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Correlation Report

1979 EPA-Volkswagen
Light Duty Diesel Correlation Study

by

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Introduction

In response to a meeting with representatives of Volkswagen on September 14, 1979, a correlation study was organized to characterize some of the factors causing hydrocarbon offsets during the 1980 diesel certification program. (Volkswagen read 40% lower hydrocarbon emissions than EPA) The hypotheses presented at this time by Volkswagen were: (1) offsets do not occur because of sample line variations from lab to lab, and (2) offsets are caused by diesel fuel composition differences between EPA's fuel and Volkswagen-Wolfsburg's fuel. These two hypotheses were tested in two separate experiments at EPA as part of the correlation study.

After completing the testing for the above two studies, Volkswagen returned the test vehicle to their Wolfsburg facility in Germany and performed an independent study with larger vehicle cooling fans. VW also began a second, but similar, vehicle in an interlaboratory round robin with the first vehicle. The purpose of the fourth study using the two vehicles was to identify test cell environment effects on vehicle warmup during testing.

In November Volkswagen brought both vehicles to the United States and requested EPA to do a series of six Hot LA-4s on each vehicle at the EPA facility. We agreed to do the test cell environment effects study if they would test the vehicles in as many non-Volkswagen laboratories as they could. They accepted. These tests were performed on Volkswagen's test fuel used in this country and performed in an identical manner at the six facilities participating in the round robin.

This report is the summary of the three different studies performed in cooperation with EPA plus the results of the independent Volkswagen cooling fan experiments. These studies included similar vehicles and facilities, but addressed different correlation cause/effect relationships.

Conclusions

Factors which can cause a hydrocarbon offset between EPA and VW's development facility in Wolfsburg have been indentified as cooling fan capacity, test cell environment's effect on vehicle and/or sample system temperature stabilization, and possibly an effect due to fuel characteristics and/or a fuel change effect.

The offsets between Volkswagen-Wolfsburg, Chrysler Proving Grounds, and EPA-Ann Arbor on a large number of LA-4s on two Rabbit diesels is below 6%. VW-Toledo and VW-Westmoreland are 25% below EPA and FIAT is 50% lower.

Recommendations

It is unfortunate that a better real world simulation of air movement over the test vehicle is not readily adaptable to present certification testing, but the use of a standardized single speed fan would facilitate more comparable results between test facilities. It is also desirable that test personnel have adequate direction to duplicate the fan to vehicle placement that is desired by the manufacturer, within the constraints of the Federal Register.

The soak control vs. oil temperature controlled vehicle tests indicate cell environment does effect the vehicle and/or sampling system thermal state before startup.

Since test cells are not easily redesigned to reflect one another one must therefore perform hot temperature stabilized LA-4s vs. hot soak controlled LA-4s to quantify offsets due to the cell environment.

The fuel controversy is best resolved by a standard test fuel that can be bought by all manufacturers from a single lot.

Vehicles and Test Plans

The chronology of events, test plans, test fuels, and locations are summarized below:

Location	Test Site	Vehicle	Fuel	n/Vehicle	Fan	Sample Line Temp. °F
VW-Toledo	1	1	AMOCO-50	6	5000 SCFM	375
VW-Westmoreland	2	1	AMOCO-50	6	5000 SCFM	375
EPA-Ann Arbor	6	1	AMOCO-50	6	5000 SCFM	375
EPA-Ann Arbor	6	1	AMOCO-50	6	5000 SCFM	322
VW-Toledo	1	1	AMOCO-50	6	5000 SCFM	375
EPA-Ann Arbor	6	1	AMOCO-50	6	5000 SCFM	375
EPA-Ann Arbor	6	1	Wolfsburg	6	5000 SCFM	375
EPA-Ann Arbor	6	1	EPA	6	5000 SCFM	375
EPA-Ann Arbor	6	1	AMOCO-50	6	5000 SCFM	375
VW-Toledo	1	1	AMOCO-50	6	5000 SCFM	375
Vehicle was shipped to Wolfsburg, Germany.						
VW-Wolfsburg	6	1	AMOCO-50	11	5000 SCFM	375
VW-Wolfsburg	6	1	AMOCO-50	18	5000 SCFM	375
VW-Wolfsburg	Inspection 4,6,8	1	AMOCO-50	40	5000 SCFM	375
VW-Wolfsburg	Inspection 4,6,8	2	AMOCO-50	34	5000 SCFM	375
VW-Wolfsburg	6	2	AMOCO-50	6	5000 SCFM	375
VW-Wolfsburg	6	2	AMOCO-50	6	5000 SCFM	375
Vehicles were shipped to the United States.						
VW-Westmoreland	2	1&2	AMOCO-50	6	5000 SCFM	375
VW-Toledo	1	1	AMOCO-50	6	5000 SCFM	375
VW-Toledo	1	1&2	AMOCO-50	6	5000 SCFM	375
FIAT-Dearborn	1	1&2	AMOCO-50	6	5000 SCFM	375
Chrysler	5	1&2	AMOCO-50	6	5000 SCFM	375
EPA-Ann Arbor	6	1&2	AMOCO-50	6	5000 SCFM	375

All test sequences were 6 Hot LA-4s or 1 FTP and 5 Hot LA-4s to maximize the amount of data that could be collected in the allotted test time and equipment availability. The specifics on vehicle preps and mileage accumulation for the three studies are outlined in Tables 1, 3, and 5 in the appendix.

Vehicle #1 was a 1978 production VW diesel Rabbit and is referred to as the soak controlled vehicle in the test cell environment study. Vehicle #2 was another

1978 production VW diesel Rabbit but with temperature monitoring of engine oil, engine intake air, and fuel in the fuel tank . This #2 vehicle was the temperature controlled vehicle which, after the 10 minute soak, was driven at 30 mph until the engine oil temperature was 200°F. The vehicle then returned to idle and the hot LA-4 began.

Discussion of Results

Test results are presented in the appendix for each specific vehicle/test procedure combinations.

Volkswagen's claim of hydrocarbon measurement insensitivity to sample line temperature on the Rabbit diesel was validated at EPA. It is interesting to note that most diesel vehicles including the VW powered Volvo and VW built Audi 5000 are sensitive to sample system temperature in the continuous diesel hydrocarbon system. This has been verified by EPA-Ann Arbor, VW-Wolfsburg, and Volvo-Goteborg. Figure 1 in the appendix demonstrates it is characteristic for diesel hydrocarbon measurements to be sensitive to temperatures, but this sensitivity was not observed for the VW Rabbit that was tested at EPA.

Volkswagen's hypothesis that different fuels cause offsets on hydrocarbon emissions was not proved or disproved in our test procedure. Statistically there are emission offsets for both HC and CO_2 between EPA's diesel #2 and Wolfsburg fuel, AMOCO-50 and Wolfsburg fuel, but not between AMOCO-50 and EPA's diesel #2. When viewing data chronologically, however, the total variability of the vehicle ranged from .55gram/mile to a low of .34 gram/mile on the baseline fuel. This contained the sample means of the other test fuels. Experience with Volvo certification vehicles using Volkswagen technology indicates that something during a fuel switch may cause a large hydrocarbon offset that becomes smaller as the vehicle accummulates mileage. This report therefore does not resolve the fuel switch controversy. (See Fig. 2, 3, 4 for chronological test data.)

The analysis of the fuels used in the study are shown in the appendix. The differences in Volkswagen's and EPA's analysis were dramatic. Using EPA's analysis, the AMOCO-50 was within Federal Register specifications, except for the initial boiling point and 10% point in the distillation. The Wolfsburg fuel was out of specification for aromatics, API Gravity, viscosity, flash point, initial boiling point, 10%, and 50% in the distillation.

Hypothesis testing (T-stat) accepted the hypothesis that the cold start hydrocarbon data mean was equivalent to the hot start data, on all three fuels overall during the fuel switch test procedure.

The result of the two vehicle test procedures, soak time vs. soak time plus oil temperature stabilization, did indicate the degree of offset between EPA and the other labs due to cell environment differences. The vehicle that was temperature stabilized had approximately the same test to test variability as the soak time stabilized vehicle, but had a lower lab to lab offset for hydrocarbon emissions, indicating ambient cooling conditions during phase 1 and the 10 minute soak causes some of the offset found between manufacturers and EPA.

Variability over time can be seen in Figure 4, 5, 6, and 7 for both test vehicles. The soak controlled test vehicle displays more variability in hydrocarbon emissions, even site to site within Volkswagen-Wolfsburg, than the temperature controlled vehicle. Whether the temperature of importance is vehicle intake air, engine oil or sample exhaust system through to the continuous hydrocarbon sample point was not determined by this study.

Volkswagen performed tests on both vehicles using a different capacity cooling fan, both in Germany and Toledo on vehicle #1 and in Germany only for vehicle #2 using the vehicle handling procedure outlined in Table 5. The larger cooling fans caused an approximate 20% increase in HC. The small capacity fans were the original cooling fans used in Wolfsburg for Volkswagens certification work. At that time Volkswagen was 40% lower than EPA in diesel hydrocarbon results in the FTP. The critical temperature in this study, as measured by vehicle #2 temperature recorder, was engine intake air. The cooler the intake air the higher the hydrocarbon emissions. (See Figure 8 and 9).

The tests conducted by Fiat in Dearborn and Volkswagen Toledo indicated the importance of cooling fan location. LA-4s 1 to 3 in the Fiat tests had a different fan location than Run's 4 to 6 (see Figure 10) on the temperature controlled vehicle. The lower temperature traces for Run's 4 to 6 resulted in slightly higher HC results. Toledo tests for the same vehicle was an attempt to better simulate air intake temperature traces generated at EPA. The result of the experiment did bringToledo's HC emissions closer to the level of hydrocarbon emissions measured at EPA on the same vehicle over the same test procedure. (Figure 11 and 12)

APPENDIX

Figure 11 VW-Mobile Lab Toledo, Fan Location #1 for Six LA-4s.

