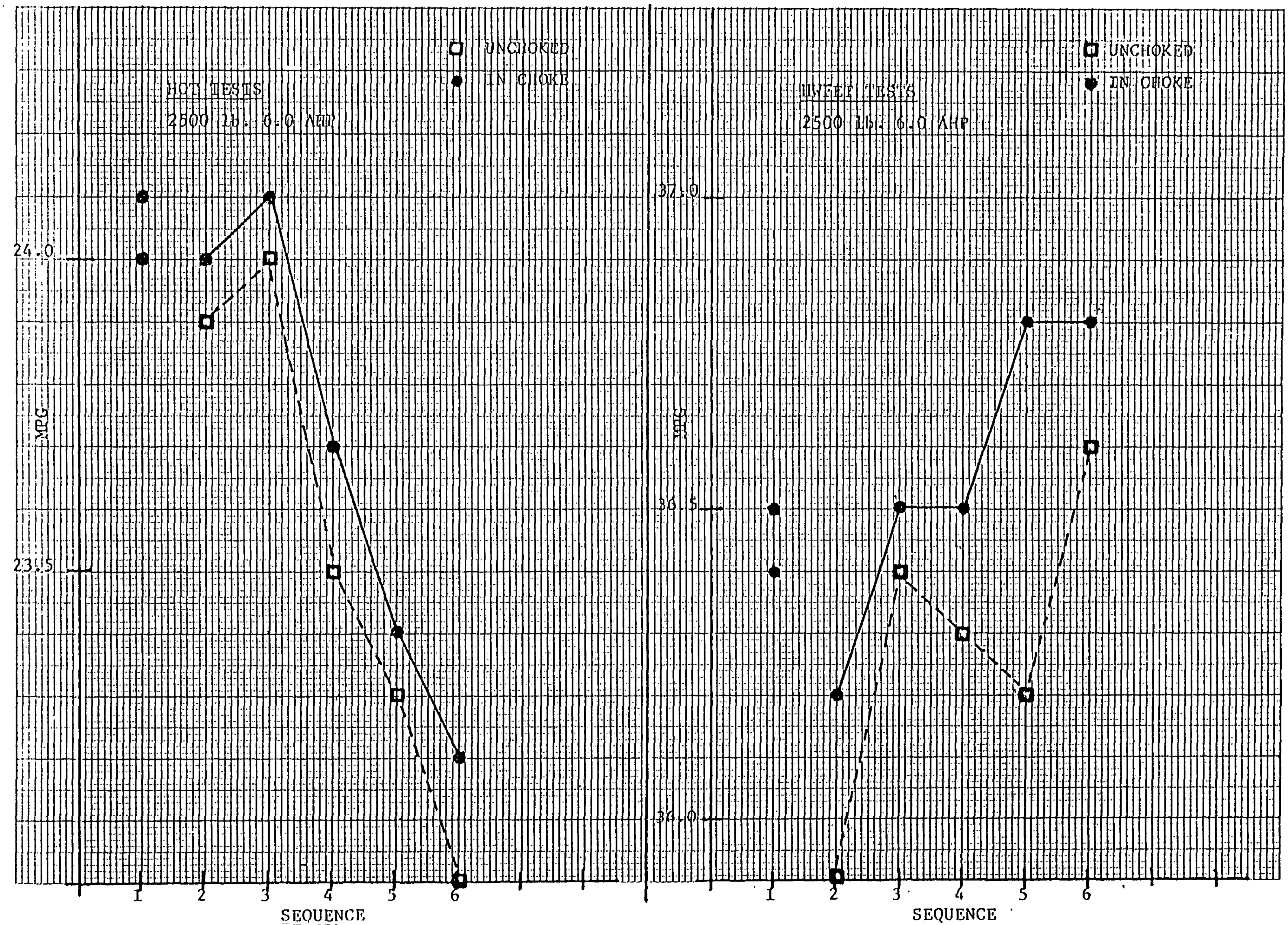
BEE 20x20 TO INCH

SEQUENTIAL PAIRED DIFFERENCES - 4500 lb.