Figure 12 VW-Mobile Lab Toledo, Fan Location #2 for Six LA-4s.

Calculations

Table 1 Vehicle Test Plan for Volkswagen
HFID Sample System Temperature Study

Vehicle #1 Fuel Used: AMOCO 50 EPA Tests

Procedure	Sample System Temp in °F
LA-4 prep, no fuel drain, 12 hr. soak	--
FTP + 10 min. soak	375°F
LA-4 + 10 min. soak	375°F
LA-4 + 10 min. soak	322°F
LA-4 + 10 min. soak	322°F
LA-4 + 10 min. soak	322°F
LA-4 + 10 min. soak	375°F
LA-4 prep, no fuel drain, 12 hr. soak	--
FTP + 10 min. soak	375°F
LA-4 + 10 min. soak	375°F
LA-4 + 10 min. soak	322°F
LA-4 + 10 min. soak	322°F
LA-4 + 10 min. soak	322°F
LA-4 + 10 min. soak	375°F

Table 2 HFID Sample System Temperature Study
Gaseous Emissions from VW Rabbit #1 for Hot Start LA-4s

Facility	Statistic	HC g/mile	CO g/mile	NO_x g/mile	CO_2 g/mile	Fuel	Sample Filter Temp.
EPA-	$\bar{x}$	.50	.98	.96	232.4	AMOCO-50	375°F
Ann Arbor	s	.02	.02	.02	1.3		
n=5	%C.V.	4	2	2	1		
EPA-	$\bar{x}$	.49	.98	.94	231.	AMOCO-50	322°F
Ann Arbor	s	.04	.05	.02	1.4		
n=4	%C.V.	8	5	2	1		

Table 3 Vehicle Test Plan for Volkswagen Fuel Effects Study: EPA Tests

Vehicle #1 Sample Line 375°F

Procedure	Fuel
LA-4 prep	AMOCO 50
FTP, 5 Hot LA-4s, 10-12 min. soaks between tests	AMOCO 50
Fuel drained and filled to 50%	Wolfsburg fuel
40 road miles and LA-4 prep, 12 hr. soak	Wolfsburg fuel
FTP, 5 Hot LA-4s, 10-12 min. between tests	Wolfsburg fuel
Fuel drained and filled 50%	EPA's diesel #2
40 road miles and LA-4 prep, 12 hr. soak	EPA's diesel #2
FTP, 5 Hot LA-4s, 10-12 min. between tests	EPA's diesel #2
Fuel drained and filled 50%	AMOCO 50
40 road miles and LA-4 prep, 12 hr. soak	AMOCO 50
FTP, 5 not LA-4's, 10-12 min. between tests	AMOCO 50

Table 4 Hot LA-4 Emission Results for Volkswagen Fuel Effects Study: Three Fuels, Vehicle #1, Sample Line at 375°F, EPA Tests

Facility	Test Date	Statistic	HC g/mile	CO g/mile	NO_x g/mile	CO_2 g/mile	Fuel
EPA	Sept. 25,	$\overline{x}$	.40	.95	.96	234.0	
Ann Arbor	1979	s	.01	.01	.01	1.5	AMOCO-50
n=4		%C.V.	2.5	1	1	1	
FTP	(n=1)		.43	1.0	.98	239	
EPA	Sept. 27,	$\overline{x}$	.36	.94	.94	221.0	Wolfsburg
Ann Arbor	1979	s	.04	.06	.02	1.6	
n=5		%C.V.	11	6	2	2	
FTP	(n=1)		.32	.90	.94	224	
EPA	Sept. 29,	$\overline{x}$	.45	.93	.91	224.6	EPA's
Ann Arbor	1979	s	.02	.05	.03	2.2	#2 diesel
n=6		%C.V.	4	5	3	1.0	
FTP	(n=1)		.44	.90	.93	229	
EPA	Sept. 28,	$\overline{x}$	.43	.94	.93	226.0	AMOCO-50
Ann Arbor	1979	s	.05	.05	.02	2.2	
n=6		%C.V.	12	5	2	1	
FTP	(n=1)		.41	1.0	.96	235	
EPA*	Sept	$\overline{x}$	.41	.94	.93	226.1	AMOCO
Ann Arbor	1979	s	.05	.03	.03	5.2	Wolfsburg
n=21		%C.V.	12	3	3	2	EPA's #2 diesel
FTP	(n=4)		.40	.952	.95	231.75	

*The mean and standard deviation of all tests in the fuel effect study at EPA on Vehicle #1

Table 5 Vehicle Test Plan for Volkswagen
Test Cell Effects Study at Six Facilities

Fuel used: Toledo AMOCO Sample lines at 375°F

Testing Sequence	Vehicle #2	Vehicle #1
1	LA-4 prep	LA-4 prep
2	12-hour soak	12-hour soak
3	FTP	FTP
4	10-min. soak+	10-min. soak
5	30mph until oil temp=100 C stop vehicle	
6	Hot LA-4	Hot LA-4
7	Repeat sequence 4 thru 6 until 5 Hot LA-4's are completed	Repeat sequence 4 thru 6 until 5 Hot LA-4's are completed
8*	(3) 55 to 45mph coast downs	(3) 55 to 45mph coast downs

*At EPA and VW-Westmoreland only.

Table 6 Vehicle Coast Down Times (In Seconds)

Facility	Date	Vehicle #1 55-5mph	55-45mph	Date	Vehicle #2 55-5mph	55-45mph
VW-Westmoreland	9/79	96	11.6	12/79	91	12.1
VW-Toledo	9/79	82	10.2	--	--	--
EPA-Ann Arbor	9/79	95	11.3	12/79	--	11.1
EPA-Ann Arbor	1/80	--	11.2	--	--	--

Table 7 Gaseous Emissions from Vehicle #2 Temperature Controlled Vehicle At Six Facilities for Volkswagen Test Cell Effects Study

Facility	Test Date	Statistic	HC g/mile	CO g/mile	NO_x g/mile	CO_2 g/mile	Fuel
VW-Wolfsburg Cells 4,6, 8,Inspection n=34	Nov 1979	$\bar{x}$ s %C.V.	.30 .045 15	.85 .085 10	.90 .08 8	244.8 7.3 3	Toledo AMOCO
VW-Westmoreland n=14	Dec 1979	$\bar{x}$ s %C.V.	.27 .03 11	.85 .05 6	.93 .04 4	239.5 3.5 1	Toledo AMOCO
VW-Toledo n=18	Nov-Dec 1979	$\bar{x}$ s %C.V.	.30 .04 13	.98 .07 7	.92 .025 3	247.8 3.3 1	Toledo AMOCO
FIAT Ann Arbor n=6	Dec 1979	$\bar{x}$ s %C.V.	.23 .02 9	.87 .03 3	1.03 .09 9	255.6 9.8 4	Toledo AMOCO
Chrysler n=6	Dec 1979	$\bar{x}$ s %C.V.	.30 .03 10	.94 .04 4	1.04 .035 3	247.4 2.15 1	Toledo AMOCO
EPA Ann Arbor n=6	Dec 1979	$\bar{x}$ s %C.V.	.30 .02 7	.801 .036 4	.996 .012 1	237.4 3.3 1	Toledo AMOCO

Table 8 Gaseous Emissions from Vehicle #1 Soak Controlled Vehicle At Six Facilities for Volkswagen Test Cell Effects Study

Facility	Test Date	Statistic	HC g/mile	CO g/mile	NO_x g/mile	CO_2 g/mile	Fuel
VW- Wolfsburg Cells 4,6, 8,Inspection n=30	Nov 1979	$\bar{x}$ s %C.V.	.40 .08 20	.99 .16 16	.92 .08 9	247.1 19.8 8	Toledo AMOCO
VW- Westmoreland PA n=6	Nov-Dec 1979	$\bar{x}$ s %C.V.	.30 .018 6	.96 .035 4	.97 .05 5	239.7 2.5 1	Toledo AMOCO
VW- Toledo n=6 FTP	Nov-Dec 1979 (n=1)	$\bar{x}$ s %C.V.	.30 .005 2 6 .35	.93 .067 7 1.0	.91 .03 3 1.09	242.2 5.26 2 246	Toledo AMOCO
FIAT n=6	Dec 1979	$\bar{x}$ s %C.V.	.20 .02 10	.87 .03 3	1.00 .03 3	247.8 3.1 1	Toledo AMOCO
Chrysler n=6	Dec 1979	$\bar{x}$ s %C.V.	.41 .015 4	1.01 .025 2	.966 .015 2	234.0 1.7 7	Toledo AMOCO
EPA Ann Arbor n=6 FTP	Jan 1979 (n=1)	$\bar{x}$ s %C.V.	.39 .04 10 .35	.96 .03 3 1.0	1.06 .02 2 1.09	232.9 3.4 1 246	Toledo AMOCO

Table 9 Offset[1] on Two Volkswagen Rabbits at Five Facilities for Hot Start LA-4's: Fuel AMOCO-50 Sample Lines at 375°F

Offsets on Vehicle #1 6 tests at EPA	VW-Wolfsburg n=30	VW-Toledo n=21	VW-Westmoreland n=6	Fiat n=6	Chrysler n=6
HC	2.6%	-23%	-23%	-48.7%	5.1%
CO	3.1%	-3.1%	0%	- 9.4%	5.2%
NO_x	-13.2%	14.2%	-8.4%	5.6%	-8.9%
CO_2	6.1%	4.0%	2.9%	6.4%	4.7%
Offsets on Vehicle #2 6 Tests at EPA	n=34	n=18	n=14	n=6	n=6
HC	0.0%	0.0%	-10.0%	-23.0%	0.0%
CO	6.1%	22.3%	6.1%	8.6%	17.4%
NO_x	-9.6%	-7.6%	- 6.6%	3.4%	4.4%
CO_2	3.1%	4.4%	0.9%	7.7%	4.2%

[1] $\% \text{ offset} = \frac{(\text{Facility} - \text{EPA})}{\text{EPA}} * 100$

Table 10 Cooling Fan Capacity Study on VW Rabbits #1 and #2: Fuel AMOCO-50, Sample Lines at 375°F

Facility	Test Date	Statistic	HC g/mile	CO g/mile	NO_x g/mile	CO_2 g/mile	Fan Capacity
Vehicle #1							
VW-Wolfsburg Cell #6 n=11	10-79	$\bar{x}$ s %C.V.	.42 .055 13	1.03 .115 11	.88 .033 4	239.0 8.84 4	approx. 5000cfm
VW-Wolfsburg Cell #6 n=18	10-79	$\bar{x}$ s %C.V.	.33 .04 12	.92 .04 4	.89 .04 4	237.3 5.9 2	Less than 5000cfm
VW-Toledo n=6	12-79	$\bar{x}$ s %C.V.	.30 .005 2	.93 .067 7	.91 .028 3	242.2 5.3 2	high capacity
VW-Toledo n=6	12-79	$\bar{x}$ s %C.V.	.25 .023 9	.93 .09 10	.97 .02 2	241.5 3.6 1	low capacity tan
Vehicle #2							
VW-Wolfsburg Cell #6 n=6	8-79 9-79	$\bar{x}$ s %C.V.	.24 .015 6	.82 .01 1	.83 .012 1	243 3.2 1	Less than 5000cfm
VW-Wolfsburg Cell #6 n=6	10-16 11-8	$\bar{x}$ s %C.V.	.30 .015 5	.82 .02 2	.90 .037 5	241.9 3.7 2	approx. 5000cfm

Table 11 Analysis of Diesel Test Fuels

	AMOCO 50 VW's Analysis	AMOCO 50 EPA's Analysis[1]	Wolfsburg diesel #1 VW's Analysis	Wolfsburg diesel #1 EPA's Analysis	EPA's diesel #2	Federal Register Specification
Cetane Number	49.2	43.3	54.5	48.2	44.0	42-50
Aromatics		29.0%		20.0%	35.6	27% min.
Olefins		.5%		.5%		
Saturates		70.5%		79.5%		
API Grav.	36.5	35.4	42.34	41.2	34.4	33-37
Vis at 40 C	2.0cst	2.21cst	1.7cst	1.87cst	2.61cst	2.0-3.2cst
Flash Point	153°F	131°F	137°F	118°F	138°F	130°F min.
Sulfur		.271wt%		.276wt%	.38wt%	0.2-0.5
Distillation Data in °F						
IBP	341	276	318	249	360	340-400
5%		379		345		
10%	402	396	368	370	420	400-460
20%		425		391		
30%		446		408		
40%		467		430		
50%	495	486	455	452	510	470-540
60%		506		475		
70%		526		501		
80%		548		530		
90%	601	580	582	573	596	550-610
95%		610		607		
EP	615	626	623	627	627	580-660
Recovery		98.3		98.1		
Residue		1.7		1.9		
Total Recovery		100.0		100.0		
Loss		0.0		0.0		
C/H Ratio					6.80	

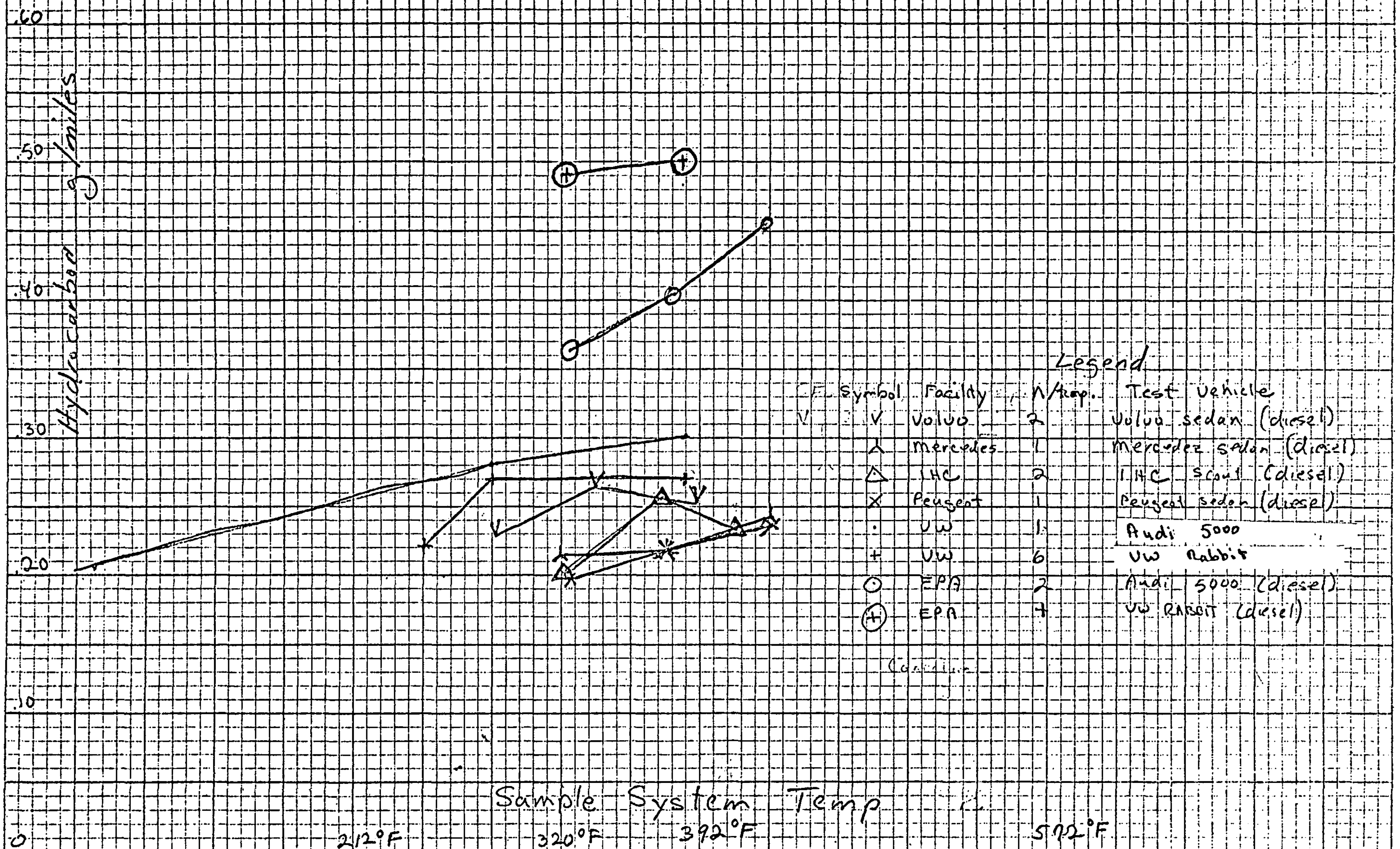
[1]The average of two samples drawn from the same fuel batch.

Table 11 Analysis of Diesel Test Fuels

	AMOCO 50 VW's Analysis	AMOCO 50 EPA's Analysis[1]	Wolfsburg diesel #1 VW's Analysis	Wolfsburg diesel #1 EPA's Analysis	EPA's diesel #2	Federal Register Specifications
Cetane Number		43.3		48.2	44.0	42-50
Cetane Index	48.5	45.6	50.0	50.0	47.4	
Aromatics		29.0%		20.0%	35.6	27% min.
Olefins		.5%		.5%		
Saturates		70.5%		79.5%		
API Grav.	36.5	35.4	42.34	41.2	34.4	33-37
Vis at 40 C	2.0cst	2.21cst	1.7cst	1.87cst	2.61cst	2.0-3.2cst
Flash Point	153°F	131°F	137°F	118°F	138°F	130°F min
Sulfur		.271wt%		.276wt%	.38wt%	0.2-0.5
Distillation Data in °F						
IBP	341	276	318	249	360	340-400
5%		379		345		
10%	402	396	368	370	420	400-460
20%		425		391		
30%		446		408		
40%		467		430		
50%	495	486	455	452	510	470-540
60%		506		475		
70%		526		501		
80%		548		530		
90%	601	580	582	573	596	550-610
95%		610		607		
EP	615	626	623	627	627	580-660
Recovery		98.3		98.1		
Residue		1.7		1.9		
Total Recovery		100.0		100.0		
Loss		0.0		0.0		
C/H Ratio					6.80	

[1]The average of two samples drawn from the same fuel batch.

Fig 1 Hydrocarbon Response vs Sample System Temp for Vehicles Driving Hot Start LA-4s