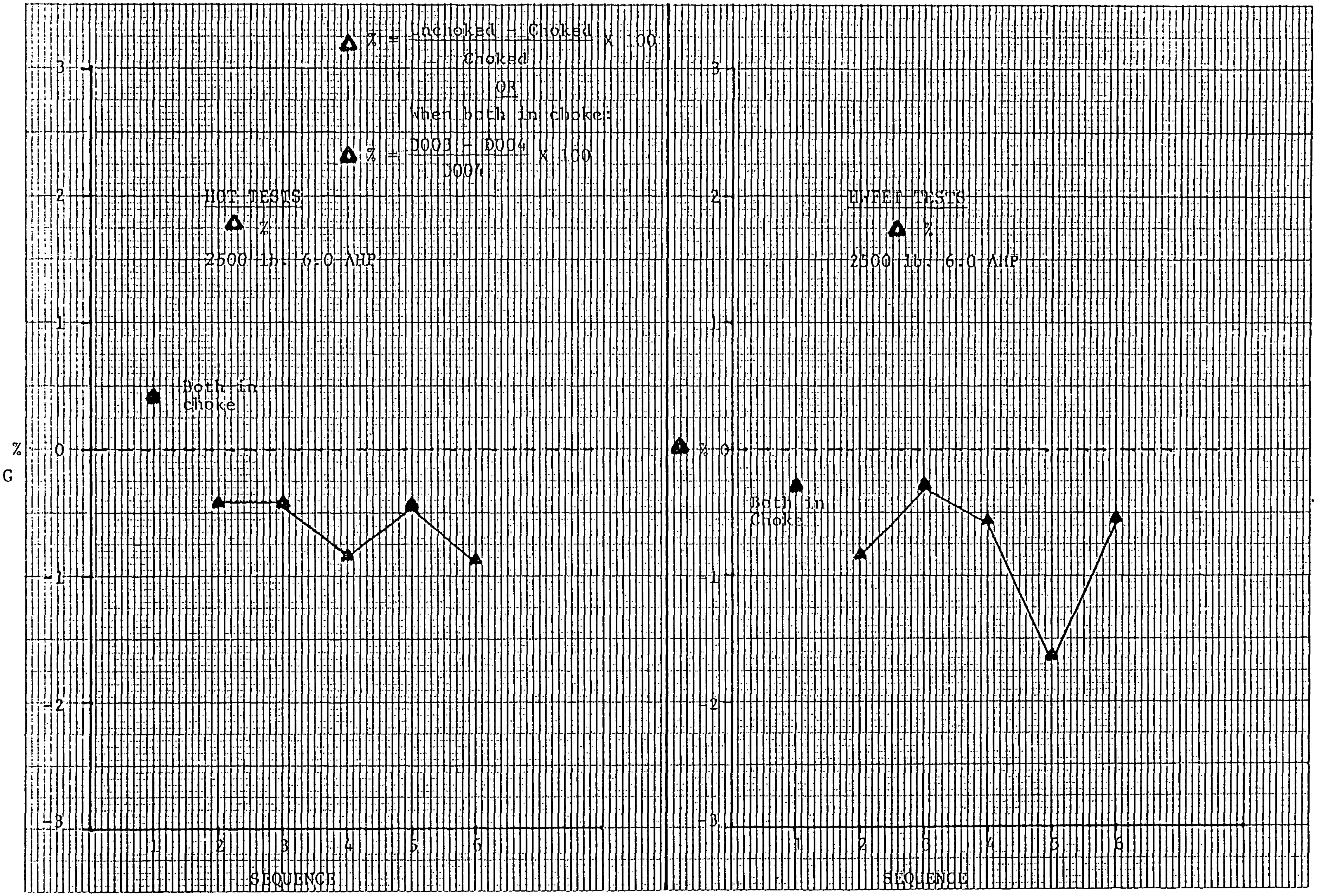
BEE 20x20 TO INCH

SEQUENTIAL ABSOLUTE FUEL ECONOMY - 2500 lb.



DEF 20x20 TO INCH

SEQUENTIAL PAIRED DIFFERENCES - 2500 lb.