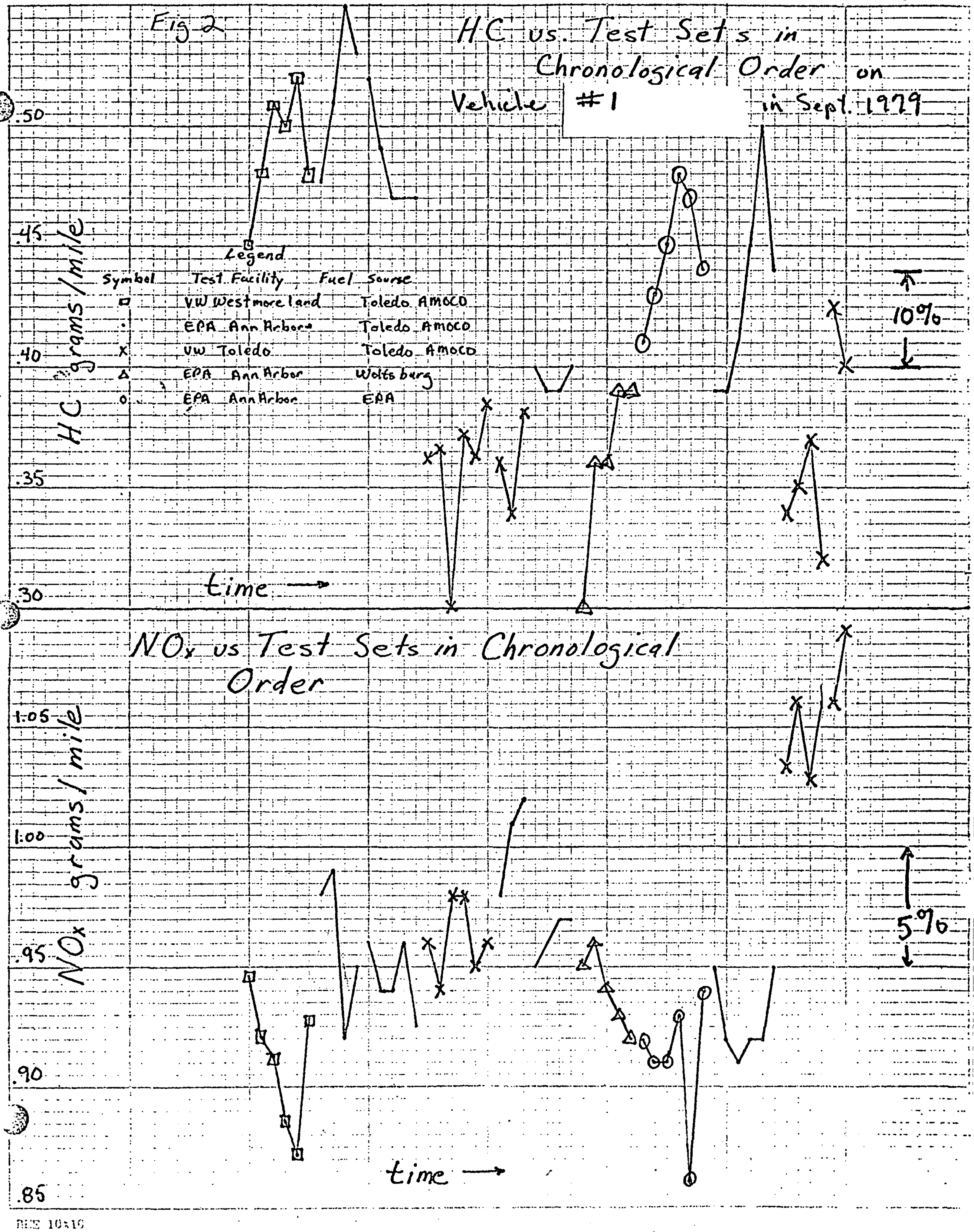
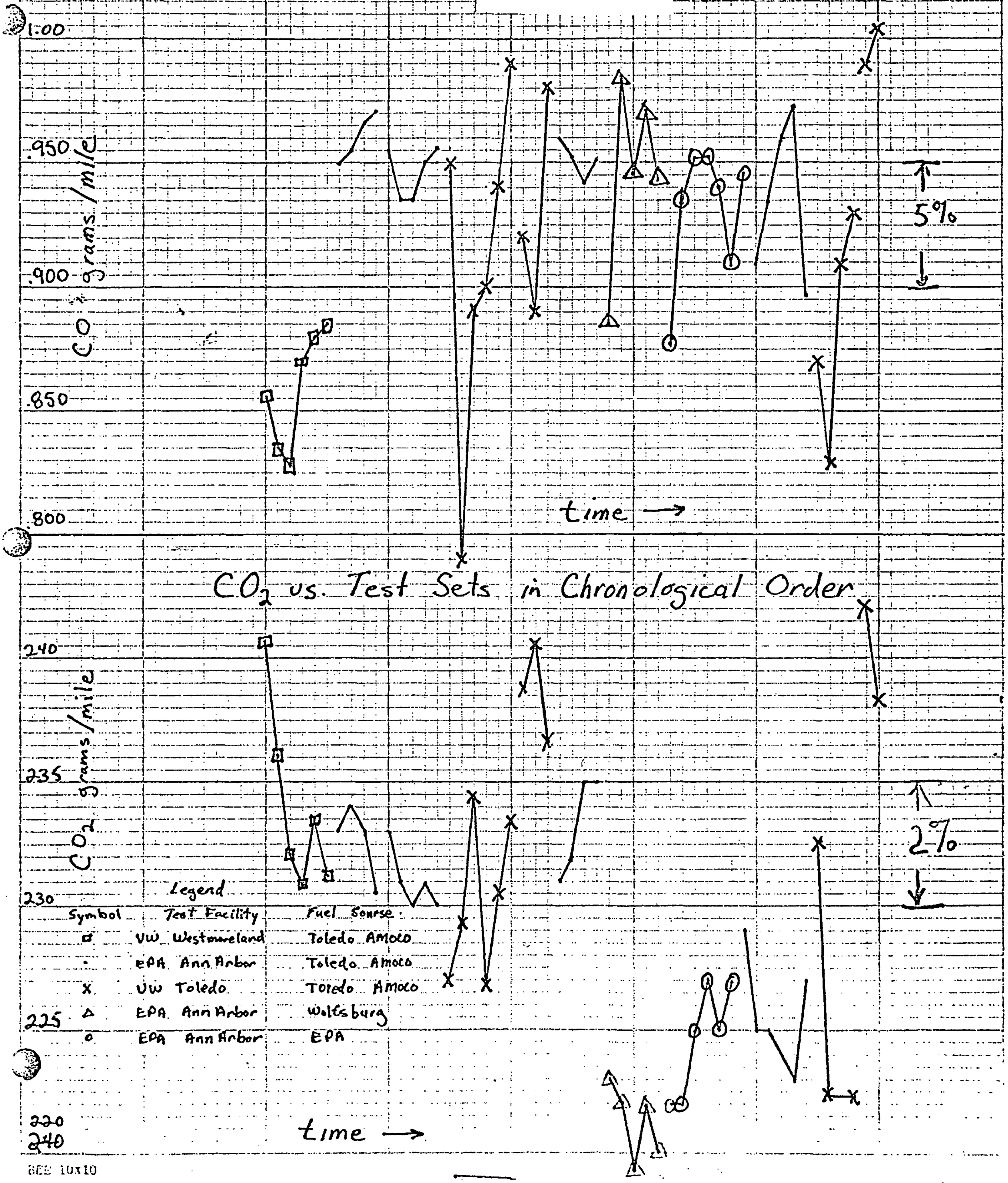


Fig 2
HC vs. Test Sets in Chronological Order on Vehicle #1 in Sept. 1979
Legend
Symbol Test Facility Fuel Sourse
□ VW Westmoreland Toledo AMOCO
· EPA Ann Arbor Toledo AMOCO
X VW Toledo Toledo AMOCO
Δ EPA Ann Arbor Wolfsburg
O EPA Ann Arbor EPA
HC grams/mile
.50
.45
.40
.35
.30
10%
time →
NOx vs Test Sets in Chronological Order
NOx grams/mile
1.05
1.00
.95
.90
.85
5%
time →

BEE 10x10

Fig 3 CO vs. Test Sets in Chronological Order on Vehicle #1 in Sept 1979



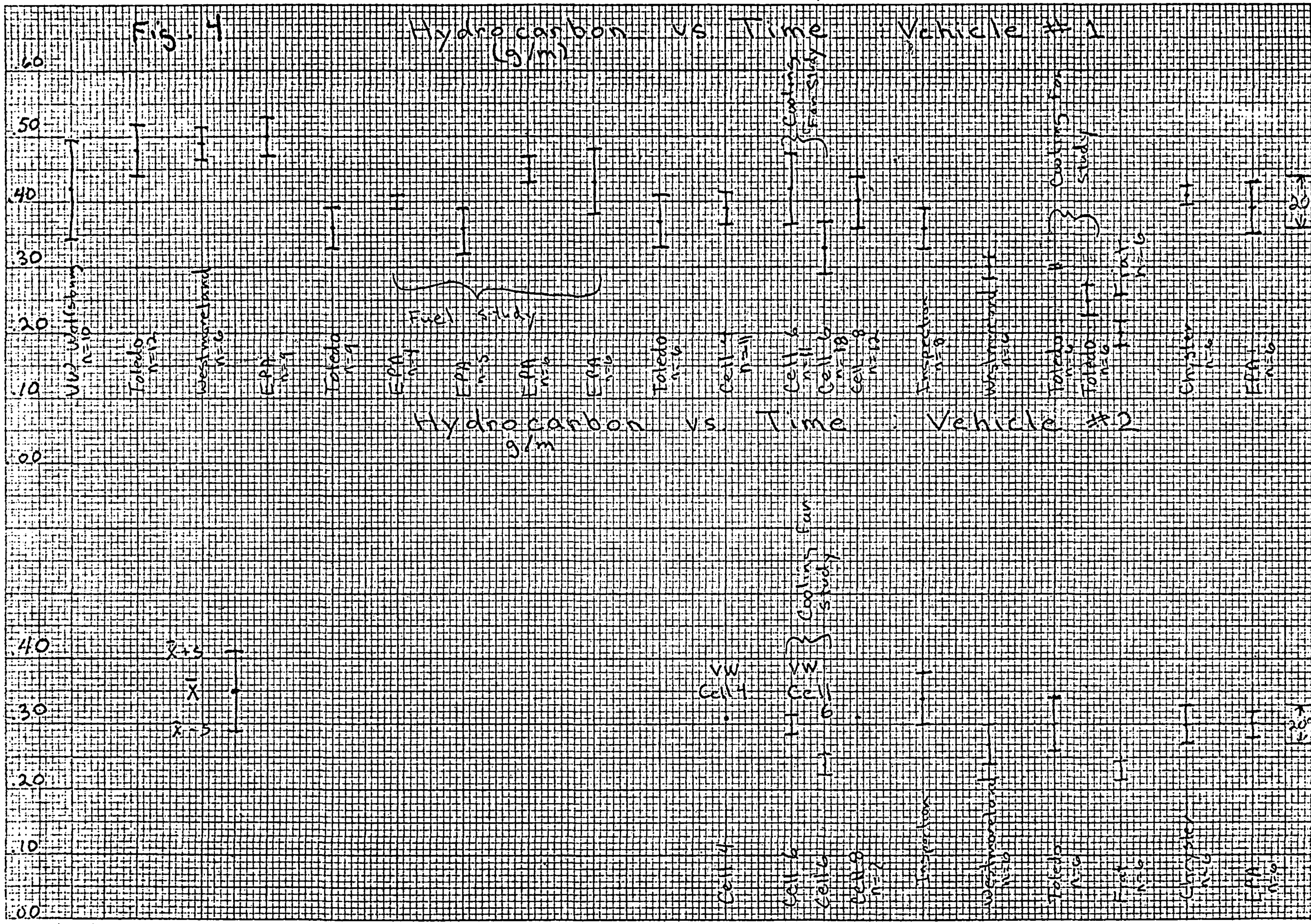


Fig. 4
Hydrocarbon vs Time Vehicle #1
(g/m)
.60
.50
.40
.30
.20
.10
.00
VW-Wolfsburg n=10
Toledo n=12
Westmoreland n=6
EPA n=9
Toledo n=9
EPA n=3
EPA n=5
EPA n=6
EPA n=6
Fuel study
Toledo n=6
Cell 4 n=11
Cell 6 n=11
Cell 6 n=18
Cell 8 n=12
Coding Fan Study
Inspection n=8
Westmoreland n=6
Toledo n=6
Toledo n=6
Coding Fan study
Fiat n=6
Chrysler n=6
EPA n=6
20%
Hydrocarbon vs Time Vehicle #2
g/m
.40
.30
.20
.10
.00
X̄+s
X̄
X̄-s
VW Cell 4
VW Cell 6
Coding fan study
Cell 4
Cell 6
Cell 6
Cell 8 n=2
Inspection
Westmoreland n=6
Toledo n=6
Fiat n=6
Chrysler n=6
EPA n=6
20%

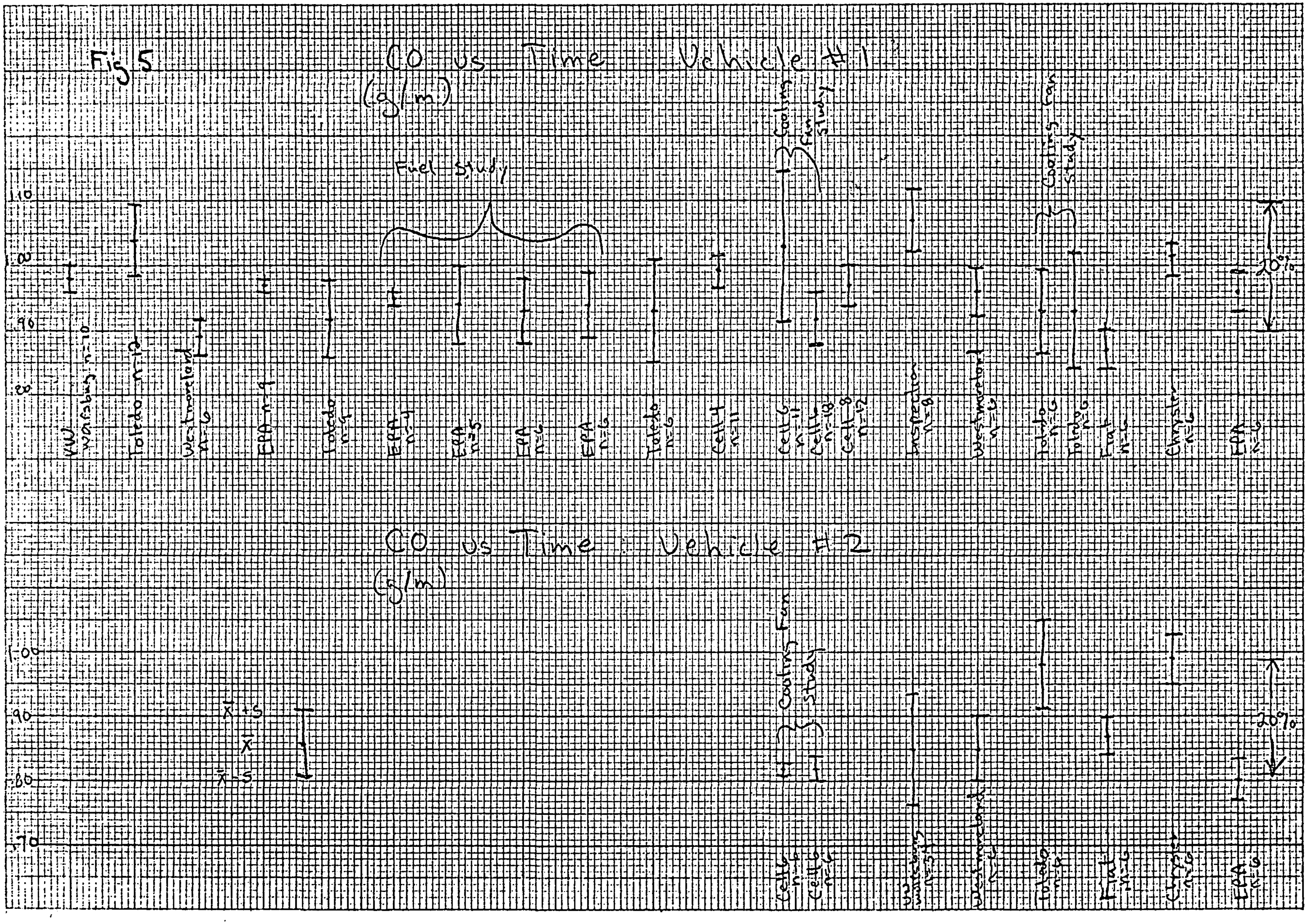


Fig 5
CO vs Time Vehicle #1
(g/m)
Fuel Study
Cooling fan study
20%
CO vs Time Vehicle #2
(g/m)
Cooling Fan Study
$\bar{x}+s$
$\bar{x}$
$\bar{x}-s$
20%

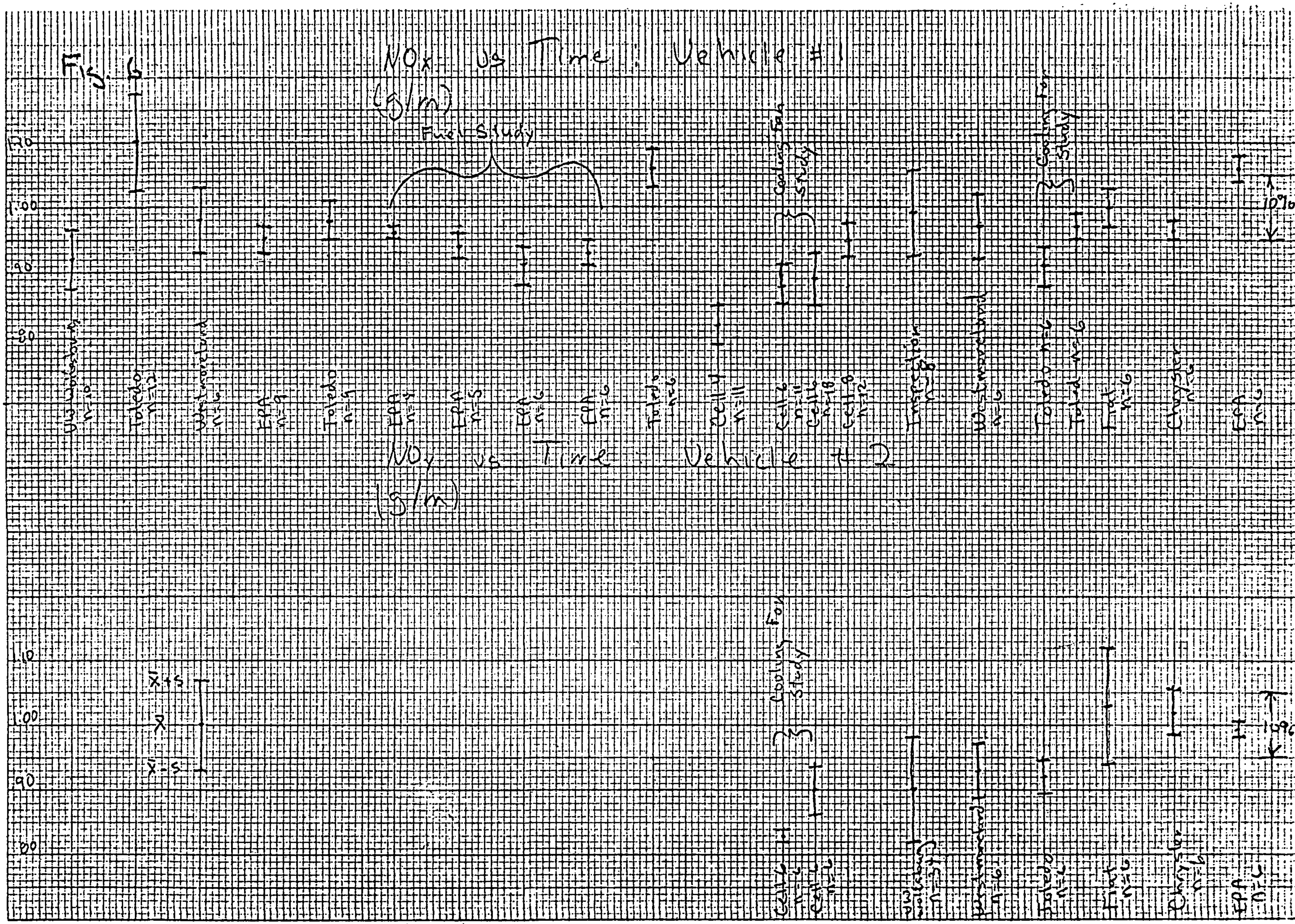


Fig. 6
NOx vs Time: Vehicle #1
(g/m)
Fuel Study
Cooling Fan Study
10%
1.20
1.00
.90
.80
Toledo
EPA
Chrysler
NOx vs Time Vehicle #2
(g/m)
Cooling Fan Study
1.10
1.00
.90
.80
x̄+s
x̄
x̄-s
10%