CVS PROBE STUDY
Test Plan 2
Fuel Economy
.90 Confidence Intervals

(Student's t-distribution test)

VEHICLE	HOT CITY 2-BAG's	HWFET's
2500 lb, 6.0 AHP Mean MPG	23.7	36.4
Absolute ΔMPG-interval (min, max)	(-0.09, -0.19)	(-0.10, -0.46)
Δ% - interval (min, max)	(-0.36, -0.82)	(-0.26, -1.26)
% confidence that a difference may exist	99	97
4500 lb, 13.0 AHP Mean MPG	16.4	23.6
Absolute ΔMPG - int. (min, max)	(-0.03, -0.16)	(-0.07, -0.47)
Δ% - interval (min, max)	(-0.16, -1.04)	(-0.29, -2.05)
% confidence that a difference may exist	96	93

$$\Delta\% = \left(\frac{\text{MPG unchoked} - \text{MPG choked}}{\text{MPG choked}}\right) \times 100$$

$$\text{Absolute } \Delta\text{MPG} = \left(\text{MPG unchoked} - \text{MPG choked}\right)$$

ATTACHMENT G

ATTACHMENT H

Theoretical Analysis

Sonic velocity is defined as the maximum obtainable velocity of gas that can be achieved regardless of the outlet pressure depression. The term "critical" or "choked flow" means that sonic velocity exists at the minimum area or throat section of the venturi. This means that when "choked" or "critical" flow conditions are reached the venturi reaches a maximum flow in actual cubic feet per minute (ACFM). The flow in ACFM is then independent of flow variations due to venturi outlet pressure or other variations. Thus, a CFV provides a constant volumetric metering element. The basic flow equation for a CFV is derived in CVS technical note #1 and 3 by Warren F. Kaufman for Ford/Philco October 6, 1971.

Critical Flow Venturi:

$$Q=A\sqrt{\frac{kg\bar{R}T_o}{M_w}}\sqrt{\left(\frac{2}{K+1}\right)^{\frac{k+1}{k-1}}}\left[1+\left(\frac{k-1}{2}\right)M^2\right]^{\frac{1}{k-1}} \qquad (1)$$

Q = Volumetric flow rate (ft^3/sec)
A = CFV effective metering area (ft^2)
g = Gravitational constant (32.2 ft/sec^2)
$\bar{R}$ = Universal gas constant (1545 ft-lb/°R mol)
M_w = Molecular weight of gas (lb-mol)
T_o = Gas total temperature (°R)
K = Gas Specific heat ratio (dimensionless)
M = Mach No. at inlet to venturi = v/c (dimensionless)
V = Gas velocity - (ft/sec)
C = Velocity of sound $=\sqrt{Kg\bar{R}T/M_w}$ (ft/sec)
T = Gas static temperature (°R)

The flow rate equation does not contain inlet or venturi differential pressures as factors.

The bracketed term in the preceeding equation is a function of the inlet Mach number which in turn is a function of the ratio of the venturi inlet section area (A_I) to throat area (A^*):

$$\frac{A_I}{A*}=\frac{1}{M}\left[\frac{2}{k+1}\left[1+\left(\frac{k-1}{2}\right)M^2\right]\right]^{\frac{k+1}{2(k-1)}} \qquad (2)$$

M = Mach no. at inlet to venturi (dimensionless)
K = Gas specific heat ratio (dimensionless)

A typical EPA CVS main venturi inlet diameter is approximately 3.875" and the throat diameter is approximately 1.3". The ratio of specific heats (K) for air and for nitrogen (largest mol fraction in the exhaust gas) are constant and equal to 1.40 for the temperature range of interest. Equation (2) reduces to:

$$M = 0.064$$

A typical EPA CVS sample probe venturi inlet diameter is approximately 0.185" and throat diameter approximately 0.035" yields:

$$M = 0.021$$

Substitution of either of these values for M into equation (1) results in the bracketed term being essentially equal to unity. Equation (1) thus reduces to:

$$Q = A\sqrt{\frac{kg\bar{R}T_o}{M_w}}\sqrt{\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}} \qquad (3)$$

By definition g, and R are constants. For the temperature range of interest specific heat ratio (K) and molecular weight (M_w) are essentially constant. Finally, the area of each venturi remain constant.

Formula (3) then reduces to:

$$Q_{sample} = C_{sample}\sqrt{T_{sample}} \quad \text{and} \quad Q_{main} = C_{main}\sqrt{T_{main}}$$

Or actual flow in the sample probe and main venturis are proportional to the square root of the absolute temperature of the gas mixture. The ratio of the flow equations for the main and sample venturis will be:

$$\frac{Q_{sample}}{Q_{main}} = \frac{C_{sample}\sqrt{T_{sample}}}{C_{main}\sqrt{T_{main}}}$$

The sample probe is physically located at the main venturi inlet, consequently:

$$T_{sample} = T_{main}$$

$$\frac{Q_{sample}}{Q_{main}} = \text{Constant}$$

or the two venturis being in choked flow guarantees a constantly proportional sample.