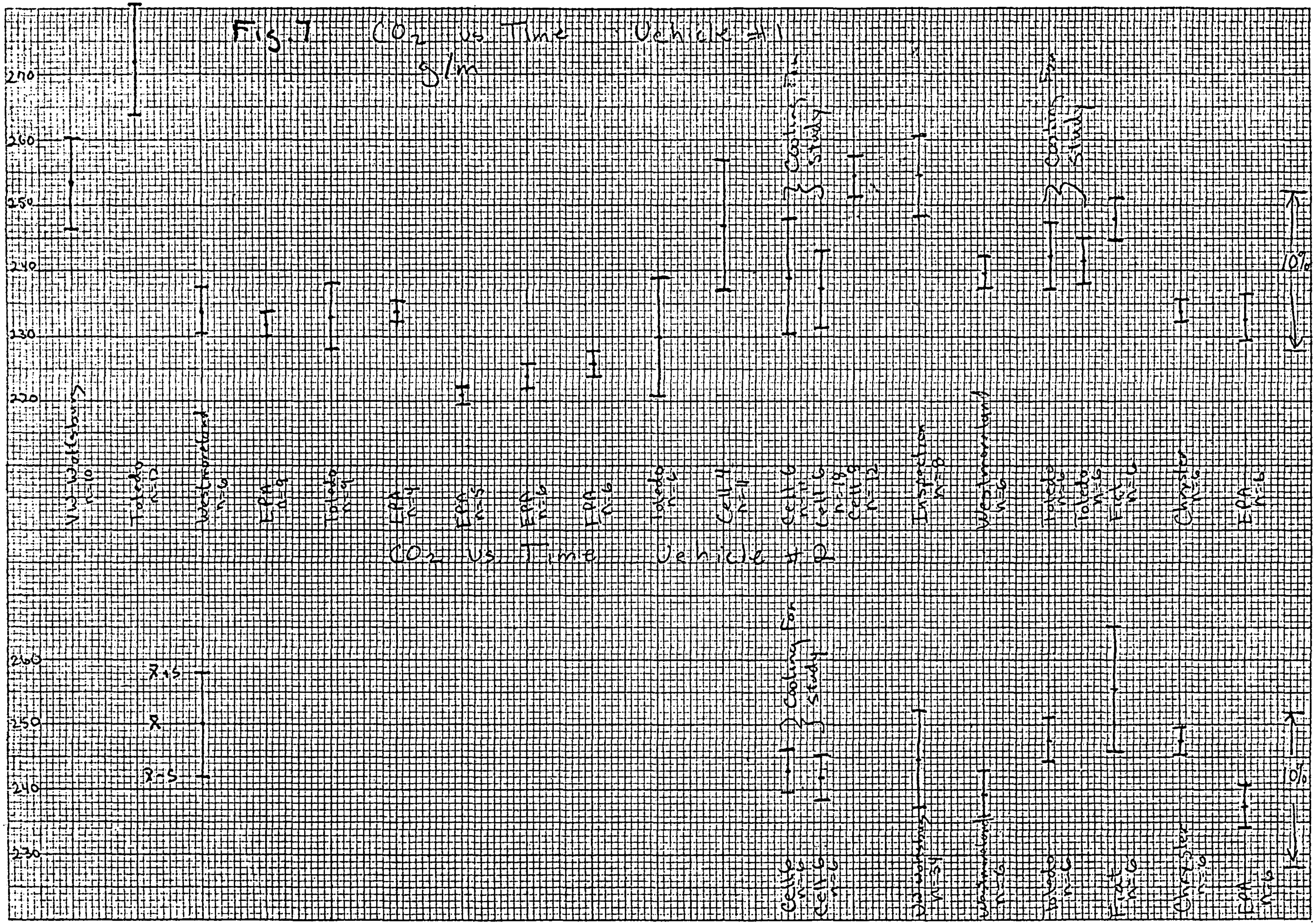
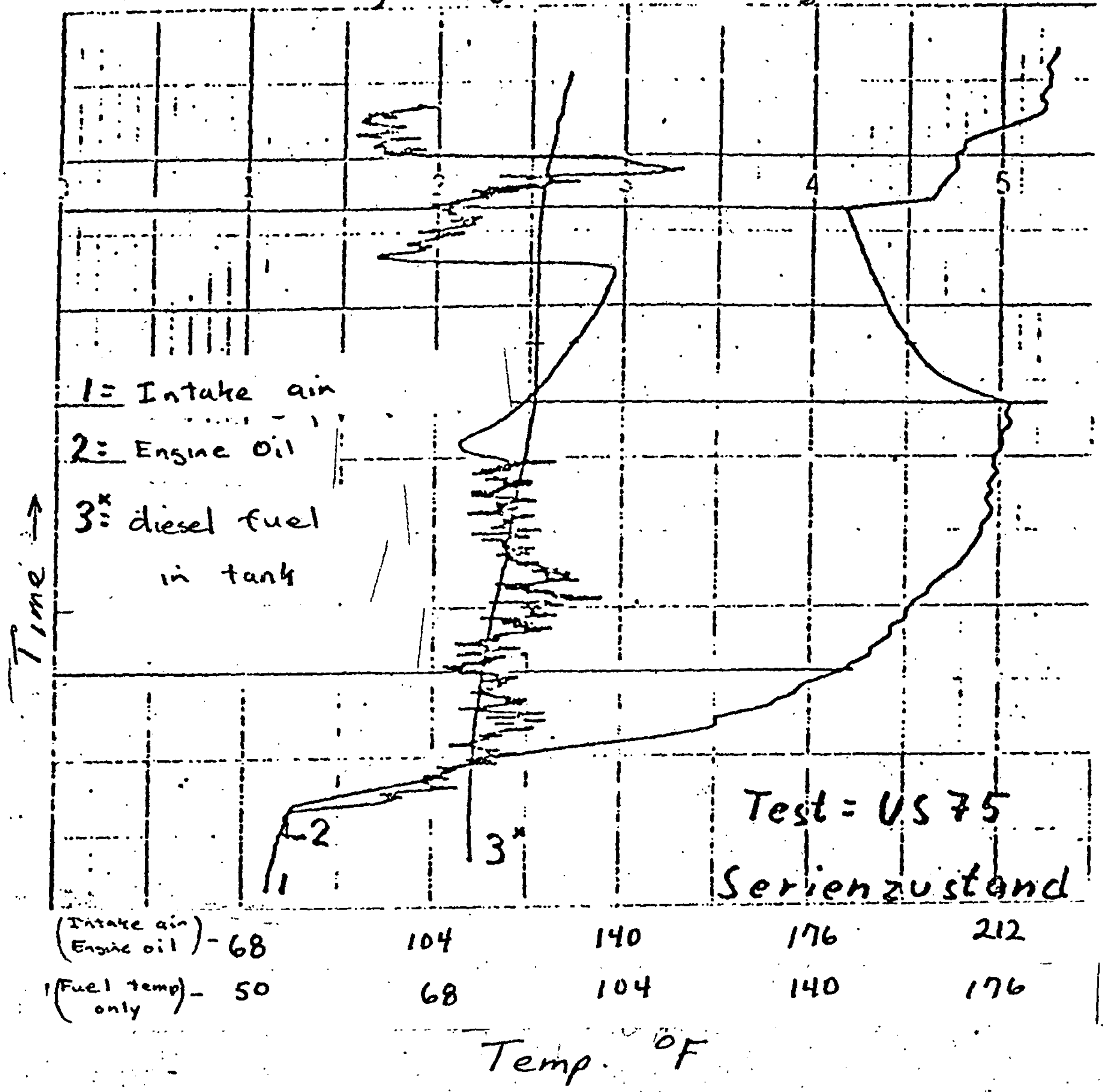


Fig. 7 CO2 vs Time Vehicle #1
g/m
270
260
250
240
230
220
VW Wolfsburg n-10
Toledo n-12
Westmoreland n-6
EPA n-9
Toledo n-9
EPA n-4
EPA n-5
EPA n-6
EPA n-6
Toledo n-6
Cell 4 n-11
Cell 6 n-11
Cell 6 n-18
Cell 9 n-12
Cooling Fan Study
Inspection n-8
Westmoreland n-6
Toledo n-6
Toledo n-6
Cooling Fan Study
Fiat n-6
Chrysler n-6
EPA n-6
10%
CO2 vs Time Vehicle #2
260
250
240
230
X̄+5
X̄
X̄-5
Cell 6 n-6
Cell 6 n-6
Cooling Fan Study
VW Wolfsburg n-34
Westmoreland n-6
Toledo n-6
Fiat n-6
Chrysler n-6
EPA n-6
10%

Fig 8 VIN : 178330 2613

Dyno # 6 VW Wolfsburg Fan-cap.: < 5000 cf/m

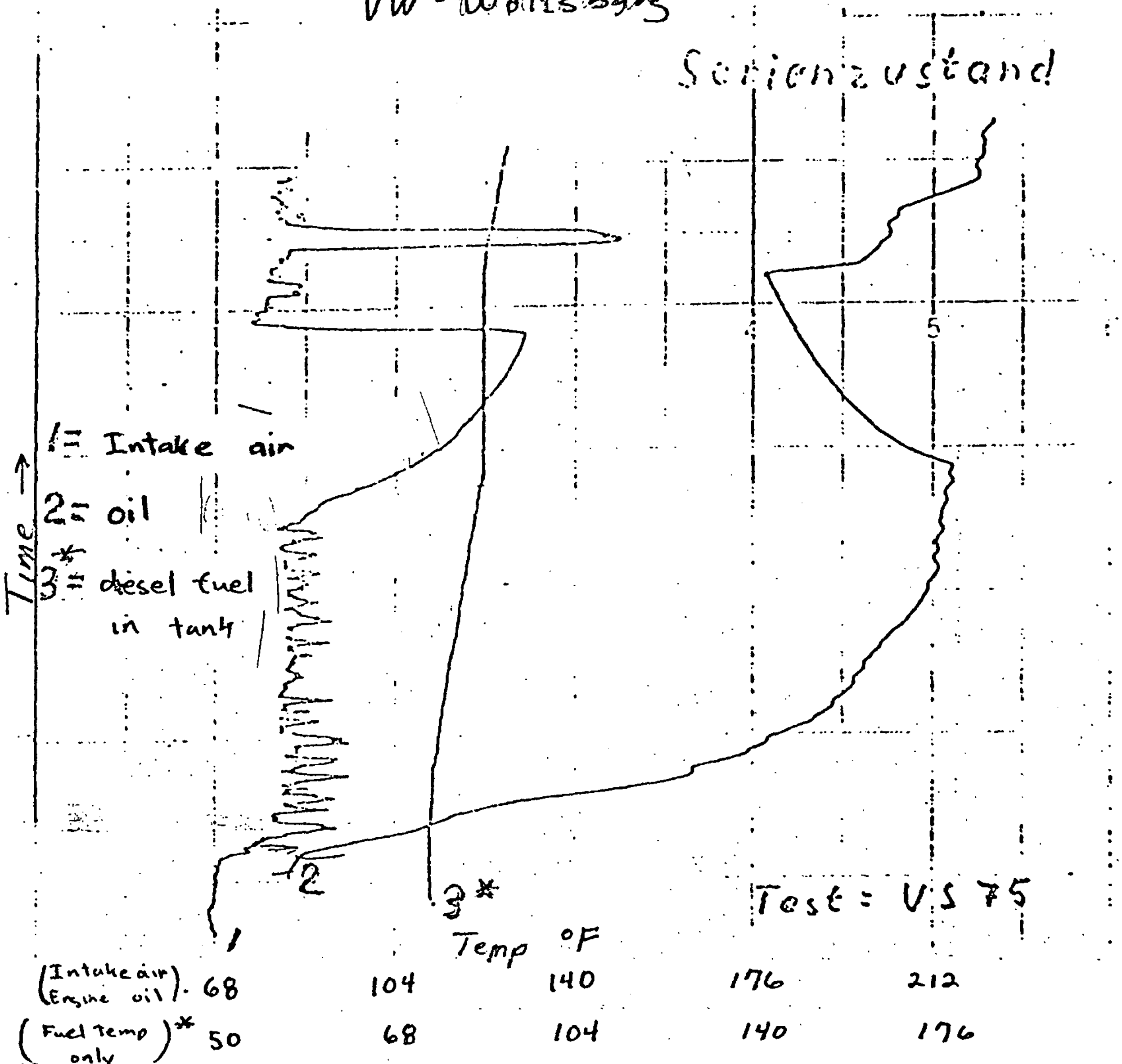


Test #	Date	HC (g/mi)	CO (g/mi)	NO_x (g/mi)	CO_2 (g/mi)
71244	8-23	0.25	0.82	0.84	242.6
71245	8-23	0.24	0.82	0.84	242.8
71261	8-29	0.25	0.81	0.85	249.2
71262	8-29	0.26	0.81	0.82	242.3
71290	9-6	0.22	0.83	0.82	240.6
71291	9-6	0.23	0.80	0.83	246.3
	$\bar{x}$	0.24	0.82	0.83	243
	s	0.015	0.01	0.012	3.2
	2 s	0.03	0.02	0.02	6.4
	$\frac{t \cdot s}{\sqrt{n}}$	0.02	0.01	0.01	3.2

Fig 9. VIN: 178335 2693 Rab · Diesel

Dyno: #6 .Fan - cap.: ca 5000 cfm

VW - Wolfsburg

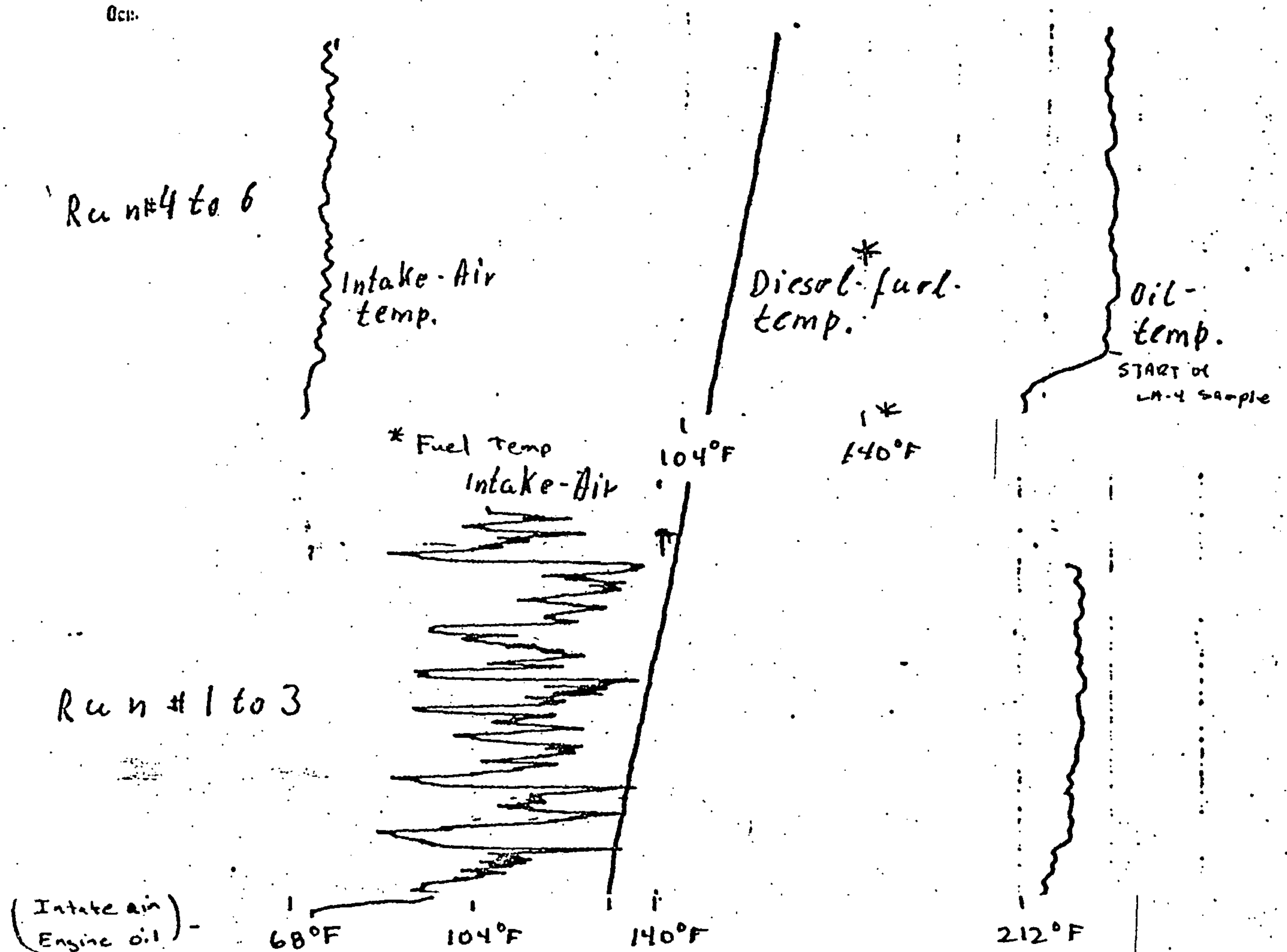


Test #	Date	HC (g/mi)	CO (g/mi)	NO_x (g/mi)	CO_2 (g/mi)
72456	10-16	0.31	0.82	0.91	242.1
72469	10-19	0.32	0.80	0.96	244.6
72475	10-20	0.28	0.81	0.91	237.5
73033	11-8	0.29	0.80	0.89	237.6
73037	11-9	0.29	0.83	0.85	246.5
73048	11-12	0.29	0.85	0.88	243.3
	$\bar{x}$	0.30	0.82	0.90	241.9
	s	0.015	0.02	0.037	3.70
	2s	0.03	0.04	0.07	7.4
	$\frac{t \cdot s}{\sqrt{n}}$	0.02	0.02	0.04	3.7

Fig. 10 VIN: 1783352693 Rab. - Diesel

FIAT - Dearborn

LA-4, Hot



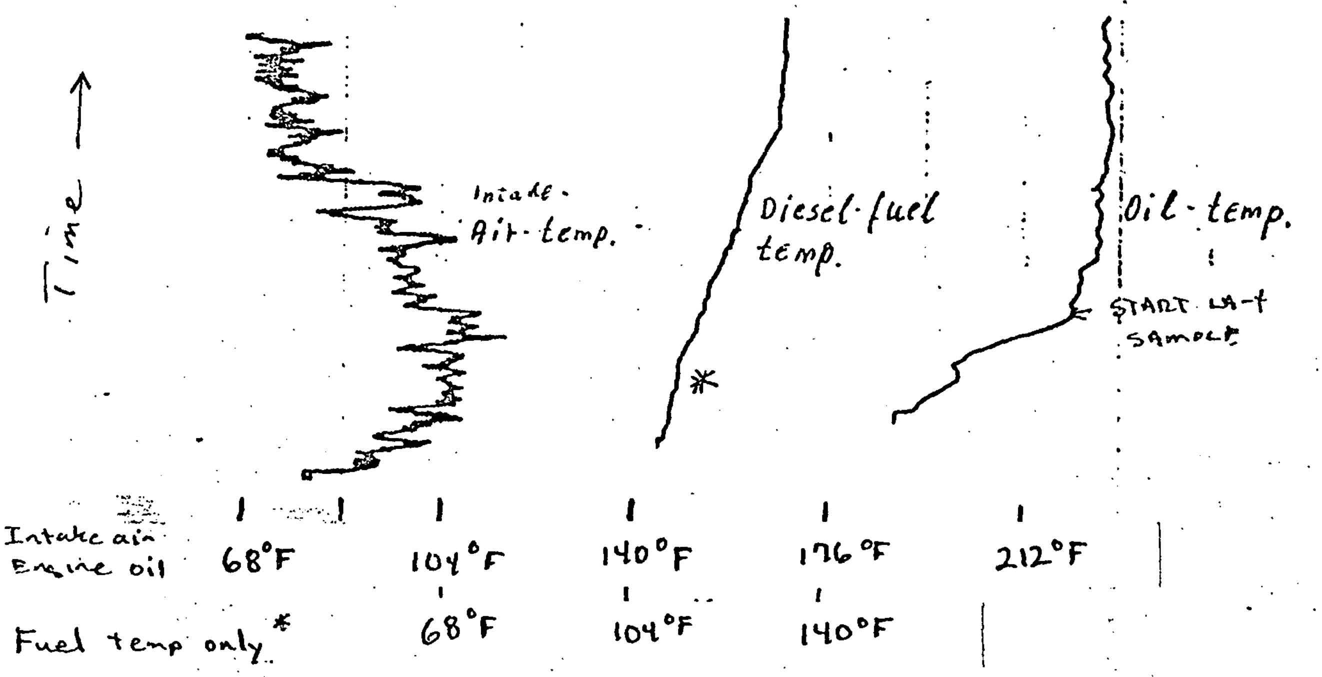
Test #	Date	HC (g/mi)	CO (g/mi)	NO_x (g/mi)	CO_2 (g/mi)
1	12-3	0.23	0.88	1.131	271.5
2	12-3	0.21	0.84	1.119	260.0
3	12-3	0.22	0.86	1.077	256.1
4	12-3	0.25	0.83	0.962	245.7
5	12-3	0.24	0.91	0.936	246.0
6	12-3	0.24	0.91	0.980	254.4
	$\bar{x}$	0.23	0.87	1.03	255.6
	s	0.015	0.034	0.085	9.63
	2s	0.03	0.07	0.17	19.3
	$\frac{t \cdot s}{\sqrt{n}}$	0.01	0.03	0.09	9.6

Fig. 11

VIN : 1783352693 Rab. - Diesel

VW - Mob. - Emission - Lab, Toledo, Ohio

LA-4 Hot



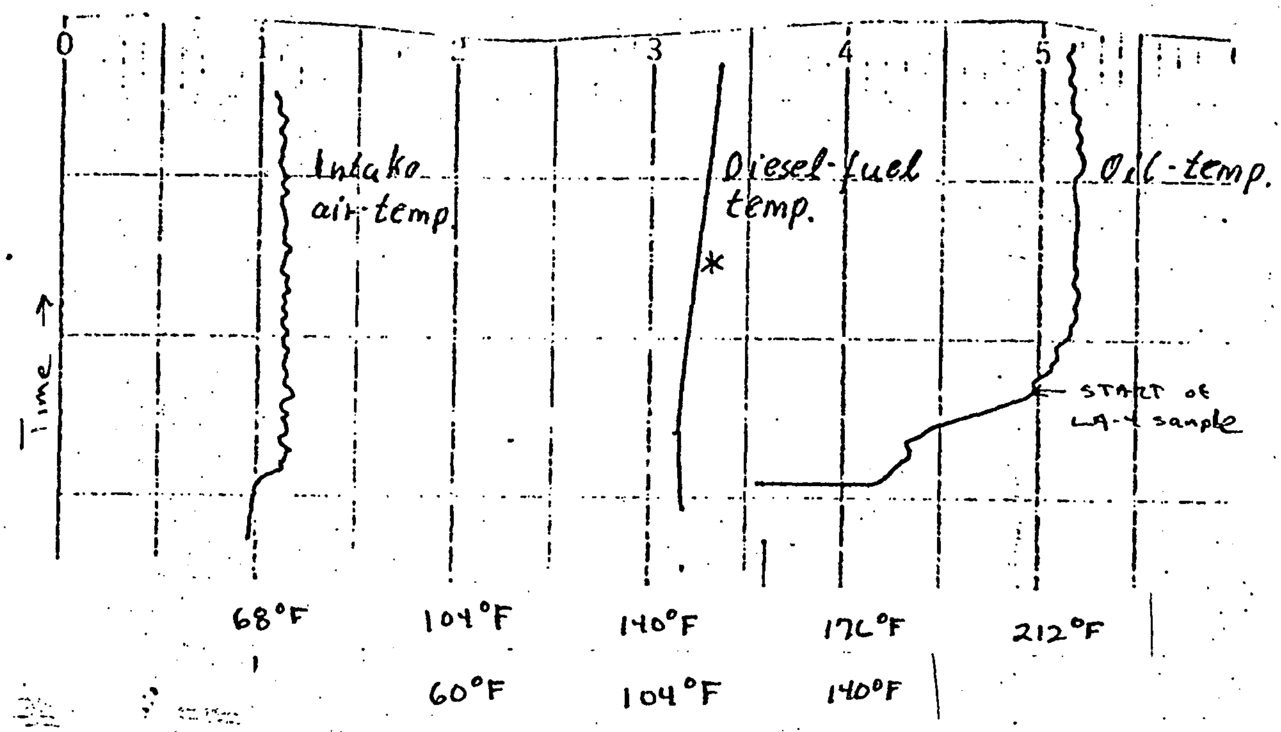
Test #	Date	HC (g/mi)	CO (g/mi)	NO_x (g/mi)	CO_2 (g/mi)
1	11-30	0.32	0.94	0.91	249.5
2	11-30	0.28	0.98	0.93	247.5
3	11-30	0.23	1.03	0.92	247.0
4	11-30	0.21	1.05	0.94	249.6
5	11-30	0.28	0.99	0.93	253.0
	$\bar{x}$	0.26	1.00	0.93	249.3
	s	0.044	0.043	0.011	2.4
	2s	0.09	0.09	0.02	4.7
	$\frac{t \cdot s}{\sqrt{n}}$	0.05	0.05	0.01	2.7

Fig. 12.

VIN: 1783352693 Rab. - Diesel

VW - Mob - Emission - Lab, Toledo, Ohio

LA-4 Hot



Test #	Date	HC (g/mi)	CO (g/mi)	NO_x (g/mi)	CO_2 (g/mi)
1	12-1	0.32	0.88	0.86	253
2	12-1	0.33	0.97	0.89	245
3	12-1	0.33	0.99	0.92	248
4	12-1	0.30	1.08	0.91	243
5	12-1	0.30	1.04	0.94	246
6	12-1	0.33	0.88	0.91	243
	$\bar{x}$	0.32	0.97	0.91	246.3
	s	0.015	0.082	0.027	3.78
	2s	0.03	0.16	0.05	7.6
	$\frac{t \cdot s}{\sqrt{n}}$	0.01	0.08	0.03	3.8

Calculations

The results of the test plan can be analyzed statistically to determine if the offsets between the various test groups are real. The variation between control groups vs. experimental groups must be statistically similar, caused by similar effects in both groups. This allows us to ascribe the offset in group means to the experimental parameter changed in the test procedure.

In the case of the fuel study the values of interest are summarized in the following table:

Fuel	i	HC(g/mile) x_i	sample size n_i	degrees of freedom n_i-1	standard deviation s_i
EPA	1	.45	6	5	.02
AMOCO-50	2	.42	10	9	.02
Wolfsburg	3	.36	5	4	.04

The variance, s_1^2 are equal for fuels 1 and 2 and the hypothesis that the means of these fuel are equal is accepted with the T-stat test.

$$t = \frac{x_1 - x_2}{\sqrt{\frac{SP^2}{n_1} + \frac{SP^2}{n_2}}}$$

where, SP^2, the pooled variance is

$$SP^2 = \frac{(n_1-1)(S_1)^2 + (n_2-1)(S_2)^2}{(n_1-1) + (n_2-1)}$$

then,

$$t = 2.90.$$

Now the critical value of t where the probability of not accepting a true hypothesis is 1 out of 100 times (= .01) is $\pm$ 2.9768. Our calculated t lies within the bounds of our critical value. We accept the hypothesis that the hydrocarbon emissions generated or AMOCO-50 and EPA fuels are statistically similar.

The variances between fuels 1 and 3 are not equal but may be similar. The F statistic will help us determine this by knowing the variance, the degrees of freedom for each sample, and the probability of not accepting a true hypothesis we are willing to accept.

$$F_{5,4} = \frac{S_1^2}{S_3^2} = .25$$

If the hypothesis is correct that the variances are equal, then the above calculated F will be between .0644 and 15.52. They are similar statistically. The calculated T statistic therefore can be calculated with the pooled variance sp^2.

$t = 4.865$

The critical t value for = .01 is $\pm$ 3.2498. The means are not equal. The hydrocarbon emissions are different because of the difference in fuels, EPA vs. Wolfsburg diesel fuel.

The hydrocarbon emission test variances for fuel 2 and 3 are again tested for the hypothesis of equality with the F statistic,

$$F_{9,4} = \frac{S_2^{\,2}}{S_3^{\,2}} = .25$$

where the critical values of F are .069 and 14.55 when =.01. The variances are statistically similar. The calculated t statistic is -3.95 and the critical value for t when =.01 is / 3.0123. The hydrocaron emissions are not equal between the AMOCO-50 and Wolfsburg diesel fuels.

Similar F and t stat tests indicate several important facts; that the variance for the temp controlled vs. soak controlled vehicle are equal, the variance between Hot LA-4s and FTPs on both vehicles are equal and that hydrocarbon emission results between Hot LA-4s and FTPs are similar statistically.

The use of an analysis of variance (ANOVA in MIDAS the MTS statistical service) using fuel as the method of stratifying the data groups, indicates that there is a difference in the emission results between the groups for HC and CO_2.